Review article

Height in relation to dementia death: individual participant meta-analysis of 18 UK prospective cohort studies

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Background
That risk factors measured in middle age may not fully explain future dementia risk implicates exposures acting earlier in life. Height may capture early-life illness, adversity, nutrition and psychosocial stress.

Aims
To investigate the little-explored association between height and dementia death.

Method
Individual participant meta-analysis using 18 prospective general population cohort studies with identical methodologies (1994–2008; $n = 181\,800$).

Results
Mean follow-up of 9.8 years gave rise to 426 and 667 dementia deaths in men and women respectively. The mean heights were 174.4 cm (s.d. = 7.3) for men and 161.0 cm (s.d. = 6.8) for women. In analyses taking into account multiple covariates, increasing height was related to lower rates of death from dementia in a dose–response pattern ($P \leqslant 0.01$ for trend). There was evidence of a differential effect by gender ($P = 0.016$ for interaction). Thus, the association observed in men (hazard ratio per s.d. decrease in height 1.24, 95% CI 1.11–1.39) was markedly stronger than that apparent in women (HR = 1.13, 95% CI 1.03–1.24).

Conclusions
Early-life circumstances, indexed by adult height, may influence later dementia risk.

Declaration of interest
None.

With no current disease-modifying treatment for dementia, there is a pressing need to understand the aetiology of this condition with a view to delaying or preventing its onset. It is evident that known risk factors for dementia measured in middle age – hypertension, smoking, obesity and dyslipidaemia – do not seem to fully explain the occurrence of the disease.[1–3] This has prompted some recent interest in the pre-adult origins of dementia.[4] In the absence of cohort studies beginning in childhood with a sufficiently long period of follow-up to allow enough individuals to develop dementia in later life, investigators have relied on the distant recall of early-life risk factors, such as early parental death and childhood socioeconomic adversity.[5–7] This raises concerns regarding reporting bias.[8] Height may be more useful in this context. It is regarded as a marker of early-life illness, adversity, nutrition and psychosocial stress,[9] environmental characteristics that influence brain development which may then affect dementia risk.[10] Importantly, although there may be some loss of height in late life, it remains relatively stable from early to late adulthood and may therefore be a reliable marker of early-life exposures.

Findings from a small series of cohort studies indicate that lower physical stature is associated with elevated rates of dementia,[11] and this effect may be different in men and women.[12] However, in general, studies have been underpowered. The fact that the few extant studies are small in scale hampers examination of the height–dementia association in detail, for example in exploring threshold effects and planned subgroup analyses of the height–dementia relationship, including by gender. Accordingly, in this study we add to the limited evidence base by presenting an individual participant meta-analysis of 18 large, prospective, general population-based cohort studies. Individual participant meta-analysis has several advantages relative to the more commonly used literature-based approach: the inclusion of unpublished data, so minimising publication bias; a more precise estimate of associations between risk marker and disease than in lesser-powered single studies; reliable information on the 'shape' of the association; and a consistent approach to statistical control for plausible covariates. To the best of our knowledge, this is the largest study to date to examine the association between height and dementia and the first individual participant meta-analysis on the topic.

Method

Participants were taken from the Health Survey for England (HSE) for the years 1994–2008 and the Scottish Health Survey (SHS) for 1995, 1998 and 2003. Both surveys were representative, general population-based health examination studies sampling individuals living in households in the UK.[13,14] From 1994 to 2008, 18 independent, cross-sectional studies with almost identical methodologies were conducted on either an annual (HSE) or an occasional (SHS) basis. The majority of study members (88%) consented to mortality surveillance by linkage to the UK National Health Service death register. The near-identical nature of these surveys, allied with this recent retrospective and prospective linkage of study members to mortality records, makes possible a unique individual participant meta-analysis. Study participants gave full informed consent, and ethical approval for data collection was granted by the London research ethics council or the local research ethics councils.

Participants were visited by a trained interviewer who measured height and weight, and subsequently by a nurse who collected biomedical data. The interviewer measured height once with shoes removed (to the nearest millimetre) with the informant stretching to maximum height. The head was positioned in the Frankfort plane and a portable stadiometer with a sliding plate, a base plate and three connecting rods marked with a metric measuring scale was used. Weight was measured using electronic digital scales and, with height, allowed computation of body mass index in kg/m^2. Information on occupational social class was

collected during the interview and coded according to the Registrar General's classification (professional, intermediate, skilled non-manual, skilled manual, part skilled and unskilled), a standard approach in the UK.[15] Age in years on leaving full-time education was recorded as <15, 15, 16, 17, 18, >18, 'never went to school' and 'still in full-time education'. Ethnic group was based on self-report. Smoking status was classified as never a regular smoker, ex-smoker and smoker with daily consumption recorded. During the interview participants were asked whether or not they suffered from a longstanding illness. At the nurse visit, systolic blood pressure was measured with the mean of the second and third readings used in the present analyses. Blood was drawn to measure serum cholesterol.

Ascertainment of dementia

Causes of death (up to ten) recorded on certificates were coded using the International Classification of Diseases (ICD-9 and ICD-10).[16,17] Any mention of dementia death was identified using codes 290.0 to 290.4, 294.9, 331.0 to 331.2 and 331.9 for ICD-9 and codes F00, F01, F03, F09, G30 and G31 for ICD-10. In preliminary analyses we examined the impact of using broad definitions of dementia (any mention of dementia) or narrow definitions (where dementia was the underlying cause of death). Since results were essentially the same but the broader definition resulted in greater power (online Table DS1) we used 'any mention' of dementia in all survival analyses.

Statistical analysis

After ascertaining that the proportional hazards assumption had not been violated we used Cox proportional hazards models to compute study-specific hazard ratios with accompanying 95% confidence intervals for the association between height and dementia death.[18] We report hazard ratios for height quartiles with the tallest group as the referent. With preliminary analyses revealing that the height–dementia association was linear, we also report hazard ratios per 1 standard deviation reduction in height (1 s.d. = 6.8 cm in women, 7.3 cm in men). Heterogeneity in the effect estimates between studies was examined using the I^2 statistic, which indicates the proportion of the total variation in the estimates that is due to between-studies variation. Preliminary analyses revealed that I^2 ranged between 0% and 58%, so we pooled the study-specific effect estimates and their standard errors in random effects meta-analyses, an approach we have taken in previous analyses.[15,19,20] Calendar time (months) from survey date was the underlying time scale; for participants who did not die from dementia, data were censored at the end of March 2011.

Data for men and women were analysed separately. Models were initially adjusted for age and then additionally for a series of covariates comprising occupational social class, educational attainment, ethnic group, body mass index, smoking status and self-reported longstanding illness. We also controlled for birth year to allow for secular increases in height.[21] Data for blood pressure and serum cholesterol were not collected in every survey (see online Table DS2) and were additionally missing for some participants during the survey years when data collection took place; these data therefore only feature in subgroup analyses. We compared the effects of controlling for different confounding and mediating variables on the magnitude of the association by examining the change in hazard ratio rather than a change in significance level.[22] Individuals with data missing for one or more variables and those with no missing data were compared using Student's t-test for continuous variables and χ^2-tests for categorical variables. All analyses were conducted using R for Mac version 3.0.2. The reporting of our analyses conforms to the Strengthening

the Reporting of Observational Studies in Epidemiology (STROBE) statement.[23]

Results

Figure 1 shows the derivation of the analytical sample. Excluding 1840 individuals missing consent data and 1365 missing survival time reduced the sample size from 222 829 to 219 624. With other exclusions (survey participants who declined mortality follow-up or whose height was not measured) the final analytic sample was 181 800 (55% female). The mean age at baseline was 45.0 years (s.d. = 18.0); among those who died the mean age at death was 55.8 years (s.d. = 17.5). Further details of the individual cohort studies and individuals who did and did not consent to mortality follow-up are provided in online Tables DS2 and DS3 respectively. Baseline characteristics of the sample categorised by height quartile are shown in Table 1. Increasing height was generally associated with a more favourable risk factor profile in both men and women: taller study members were younger, from higher socioeconomic backgrounds, had slightly lower body mass index, a lower prevalence of longstanding illness and lower levels of blood pressure and serum cholesterol. Taller men were also less likely to smoke, but the reverse was true of women. Of the 17 553 deaths recorded during a mean follow-up of 9.8 years (s.d. = 4.4), 1093 were dementia-related. Figure 2 shows the age-adjusted hazard ratios for the association between 1 s.d. decrease in height and dementia death in men and women for each cohort study. Overall, there was a 26% increased risk of dementia death per s.d. decrease in height in men (HR = 1.26, 95% CI 1.14–1.40; $P<0.001$ for trend) and 10% increased risk of dementia death in women (HR = 1.10, 95% CI 1.01–1.19; $P = 0.031$ for trend). Table 2 shows the association between height quartile and dementia death after
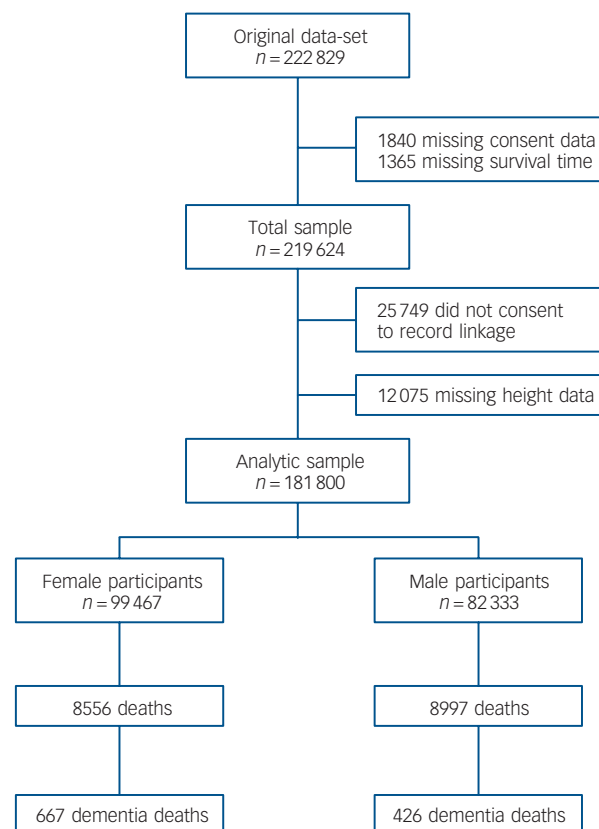

Fig. 1 Flow chart of participants from initial pooled sample through to analytic sample showing subsequent mortality.

Table 1 Baseline characteristics of study participants according to height quartile

	Height quartile[a,b]				
	Q₁ (shortest)	Q₂	Q₃	Q₄	Total n^c
Men					
n	20 398	20 890	20 667	20 376	82 333
Age, years: mean (s.d.)	53.6 (18.8)	47.4 (17.6)	43.5 (16.7)	39.5 (15.0)	82 333
Non-manual social class, %	38.6	45.5	51.1	56.6	79 251
Left school >16 years, %	51.9	64.6	73.4	81.9	82 290
White British, %	85.3	90.4	92.8	94.7	82 333
BMI, kg/m²: mean (s.d.)	26.9 (4.4)	26.9 (4.2)	26.6 (4.2)	26.2 (4.0)	80 281
Never smoker, %	38.8	41.5	44.5	48.1	81 972
Longstanding illness, %	50.6	44.4	38.9	36.8	82 314
Systolic blood pressure, mmHg: mean (s.d.)	137.9 (19.8)	135.1 (17.2)	133.6 (15.8)	132.4 (14.5)	53 255
Serum cholesterol, mmol/l: mean (s.d.)	5.7 (1.2)	5.7 (1.2)	5.5 (1.1)	5.4 (1.1)	27 017
Women					
n	24 443	25 266	24 971	24 787	99 467
Age, years: mean (s.d.)	54.2 (19.6)	47.2 (17.6)	43.4 (16.6)	39.3 (14.8)	99 467
Non-manual social class, %	54.8	62.5	66.8	71.5	92 695
Left school >16 years, %	51.2	64.7	72.6	82.3	99 410
White British, %	85.8	90.9	93.0	94.5	99 467
BMI, kg/m²: mean (s.d.)	27.4 (5.6)	26.8 (5.3)	26.2 (5.2)	25.6 (4.9)	94 147
Never smoker, %	57.0	53.7	52.1	52.0	99 130
Longstanding illness, %	51.3	43.4	40.5	36.1	99 450
Systolic blood pressure, mmHg: mean (s.d.)	135.4 (23.7)	130.4 (20.5)	127.1 (18.7)	124.7 (16.3)	63 874
Serum cholesterol, mmol/l: mean (s.d.)	5.9 (1.3)	5.8 (1.2)	5.6 (1.2)	5.4 (1.1)	31 519

BMI, body mass index.
a. Mean heights across the studies were 174.4 cm (s.d. = 7.3) in men and 161.0 cm (s.d. = 6.8) in women.
b. Gender-specific height quartiles were calculated using the following cut-points: men 179.3 cm, 174.4 cm, 169.6 cm; women 165.5 cm, 161.1 cm, 156.5 cm.
c. Total number of participants with complete data for each variable.

adjustment for covariables. In age-adjusted analyses there was a dose–response association in both men and women such that lower physical stature was associated with raised dementia mortality rates. There was also some evidence of weaker associations in women than men: a formal test for effect modification was statistically significant at conventional levels (multivariable adjusted model $P = 0.016$ for interaction). Adjusting for measures of socioeconomic status had a modest attenuating effect on this association.
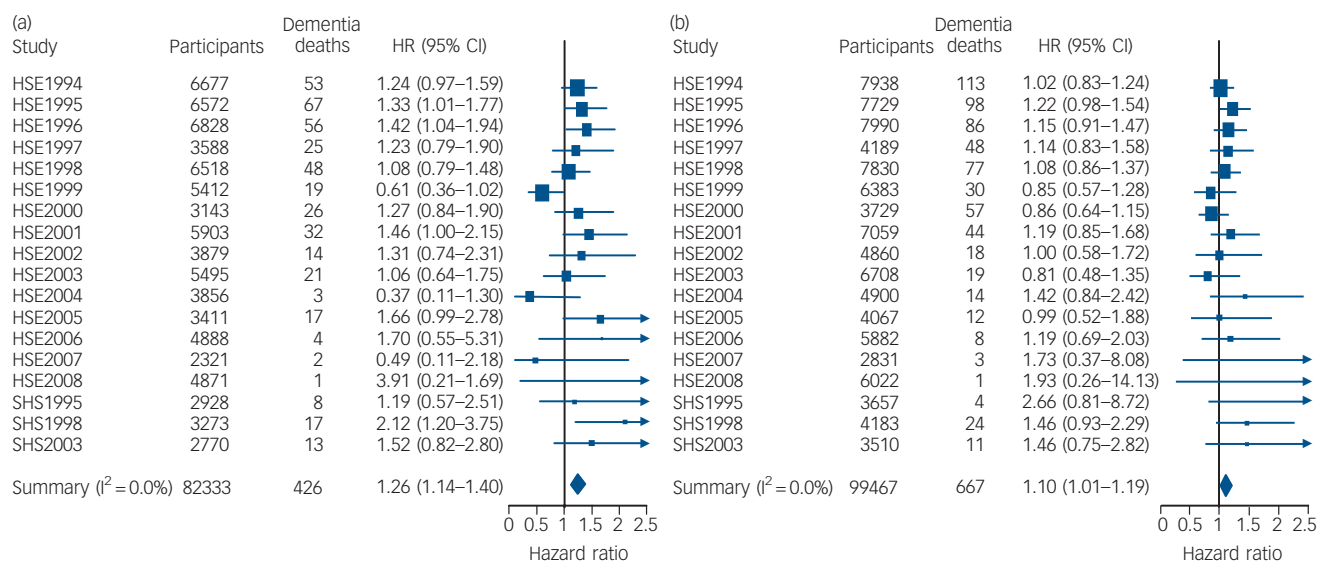
Sensitivity and subgroup analyses

We conducted a series of sensitivity and subgroup analyses to test the robustness of our results. Data were missing for one or more

variables in 34 833 individuals (18.0%). Individuals with complete data for all variables are compared with those with any missing data in online Table DS4. Although there were some differences in study characteristics, when we computed age-adjusted hazard ratios using a non-missing sample it replicated the main findings. Additionally, dropping deaths occurring in the first 5 years of follow-up to explore reverse causality did not alter our conclusions (Table 2).

Discussion

Our main finding was a dose–response association between shorter height and risk of subsequent dementia death. There was some

(a) Study	Participants	Dementia deaths	HR (95% CI)
HSE1994	6677	53	1.24 (0.97–1.59)
HSE1995	6572	67	1.33 (1.01–1.77)
HSE1996	6828	56	1.42 (1.04–1.94)
HSE1997	3588	25	1.23 (0.79–1.90)
HSE1998	6518	48	1.08 (0.79–1.48)
HSE1999	5412	19	0.61 (0.36–1.02)
HSE2000	3143	26	1.27 (0.84–1.90)
HSE2001	5903	32	1.46 (1.00–2.15)
HSE2002	3879	14	1.31 (0.74–2.31)
HSE2003	5495	21	1.06 (0.64–1.75)
HSE2004	3856	3	0.37 (0.11–1.30)
HSE2005	3411	17	1.66 (0.99–2.78)
HSE2006	4888	4	1.70 (0.55–5.31)
HSE2007	2321	2	0.49 (0.11–2.18)
HSE2008	4871	1	3.91 (0.21–1.69)
SHS1995	2928	8	1.19 (0.57–2.51)
SHS1998	3273	17	2.12 (1.20–3.75)
SHS2003	2770	13	1.52 (0.82–2.80)
Summary (I² = 0.0%)	82333	426	1.26 (1.14–1.40)

(b) Study	Participants	Dementia deaths	HR (95% CI)
HSE1994	7938	113	1.02 (0.83–1.24)
HSE1995	7729	98	1.22 (0.98–1.54)
HSE1996	7990	86	1.15 (0.91–1.47)
HSE1997	4189	48	1.14 (0.83–1.58)
HSE1998	7830	77	1.08 (0.86–1.37)
HSE1999	6383	30	0.85 (0.57–1.28)
HSE2000	3729	57	0.86 (0.64–1.15)
HSE2001	7059	44	1.19 (0.85–1.68)
HSE2002	4860	18	1.00 (0.58–1.72)
HSE2003	6708	19	0.81 (0.48–1.35)
HSE2004	4900	14	1.42 (0.84–2.42)
HSE2005	4067	12	0.99 (0.52–1.88)
HSE2006	5882	8	1.19 (0.69–2.03)
HSE2007	2831	3	1.73 (0.37–8.08)
HSE2008	6022	1	1.93 (0.26–14.13)
SHS1995	3657	4	2.66 (0.81–8.72)
SHS1998	4183	24	1.46 (0.93–2.29)
SHS2003	3510	11	1.46 (0.75–2.82)
Summary (I² = 0.0%)	99467	667	1.10 (1.01–1.19)

Fig. 2 Number of participants, total mortality and deaths from dementia categorised by year. Also shown are age- and gender-adjusted hazard ratios (HRs) of dementia death per standard deviation lower height according to survey year for (a) men and (b) women: individual participant meta-analysis of 18 cohort studies from the Health Survey for England (HSE) and the Scottish Health Survey (SHS).

Table 2 Hazard ratios for the association between height quartile and dementia-related death

	Dementia deaths	n	Hazard ratio (95% CI)					
			Q$_4$[a] (tallest)	Q$_3$	Q$_2$	Q$_1$	Per s.d. disadvantage[b]	P$_{trend}$
Men								
Age-adjusted (basic model)	426	82 333	1 (Ref.)	1.27 (0.75–2.16)	1.32 (0.80–2.17)	1.67 (1.05–2.67)	1.26 (1.14–1.40)	<0.001
+ Social class	425	79 251	1	1.22 (0.72–2.09)	1.23 (0.74–2.03)	1.52 (0.95–2.45)	1.21 (1.09–1.34)	<0.001
+ Educational attainment	425	82 290	1	1.20 (0.71–2.05)	1.25 (0.76–2.06)	1.56 (0.97–2.50)	1.24 (1.11–1.37)	<0.001
+ Ethnic group	426	82 333	1	1.29 (0.76–2.20)	1.34 (0.81–2.22)	1.73 (1.08–2.77)	1.27 (1.14–1.41)	<0.001
+ Body mass index	413	80 281	1	1.24 (0.73–2.13)	1.30 (0.79–2.16)	1.70 (1.06–2.72)	1.29 (1.16–1.44)	<0.001
+ Smoking status	426	81 972	1	1.25 (0.71–2.13)	1.28 (0.77–2.11)	1.59 (0.99–2.55)	1.25 (1.13–1.39)	<0.001
+ Longstanding illness	426	82 314	1	1.26 (0.74–2.15)	1.30 (0.79–2.15)	1.68 (1.05–2.68)	1.26 (1.14–1.40)	<0.001
+ Systolic blood pressure[c]	275	49 030	1	1.06 (0.51–2.19)	1.22 (0.60–2.49)	1.42 (0.76–2.67)	1.30 (1.14–1.49)	<0.001
+ Serum cholesterol[c]	130	23 911	1	0.59 (0.22–1.59)	1.03 (0.26–4.01)	1.11 (0.50–2.46)	1.28 (1.03–1.58)	0.025
Multivariable-adjusted[d]	411	76 927	1	1.15 (0.67–1.98)	1.18 (0.71–1.96)	1.50 (0.93–2.43)	1.24 (1.11–1.39)	<0.001
Early deaths excluded (multivariable-adjusted)[d,e]	310	65 455	1	1.15 (0.64–2.07)	1.36 (0.77–2.40)	1.44 (0.85–2.45)	1.27 (1.12–1.45)	<0.001
Non-missing sample (age-adjusted)	411	76 927	1	1.20 (0.70–2.05)	1.26 (0.76–2.08)	1.65 (1.03–2.63)	1.27 (1.14–1.41)	<0.001
Women								
Age-adjusted (basic model)	667	99 467	1 (Ref.)	1.40 (0.90–2.19)	1.04 (0.66–1.62)	1.22 (0.76–1.97)	1.10 (1.01–1.19)	0.031
+ Social class	617	86 994	1	1.37 (0.87–2.16)	0.96 (0.59–1.57)	1.19 (0.73–1.95)	1.11 (1.01–1.19)	0.026
+ Educational attainment	667	99 410	1	1.33 (0.85–2.08)	0.96 (0.62–1.50)	1.11 (0.70–1.77)	1.07 (0.98–1.16)	0.143
+ Ethnic group	667	99 467	1	1.40 (0.90–2.19)	1.04 (0.66–1.64)	1.25 (0.78–2.00)	1.11 (1.02–1.20)	0.018
+ Body mass index	651	94 147	1	1.56 (0.98–2.48)	1.19 (0.75–1.90)	1.49 (0.91–2.44)	1.15 (1.05–1.25)	0.002
+ Smoking status	666	99 130	1	1.41 (0.90–2.20)	1.04 (0.67–1.62)	1.23 (0.78–1.96)	1.10 (1.01–1.19)	0.032
+ Longstanding illness	667	99 450	1	1.43 (0.92–2.24)	1.05 (0.68–1.63)	1.25 (0.78–2.00)	1.10 (1.01–1.19)	0.033
+ Systolic blood pressure[c]	431	62 684	1	1.55 (0.87–2.78)	1.10 (0.63–1.90)	1.41 (0.85–2.34)	1.09 (0.98–1.21)	0.118
+ Serum cholesterol[c]	195	27 696	1	1.67 (0.75–3.74)	1.44 (0.66–3.16)	1.60 (0.75–3.39)	1.05 (0.90–1.22)	0.542
Multivariable-adjusted[d]	601	82 115[f]	1	1.48 (0.92–2.39)	1.06 (0.64–1.74)	1.35 (0.80–2.28)	1.13 (1.03–1.24)	0.011
Early deaths excluded (multivariable-adjusted)[d,e]	495	74 221	1	1.39 (0.81–2.39)	0.95 (0.49–1.85)	1.05 (0.45–2.49)	1.10 (0.99–1.22)	0.063
Non-missing sample (age-adjusted)	601	82 115[f]	1	1.50 (0.93–2.42)	1.08 (0.63–1.85)	1.38 (0.79–2.39)	1.14 (1.05–1.25)	0.003

Q, quartile; Ref., referent.
a. Gender-specific height quartiles were calculated using the following cut-points: men 179.3 cm, 174.4 cm, 169.6 cm; women 165.5 cm, 161.1 cm, 156.5 cm.
b. Calculated using gender-specific standard deviations: men 7.3 cm; women 6.8 cm.
c. Data were only available for a subsample and therefore these covariates were not included in the multivariable model.
d. Model adjusted for age, occupational social class, educational attainment, self-reported ethnic group, body mass index, smoking status, self-reported longstanding illness and year of birth.
e. Deaths occurring within the first 5 years of follow-up were dropped. No event occurred in the HSE 2006–2008 surveys so these were excluded.
f. No event occurred in HSE 2008 so this survey was excluded from this model.

suggestion that this relationship was stronger in men. It was robust to adjustment for a series of covariates including socio-economic status and extant illness. That we were also able to demonstrate known associations between shorter stature and an increased risk of cardiovascular disease (age- and gender-adjusted HR per s.d. decrease in height 1.11, 95% CI 1.07–1.16) but a decreased risk of cancer (HR = 0.94, 95% CI 0.89–0.98) in this meta-analysis gives us confidence in the more novel height–dementia association.[24–26]

Mechanisms of effect

The fact that the observed association between height and dementia was apparently robust to the adjustment of a series of covariables leads to speculation regarding the mechanisms that might generate this relationship. Clearly height in itself is not a risk factor for dementia; rather, the exposures it captures may be key. In addition to genetic factors, a recent review of epidemiological studies highlighted various socio-environmental determinants of adult height, including early-life socioeconomic circumstances, childhood nutrition, chronic psychosocial stress and chronic illness.[21] Insulin growth factor IGF-1 has been linked to cerebral amyloid,[27] and, similarly, growth hormone levels, which are correlated with height and also linked to hippocampal function and cognition. Thus, IGF-1 might have a role in the association between height and dementia death.[4] Furthermore, important exposures may also act *in utero*, but research linking birth characteristics to dementia is sparse. There is also the possibility

that height might be a measure of cognitive and functional reserve,[28] and a positive association has been demonstrated between height and intelligence,[29] which is also related to dementia risk, particularly vascular dementia.[10,30] A further possibility is a common genotype determining height and dementia risk. Average height in populations has generally increased in a secular fashion over the past century, with a marked increase in the first quarter of the 20th century (Fig. 3). The fact that there has been a general improvement in early-life circumstances over the same period supports the hypothesis that height captures something of early-life experience relevant to later dementia risk, particularly in the light of recent studies suggesting that the prevalence of dementia might have decreased in recent years.[31] Given the large sample size in our study the smaller effect identified in women is unlikely to be explained by statistical instability. One possibility is that physical stature in women is less sensitive to living conditions. That diminishing secular increases in female height have been observed in recent years provides some support for this.[21]

Comparison with other literature

The published research on the association between stature and dementia risk is detailed in online Table DS5. Our study is the first to examine the association between stature and dementia mortality. However, for comparison, research reporting on the association with clinical dementia is discussed here. In a Medicare study of the association between knee height and arm span and

dementia in four areas of the USA, 480 participants developed dementia over a mean 5.4 year follow-up.[12] Both measures of shorter stature were associated with a higher risk of dementia in women, but only arm span was associated with dementia risk in men. A study in Israel only of men demonstrated an odds ratio of dementia (309 cases) comparing the tallest and shortest height quartiles of 0.51 (95% CI 0.35–0.74) after adjusting for age, socio-economic status and region of birth.[11] A study of Japanese Americans in Washington, USA, as part of the Ni-Hon-Sea Project – mainly focusing on head circumference – similarly commented that individuals developing dementia (59 incident cases) were shorter than those who did not go on to develop the condition. However, this was not examined in detail.[32]

Cross-sectional studies also add to the evidence for a link between height and dementia. A study of an older Korean population ($n = 746$, 110 dementia cases) found an association between shorter leg length and demispan and dementia after adjusting for age and education.[33] When men and women were considered separately results were statistically significant only in women, but since only 41% of the sample were men this might have been a result of reduced power. Another Korean study ($n = 235$, with 46 dementia cases) found an association between decreased height and increased dementia risk (age- and gender-adjusted HR per cm decrease 1.09, 95% CI 1.05–1.14), which was attenuated with further adjustment for education, smoking, alcohol, pulse pressure, hypertension and type 2 diabetes mellitus (HR = 1.03, 95% CI 0.97–1.11).[28] The HARMONY study of Swedish twins conducted a case–control analysis of 310 people with dementia and 3063 controls.[34] They found that being more than 1 s.d. below the gender-specific mean in height was associated with an odds ratio of dementia of 1.57 (95% CI

1.11–2.22). A case–control study from the USA found a lower risk of Alzheimer's disease in women, adjusted for age and education, but not men.[35] However, when they stratified by *APOE* ε4 status they found this association only in women without that allele (OR = 0.88, 95% CI 0.80–0.97). A further Korean study found an association, only in women, between leg length and Alzheimer's disease, after adjustment for age, rural residence in childhood and education.[36]

There is growing evidence – from studies of variable quality and statistical power – that shorter body stature, measured in a variety of ways, is associated with an increased risk of cognitive decline and dementia in men and women. A number of studies have reported a dose–response association,[11,12,35,37] but the majority have treated height as a continuous measure without demonstrating a linear relationship.[28,32,33,36,38,39] We were able to demonstrate a statistically significant, dose–response association between decreasing height and dementia death. One prospective study and two cross-sectional studies showed a stronger association between height and dementia in women than in men.[12,33,36] We found the converse. It is possible that this disagreement relates to power or to the different outcomes: the studies referred to above used a clinical diagnosis of dementia as their outcome, as opposed to dementia-related death used in our study. Details of dementia incidence were not available for our included cohort studies. We are not aware of any studies directly comparing risk factors for dementia incidence and dementia-related mortality.

Limitations

Our large sample was representative of the general population in the UK and was well characterised in terms of baseline
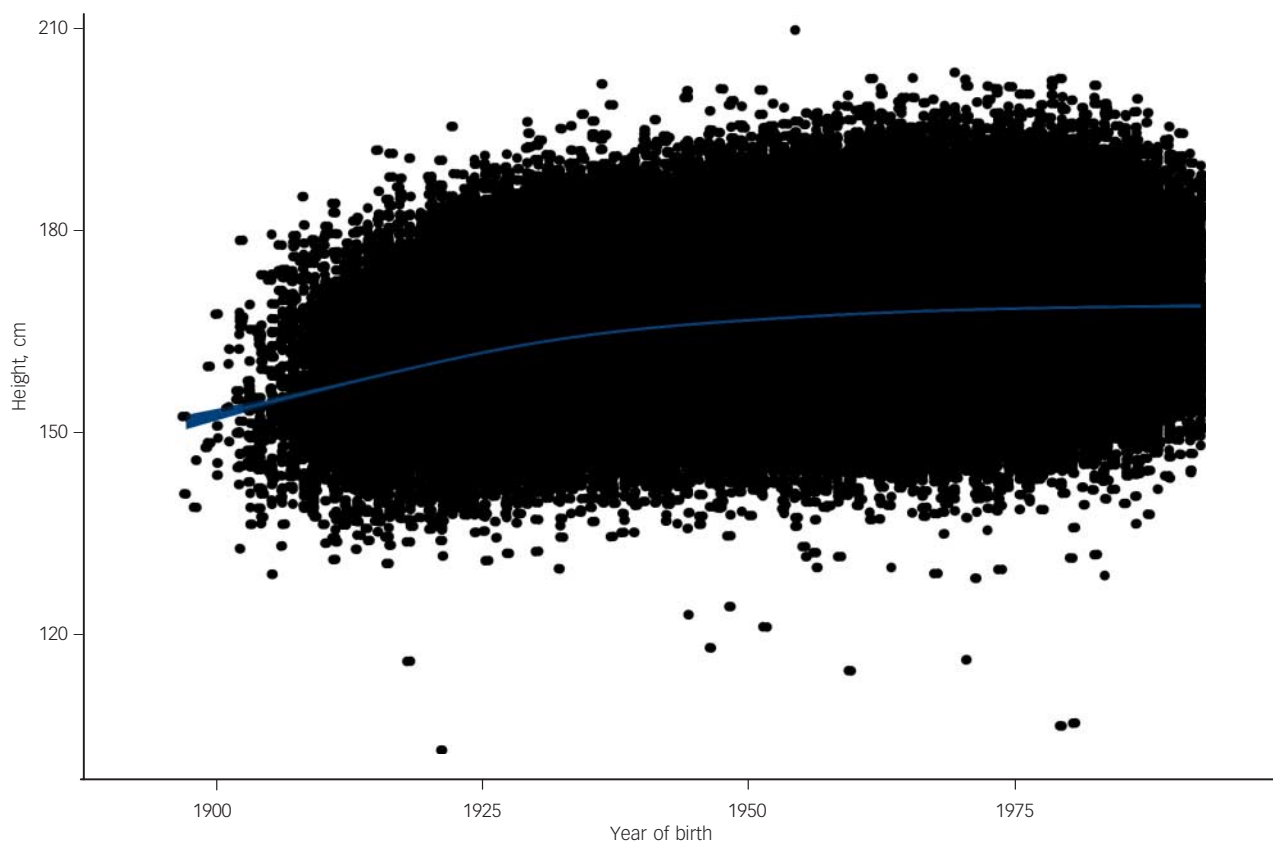
Fig. 3 Secular trend (with 95% confidence interval) in height according to birth year: 18 cohort studies from the Health Survey for England and Scottish Health Survey.

characteristics. This provided sufficient power to allow gender-specific analyses and allowed us to explore the role of a series of explanatory factors. Crucially, this study is well characterised for socioeconomic status (educational attainment and occupational social class) which is a key confounding variable given its association with dementia and height. This notwithstanding, the data also have their limitations. The number of dementia-related deaths in this study is likely to have been affected by the unavoidable problems of underdiagnosis of dementia in the community,[40] underrecording of dementia on death certificates and diagnoses being inaccurately coded. Non-recording of dementia on death certificates has been highlighted as an important issue but this seems to be improving. A recent study identified that 71.5% of a clinic sample diagnosed with probable Alzheimer's disease had dementia correctly recorded on their death certificate.[41] There was no association in that sample between correct dementia certification and area deprivation or premorbid IQ score estimated by the National Adult Reading Test (unpublished results available from the authors on request), suggesting that individuals reported as having dementia on their death certificate are representative of the population of people with diagnosed dementia in the community, at least in terms of intelligence and level of deprivation.

Future research directions

Ideally, a long-term longitudinal study with adult height and relevant covariates measured in early life could be analysed over decades of follow-up to investigate this association in more detail, including information on parental height in order to take genetic determinants of height into account. In the absence of such a study, a more detailed investigation of just what it is that height is capturing that is associated with later dementia risk would allow more accurate forecasts of dementia incidence to be calculated.

Implications of the study

We have demonstrated a dose–response association between height and later dementia death which was robust to adjustment for a series of covariates. We propose the hypothesis that the mechanism driving this association may be early-life circumstances and thus add to the growing evidence of the role of pre-adult factors in later dementia risk. Furthermore, public health policies should continue on a broad front, including pre-school education, breakfast clubs, improved parenting schemes and vaccination programmes.

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