Original Contribution

Area Deprivation Across the Life Course and Physical Capability in Midlife: Findings From the 1946 British Birth Cohort

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Physical capability in later life is influenced by factors occurring across the life course, yet exposures to area conditions have only been examined cross-sectionally. Data from the National Survey of Health and Development, a longitudinal study of a 1946 British birth cohort, were used to estimate associations of area deprivation (defined as percentage of employed people working in partly skilled or unskilled occupations) at ages 4, 26, and 53 years (residential addresses linked to census data in 1950, 1972, and 1999) with 3 measures of physical capability at age 53 years: grip strength, standing balance, and chair-rise time. Cross-classified multilevel models with individuals nested within areas at the 3 ages showed that models assessing a single time point underestimate total area contributions to physical capability. For balance and chair-rise performance, associations with area deprivation in midlife were robust to adjustment for individual socioeconomic position and prior area deprivation (mean change for a 1-standard-deviation increase: balance, −7.4% (95% confidence interval (CI): −12.8, −2.8); chair rise, 2.1% (95% CI: −0.1, 4.3)). In addition, area deprivation in childhood was related to balance after adjustment for childhood socioeconomic position (−5.1%, 95% CI: −8.7, −1.6). Interventions aimed at reducing midlife disparities in physical capability should target the socioeconomic environment of individuals—for standing balance, as early as childhood.

geography; Great Britain; health status disparities; longitudinal studies; multilevel analysis; physical endurance; residence characteristics; socioeconomic factors

Abbreviations: CI, confidence interval; GIS, geographic information system; SAHSU, Small Area Health Statistics Unit; SD, standard deviation; SEP, socioeconomic position.

It has consistently been shown that major disability affects older people's ability to live independently (1). The treatment and management of disability is expensive (2); for example, the United Kingdom Treasury has estimated that approximately £33.3 billion (approximately $54.4 billion) was spent on sickness and disability pensions in 2012 (3). Thus, identifying factors that could delay or prevent the onset of disability could have a large impact on the social and economic costs of caring for an aging population.

There is growing evidence that people who live in more deprived areas in later life also have worse physical health, when measured by self-reported functional limitations (4),

mobility disability (5), and general disability (6, 7). Objective measures of physical capability, such as grip strength, chair-rise performance, and balance (8), have been shown to be predictors of disability (9) but have not been considered in relation to area characteristics. Physical capability in midlife has been shown to be a consequence of factors that exert an influence across the life course, such as growth in childhood and adult body size (10, 11). Hence, the socioeconomic environment in which people live earlier in life may be associated with physical capability in later life. In addition, the residential mobility of individuals and socioeconomic changes in areas over time means that analyses based on place of

residence at a single time point could produce mis-estimation of the effect of area. Establishing the portion of the life course in which residence area makes the most difference to physical capability could also help focus interventions on those area characteristics that affect specific age groups.

Therefore, in this study, we linked prospectively collected residential addresses of participants in the Medical Research Council's National Survey of Health and Development at ages 4, 26, and 53 years to census area socioeconomic data to investigate when during the life course area deprivation was associated with objective measures of physical capability in midlife. We further examined whether these relationships were independent of individual life-course socioeconomic position (SEP).

MATERIALS AND METHODS

Study population

The National Survey of Health and Development is an ongoing study of a socioeconomically stratified sample of 5,362 singleton births that took place in England, Scotland, and Wales during 1 week in March 1946. Cohort members have been followed up 22 times from birth to age 53 years, and a wealth of data has been collected throughout their lives on their social circumstances and health. At age 53 years, the sample providing information consisted of 3,035 men and women, representing 70.4% of the 4,311 cohort members who were still alive and residing in England, Scotland, or Wales (12).

Physical capability

In 1999, when the study participants were aged 53 years, trained nurses visited their homes to measure performance on the chair-rise test (number of seconds needed to rise from a sitting position to a standing position and then sit down again 10 times), standing balance (the longest amount of time the person can maintain a 1-legged stand with eyes closed—maximum of 30 seconds), and grip strength (highest value (kg) from 4 measurements, 2 from each hand, taken using an electronic handgrip dynamometer). A total of 2,566 participants (84.5%) provided data on all 3 physical capability measures. The remaining 469 participants had missing data and were excluded from the analyses; 73 were missing data on all 3 tests, 182 were missing data on 1 or 2 tests, and 214 were unable to perform 1 test (133 for chair rise, 42 for standing balance, and 39 for grip strength).

Life-course area deprivation

At every data collection, current place of residence was recorded on survey forms for each study member. Place of residence at 3 different ages was chosen to represent area in childhood (age 4 years—1950), early adulthood (age 26 years—1972), and midlife (age 53 years—1999) and to be close to census years. The overall process of linking residential addresses to area deprivation measures was a 2-step one (13). First, automated matching was carried out on addresses in order to allocate to each place of residence a grid coor-

dinate. Second, these generated coordinates were used to link area data from the closest census: 1951 data for local government districts for 1950 (14, 15), 1971 data for districts for 1972 (16, 17), and 2001 data for districts or unitary authorities for 1999 (18, 19). For 1951 and 1971, Scottish addresses had to be linked to data for counties and the 4 main cities, since district data were not available (15, 17).

All 2,566 cohort members who completed all 3 physical capability tests had an address collected at age 53 years (1999). The United Kingdom's Office of National Statistics All Fields Postal Directory (20) was used to implement both linkage steps, and 2,554 postcodes (99.5%) were assigned to 2001 local government districts. For the other years, Imperial College London's Small Area Health Statistics Unit (SAHSU) used the Ordnance Survey's ADDRESS-POINT database (21) to generate grid coordinates for 2,390 postcodes from 1972 (9.8%) and 1,347 addresses from 1950 (55.0%), since 1950 predated the introduction of postcodes. The generated coordinates were then linked by the University of Portsmouth's Great Britain Historical Geographic Information System (GIS) Project to the relevant historical area boundary using county administrative diagrams (22, 23). For the 40 postcodes from 1972 (1.6%) and the 1,101 addresses from 1950 (45.0%) that could not be matched by the SAHSU team, the Great Britain Historical GIS team employed manual methods of assignment (13).

Overall, when an address or postcode was available, more than 99.0% were linked to the appropriate census area from 1951, 1971, or 2001. A further 13 were excluded because area deprivation data were missing for the area in which the participant resided for 1 of the study years. This resulted in a sample size of 2,300 persons for analysis. The percentage of employed persons in each area with occupations that were partly skilled or unskilled was selected as the primary area socioeconomic variable, since we have previously (13) shown it to be the most consistent and appropriate available census variable for approximating area deprivation across all study years.

Individual SEP

Individual SEP information from the same data collections as the address information was used in these analyses. Childhood SEP was based on father's occupation when the cohort member was aged 4 years (1950), while both young adult SEP and adult SEP were based on the cohort member's own occupation at ages 26 and 53 years, respectively. Occupational class was assigned using the Registrar General's 6-group classification (24). If SEP information was missing, then SEP at the closest available age was taken ($n = 36$ at age 4 from age 7 years, $n = 139$ at age 26 from age 36 years, and $n = 78$ at age 53 years from age 43 years).

Statistical analysis

For each study year, differences in mean area deprivation by gender, country of residence, education, and individual SEP were compared using analysis of variance (Table 1). Grip strength was divided by height in centimeters to account for body size (25) and then multiplied by 10 for presentation

Table 1. Mean Number of Persons Per Area and Mean Area Deprivation[a] of Areas in Which Cohort Members Lived at Ages 4, 26, and 53 Years, According to Selected Characteristics (n = 2,300), United Kingdom, 1946–1999

	1950				1972				1999			
	No. of Areas or Persons	%[b]	Mean (SD)	*P* for Difference Between Means	No. of Areas or Persons	%[b]	Mean (SD)	*P* for Difference Between Means	No. of Areas or Persons	%[b]	Mean (SD)	*P* for Difference Between Means
Areas												
All areas[c]	810		2.8 (3.9)		845		2.7 (2.9)		389		5.9 (3.9)	
England[d]	709	52.5	2.7 (3.4)	<0.01	761	61.1	2.6 (2.5)	<0.01	337	100.0	5.8 (3.9)	0.02
Wales[d]	67	55.4	1.9 (2.1)		53	43.8	1.9 (1.5)		22	59.5	5.4 (3.3)	
Scotland[e]	34	100.0	7.6 (8.7)		31	91.2	7.6 (7.2)		30	88.2	7.7 (4.8)	
Individuals												
All persons[f]	2,300		29.3 (7.6)		2,300		25.0 (6.1)		2,300		19.7 (2.9)	
Gender[f]												
Male	1,139		29.3 (7.6)	0.56	1,139		25.1 (6.1)	0.24	1,139		19.8 (2.8)	0.33
Female	1,161		29.2 (7.7)		1,161		24.8 (6.0)		1,160		19.7 (2.9)	
Country of residence[f]												
Scotland	257		32.9 (4.1)	<0.01	235		29.5 (4.0)	<0.01	231		21.3 (2.2)	<0.01
England	1,917		28.5 (7.8)		1,962		24.3 (6.0)		1,951		19.4 (2.8)	
Wales	126		33.1 (6.7)		103		27.7 (5.0)		118		21.6 (2.5)	
Individual socioeconomic position[f]												
Nonmanual	956		27.6 (7.6)	<0.01	1,419		24.0 (5.9)	<0.01	1,520		19.4 (2.7)	<0.01
Manual	1,285		30.6 (7.4)		850		26.5 (6.0)		726		20.3 (2.9)	
Missing data	59		27.1 (7.4)		31		26.1 (5.4)		54		21.0 (3.0)	
Physical capability[g]												
Balance time, seconds	2,300										7.1 (6.6)	
Chair-rise time, seconds	2,300										22.2 (16.4)	
Grip strength, kg/cm × 10	2,300										2.2 (0.8)	

Abbreviation: SD, standard deviation.

[a] Area deprivation was measured as the percentage of employed persons in the area working in partly skilled or unskilled occupations.
[b] Percentage of the total number of areas for that country.
[c] Mean values refer to the mean number of persons per area.
[d] Areas for England and Wales were based on local government districts.
[e] Areas for Scotland were based on counties.
[f] Mean values refer to the mean level of area deprivation for individuals.
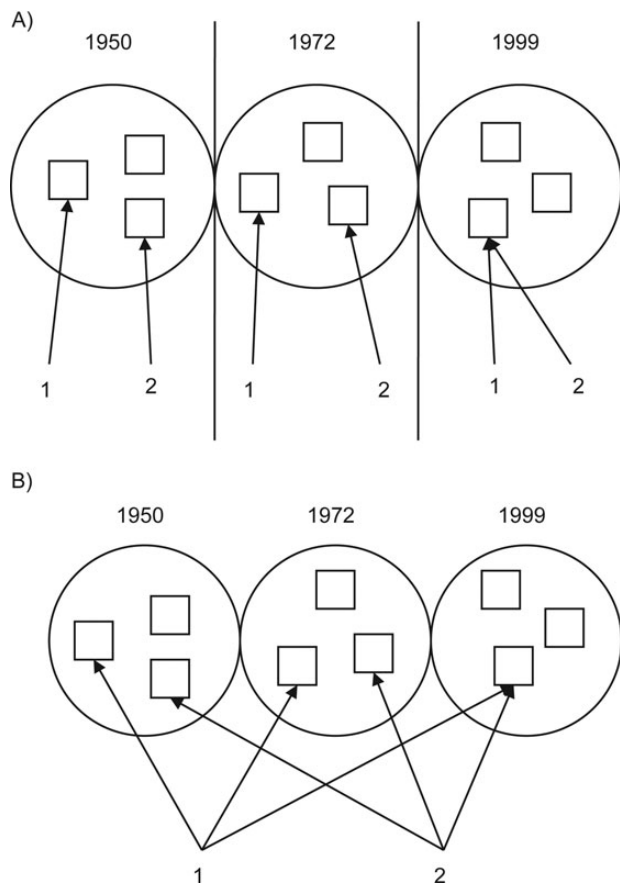[g] Mean values refer to the mean physical capability outcome for individuals.

Figure 1. Structure of 2-level nested (A) and cross-classified (B) area effects models used in a study of area deprivation across the life course and midlife physical capability, United Kingdom, 1946–1999. Circles are the years in which residential address data were collected; squares are residential areas (local government districts for England and Wales; counties for Scotland). Numbers depict participants 1 and 2. Dashed lines indicate that for 2-level nested models, each year was fitted separately, while for cross-classified models, the absence of dashed lines indicates that all 3 years were fitted in the same model.

purposes. Because of a skewed distribution, logarithmic transformation was applied to standing-balance and chair-rise data to achieve normality.

First, all models were fitted as 2-level models of individuals nested within areas for each of the 3 study years, with each year being analyzed separately without incorporation of information about residence area for the other 2 years (Figure 1A). Then, cross-classified models were fitted that extended the initial 2-level models to include random level 2 components for area, where individuals were nested within up to 3 different areas from 1950, 1972, and 1999 (Figure 1B). The percentage of the variance explained by area in each year was then compared between the 2 models. In addition, the overall percentage of variance explained by life-course area was calculated from the cross-classified models by summing area variance for all 3 study years and dividing by the total variance.

Area-level variance was assessed before and after the inclusion of area deprivation and individual SEP measures. Statistical models and formulas are presented in the Appendix.

Using both types of models, we then examined the relationship between area deprivation for each time period (1950, 1972, or 1999) and each physical capability outcome at the age of 53 years. Initially, area deprivation was modeled separately for each year. Results for the standing-balance and chair-rise tests are presented as the mean percentage change in seconds (26) for a 1-standard-deviation (SD) difference in area deprivation, with its associated 95% confidence interval. For grip strength, estimates are shown as the mean difference in kg/cm. Then, each model was fitted to include individual SEP from the same age (i.e., 1950 area deprivation adjusted for childhood SEP). Third, models were fitted to assess whether area deprivation was independent of area deprivation at prior time points (i.e., 1972 adjusted for 1950). Final models contained all prior area deprivation measures and current and prior individual SEP (i.e., 1972 area deprivation adjusted for area deprivation in 1950, young adult SEP, and childhood SEP).

Finally, to determine whether earlier area deprivation modified the effects of subsequent area deprivation measures, interaction terms were added to the models (i.e., 1950 × 1972, 1972 × 1999, and 1950 × 1999). All analyses were performed using SAS statistical software, version 9 (SAS Institute Inc., Cary, North Carolina). Since the average number of individuals within areas was low, we repeated all analyses using Markov chain Monte Carlo estimation in MLwiN (Centre for Multilevel Modelling, University of Bristol, Bristol, United Kingdom). Results remained unchanged, and hence only those from the original method using maximum likelihood analyses are presented here.

RESULTS

In 1951 and 1971, cohort members lived in over half of all local government districts in England and Wales and almost all counties in Scotland. On average, there were 2.8 and 2.7 persons per area in 1951 and 1971, respectively. Averages were higher in Scotland compared with England and Wales and in 1999 compared with earlier years, because of larger geographical areas. The average area deprivation (percentage of persons employed in semiskilled or unskilled occupations) of the areas in which cohort members lived was highest in 1951, at 29.3% (SD, 7.6), and declined steadily to 25.0% (SD, 6.1) in 1971 and 19.8% (SD, 2.9) in 2001. For cohort members, the strongest correlation in standardized area deprivation measures occurred between the years 1972 and 1999, at 0.49, while correlations were lower between 1950 and both 1972 (0.30) and 1999 (0.33).

There were no gender differences in area deprivation for any of the years. For all time periods, average area deprivation was higher for areas in Scotland and Wales compared with England and for persons who had fathers who worked in a manual occupation compared with a nonmanual occupation (Table 1). However, cohort members who changed their individual SEP from childhood to young adulthood lived in areas with lower deprivation in midlife than persons who remained in a manual social class at both ages (mean area

Table 2.   Variance in Measures of Physical Capability at Age 53 Years (1999) Explained by Area of Residence in 1950, 1972, and 1999 in 2-Level Nested Models[a] Compared With Cross-Classified Models[b] (n = 2,300), United Kingdom, 1946–1999

	1950		1972		1999		Total Life Course[c]	
	Variance Between Areas	% of Total Variance	Variance Between Areas	% of Total Variance	Variance Between Areas	% of Total Variance	Variance Between Areas	% of Total Variance
Standing-balance test, seconds								
2-level models	0.0287**	4.6	0.0518**	8.4	0.0532**	8.6	—[d]	
Cross-classified models	0.0130	2.1	0.0278*	4.5	0.0392**	6.3	0.0800	12.9
Chair-rise test, seconds								
2-level models	0.0046*	3.7	0.0128**	10.4	0.0145**	11.7	—	
Cross-classified models	0.0013	1.0	0.0063*	5.1	0.0124**	10.0	0.0199	16.1
Grip strength, kg/cm × 10								
2-level models	0.00024**	4.1	0.00023*	3.9	0.00027**	4.6	—	
Cross-classified models	0.00019*	3.3	0.00005	0.8	0.00023**	3.8	0.00047	7.9

* $P < 0.05$; ** $P < 0.01$ (2-sided P value).

[a] Results were derived from 2-level models with persons nested within areas, fitted separately for each year.

[b] Results were derived from cross-classified models (includes random level 2 components for area in each of 1950, 1972, and 1999, where individuals were nested within up to 3 different areas).

[c] Sum of area-level variance for all study years (1950 + 1972 + 1999).

[d] It was not possible to calculate "total life course" variance between areas, because the 2-level models were fitted separately for each year.

deprivation for change from a manual occupation to a non-manual occupation = 19.6%; mean area deprivation for a manual occupation at both time points = 20.6%; P for difference < 0.002). The reverse pattern occurred for persons who were downwardly socially mobile (data not shown).

For all 3 outcomes, when nested models were used, significant variation existed across areas for all study periods, with larger variation for balance than for chair rise and quite small variation for grip strength (Table 2). For balance and chair rise, the total amount of variation explained by area was larger for 1972 and 1999 than for 1950. For example, approximately 8.4% and 8.6% of the total variance for balance was explained by area in 1972 and 1999, respectively, with almost half the amount of variance (4.6%) explained by area in 1950. Area in each of the 3 years accounted for 3%–4% of the variation in grip strength. For all outcomes, use of cross-classified models reduced the percentage of variance attributable to area at each year. Summation of the area variance from all 3 years to obtain the percentage of variance explained by lifetime area gave figures of 12.9% for balance, 16.1% for chair rise, and 7.9% for grip strength. For all further analyses, we display results fitted with cross-classified models only.

For standing balance, adjustment for area deprivation at all 3 ages reduced but did not entirely explain area variation (percentage reductions: 1950, 30.0%; 1972, 3.2%; 1999, 32.4% (see Web Table 1, available at http://aje.oxfordjournals.org/)). For fixed effects (Figure 2), there were associations between area deprivation at all 3 time points and standing balance at age 53 years (1999). For example, cohort members who

resided in areas with a 1-SD higher area deprivation level in 1999 had, on average, 10.6% (95% confidence interval (CI): 6.7, 14.4) lower balance times (worse physical capability) (model 1). Associations were weaker for area deprivation in 1950 (6.3%, 95% CI: 2.9, 9.7) and 1972 (4.9%, 95% CI: 1.2, 8.5). Area deprivation in 1950 remained associated with balance, albeit reduced, after adjustment for childhood SEP (model 2). In fully adjusted models (model 4), whereas area deprivation in 1999 was robust to adjustment for all prior area deprivation and all prior and current individual SEP measures, area deprivation in 1972 was largely explained. There were no interactions between area deprivation in 1999 and area deprivation in either prior study year (for 1999 × 1950, $P = 0.55$; for 1999 × 1972, $P = 0.27$). Associations of area deprivation and physical capability measures obtained using nested models are available in Web Table 2.

For the chair-rise test, in comparison with the unadjusted models, area variances in 1972 and 1999 were only marginally reduced after adjustment for area deprivation at all 3 ages (1.6% and 2.4%, respectively) (Web Table 1). However, patterns of association were similar; the strongest association was in 1999, with an increased mean chair-rise time at age 53 years (worse physical capability) of 2.2% (95% CI: 0.3, 4.1) per 1-SD increase in area deprivation, which was only slightly attenuated by adjustment for adult SEP (Figure 2, model 2), prior area deprivation (model 3), and all prior individual SEP measures (model 4). In addition, only for the year 1999 was any of the original area variance in chair rise explained by area deprivation (2.8%) (data not shown). There was no interaction between area deprivation in 1999 and
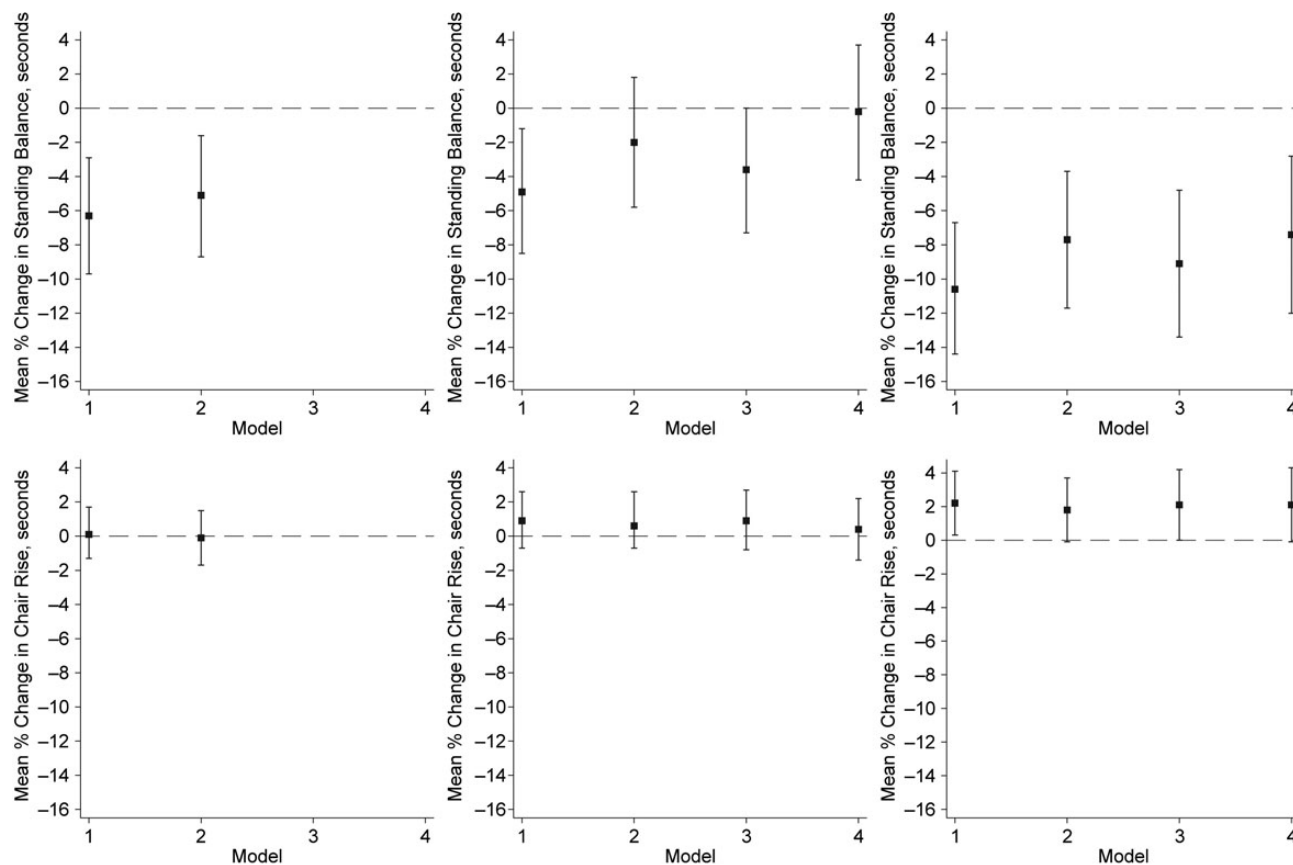
Figure 2. Mean percent change in physical capability measures at age 53 years for a 1-standard-deviation increase in area deprivation in 1950, 1972 and 1999 (from cross-classified models), United Kingdom, 1946–1999. Left column, age 4 years (1950); middle column, age 26 years (1972); right column, age 53 years (1999). In model 1, results were unadjusted ($n = 2,300$); in model 2, results were adjusted for cross-sectional individual socioeconomic position (SEP) (i.e., area deprivation in 1950 adjusted for childhood SEP only); in model 3, results were adjusted for prior area deprivation (i.e., area deprivation in 1972 adjusted for 1950); and model 4 was the full model fitted for all previous area deprivation and current and prior individual SEP (i.e., area deprivation in 1999 adjusted for area deprivation in 1950 and 1972 and individual SEP in 1950, 1972, and 1999 (ages 4, 26, and 53 years)). Area deprivation was measured as the percentage of employed persons in the area working in partly skilled or unskilled occupations. Because of missing data, models adjusting for individual SEP (models 2 and 4) contained fewer than 2,300 participants. Bars, 95% confidence interval.

area deprivation in 1972 ($P = 0.90$). The unadjusted mean differences in grip strength by area deprivation were so small as to not be clinically relevant (for all years, < 0.006 kg/cm per 1-SD increase in area deprivation), and thus no further analyses are presented.

DISCUSSION

Findings from this study show that for members of this postwar British cohort, those who resided in more deprived areas at age 53 years also had worse standing-balance and chair-rise times. Importantly, we showed that the variation in these 2 physical capability measures at midlife that could be attributed to area of residence was underestimated when residence at earlier points in the life course was not taken into consideration. In particular, the ability of cohort members to stand on 1 leg at midlife was related to both childhood and midlife exposure to area deprivation.

The finding that poorer standing-balance and chair-rise times were associated with current deprivation is consistent with previous cross-sectional studies showing that living in a socioeconomically deprived area in adulthood is associated with worse physical health (4, 5, 7, 27, 28). We have built on these previous studies by showing, for the first time, that area deprivation in childhood is related to standing balance in midlife. Further, comparisons of the cross-classified models with the simpler 2-level hierarchical models showed that by failing to account for area of residence in childhood, the overall contribution of residence area to variation in balance performance in midlife was underestimated.

To our knowledge, this is the first study to utilize geographical data linked to prospectively collected address information during childhood, early adulthood, and midlife and link these exposures to health disparities in midlife. The relationship between life-course area effects and health has been investigated previously (29–33), but not for physical capability. In

the Atherosclerosis Risk in Communities Study, a summary measure of life-course area deprivation was not associated with subclinical atherosclerosis after adjustment for life-course individual SEP, although recall of childhood residence may have resulted in bias and underestimation of effects (29). The ONS Longitudinal Study for England and Wales (30) used prospectively collected address data to show that long-term illness was a consequence of area deprivation during both childhood (1939) and later life (1981). Finally, 2 Scandinavian studies (31–33) used cross-classified models to show that area of residence at the most recent time point (1999) explained more variance in mortality than residence in earlier years (1969, 1979, and 1989). For the latter study (33), the overall variance explained by area was much less than that in our study. Discrepancies may be explained by a particular effect of area on the physical disablement process or country-specific geographical inequalities. Neither study analyzed fixed effects of areas.

The mechanism(s) by which area deprivation could be affecting physical capability in midlife is unclear. Numerous studies have shown that higher area deprivation is related to poorer dietary habits (34–37), less physical activity (34, 38–41), and higher rates of smoking (34, 39, 41–45), all of which are risk factors for declines in functional status (46, 47). Inequitable geographical distribution of these factors, such as availability of health food (48), could influence growth, thereby permanently altering or establishing vulnerability in the functional capacity of an individual (10, 11). In addition, area characteristics in childhood may influence the development of health behaviors such as physical activity (49, 50) and diet (51), which are related to physical capability and tend to track into adulthood. Future work is required to examine specific features of the area socioeconomic environment during different life periods that could lead to poor physical capability at all ages.

The finding that area deprivation in midlife was related to standing balance and chair rise but not to grip strength may suggest that these factors are influenced by different pathophysiology. All 3 measures depend on the central nervous system for sensory and motor control, but while grip strength is a test of upper-body strength, balance and chair-rise time reflect differing combinations of mainly lower-body neuromuscular speed and control (52–54). Stronger findings of area effects across the life course for balance than for chair-rise performance may also suggest that area deprivation is affecting adult physical capability through central nervous system pathways rather than through muscle atrophy. This is supported by previous findings from this cohort, where Kuh et al. (52) observed that balance and chair-rise performance were both linked to changes in adult cognition but only balance was independently related to childhood cognition. Such pathways remain speculative, as there are no current studies linking area deprivation to central nervous system outcomes in childhood or midlife.

We found associations with area deprivation to be only slightly explained by individual SEP. However, we have not investigated the complex ways in which individual SEP and area SEP interact over the life course. Family social position in childhood can influence not only the future SEP of that child (55, 56) but also potentially his or her future adulthood

residence, because of close links between individual SEP and residential SEP (57). Thus, adjustment of current area characteristics for prior individual and area deprivation may represent overadjustment. The stronger association seen with current area characteristics, as compared with childhood and young adulthood, provides some support for the role of adult environmental factors in maintaining and facilitating greater physical activity and healthy diet. However, it may also reflect a "selection effect" such that less healthy persons with poorer physical performance move to more deprived areas, thereby creating an association through reverse causation. Our data did show that downward social mobility was related to higher deprivation at midlife, making it plausible that some or all of the area effects may be due to selection (58). More work is needed to disentangle the relationships between individuals, their residence areas, and their health over the life course to create appropriate methods and to test whether observed associations are true effects of residential area or artifacts of residential selection.

A strength of this study was the repeated prospective collection of area residential addresses and individual socioeconomic characteristics across the life course. The almost 100% linkage of address data for all 3 years made it less likely that estimates were affected by selection bias. As in any longitudinal study, attrition of the sample occurred, despite high response rates (12). However, area deprivation did not predict loss to follow-up. A total of 469 persons were excluded because of the inability to perform a physical capability test or were missing data for a physical capability test. While there were no average differences in area deprivation for cohort members missing test results, those unable to perform tests (n = 214) resided in areas with higher levels of deprivation (data not shown), suggesting that associations between area deprivation and physical capability were underestimated by virtue of the exclusion of persons with the lowest physical capabilities from the analysis.

Major challenges in this study were that we were restricted in the size of the geographical units we could analyze and the area socioeconomic measures we could assess because of the limitations of historical census data (13). It is unknown whether local government district is the relevant area that might influence physical capability. When analyses of area deprivation at age 53 years and physical capability were rerun at the ward level, the estimates of association were stronger (13), suggesting that the relevant context may be at a smaller geographical level and that our findings underestimate the effect of area. District boundaries for 2001 were larger than those in 1951 and 1971 (59), with approximately 3 times the population (13), potentially introducing a larger degree of underestimation for area effects in 2001 compared with earlier years. Household-level factors may also be relevant to health outcomes (60), but information at this level was not available in our data. Extensive social change over the past 50 years (61) also makes it unclear whether the percentage of individuals in partly skilled or unskilled occupations in an area represented the same concept of area deprivation during all study periods. Future work is needed to investigate whether the mechanism(s) linking area occupational classes to physical capability are consistent across different periods of the life course.

In conclusion, findings from this study suggest that strategies for the prevention of disability need to consider not only individual characteristics but also the residential environments in which people live. Some aspects of disability, such as the ability to balance, may require interventions aimed at improving the areas in which people grow up and in which they reside in midlife in order to maximize impact. However, before interventions can be planned, further work is needed to identify the specific pathways and appropriate geographical levels by which disparities in residential socioeconomic environment could affect midlife physical performance.

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APPENDIX

Structure of Area Effects Models

Two-level nested model

Y_{ij} is the physical capability of person i in area j, γ_{00} is the grand mean physical capability score for all persons, and γ_{01} is the fixed effect of area deprivation for that particular year ($xx = 1950$, 1972, or 1999).

$$Y_{ij} = \gamma_{00} + \gamma_{01}\text{AREA19}xx_J + U_{0J} + \varepsilon_{IJ}.$$

ε_{IJ} denotes the random "person effect," that is, the deviation of person ij's score from the cell mean. These deviations are assumed to be normally distributed with mean 0 and a within-cell variance of δ_{xx}^2. U_{0j} is the random area effect for each area j, which is also assumed to be normally distributed with a mean of 0, but variance is $\tau_{xx\eta}$. Therefore, the percentage of variance attributed to areas is $\tau_{xx\eta}/(\tau_{xx\eta} + \delta_{xx}^2)$.

Cross-classified model

$Y_{i(jkl)}$ is the physical capability of person i, who resided in the areas at 3 different time periods of j (1950), k (1972), and l (1999); γ_{00} is the grand mean physical capability score for all persons; and γ_{01} is the fixed effect of area deprivation in 1950, γ_{02} the fixed effect of area deprivation in 1972, and γ_{03} the fixed effect of area deprivation in 1999.

$$Y_{i(jkl)} = \gamma_{00} + \gamma_{01}\text{AREA1950}_{(jkl)} + \gamma_{02}\text{AREA1972}_{(jkl)}$$
$$+ \gamma_{03}\text{AREA1999}_{(jkl)} + U_{0J} + U_{0K} + U_{0L} + \varepsilon_{i(jkl)}.$$

$\varepsilon_{i(jkl)}$ denotes the random "person effect," that is, the deviation of person i's score from the cell mean. These deviations are assumed to be normally distributed with mean 0 and a within-cell variance of $\delta_{(j/k/l)}^2$. U_{0j} is the random area effect for area j (1950), which is also assumed to be normally distributed with a mean of 0, but the variance is $\tau_{\eta j}$. The same distribution is assumed for areas k (1972) and l (1999).

Therefore, the percentage of variance attributed to areas for each year is $\{\tau_{(j/k/l)}\}$/all variation. The percentage of variation attributed to areas across the 3 years is $\{\tau_{\eta j} + \tau_{\eta j} + \tau_{\eta j}\}$/all variation.