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Green space and cognitive ageing: A retrospective life course analysis in the Lothian Birth Cohort 1936

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ABSTRACT

International evidence suggests that green space has beneficial effects on general and mental health but little is known about how lifetime exposure to green space influences cognitive ageing. Employing a novel longitudinal life course approach, we examined the association between lifetime availability of public parks and cognitive ageing. Lifetime residential information was gathered from the participants of the Lothian Birth Cohort 1936 using a "life-grid" questionnaire at age 78 years. Parks information from 1949, 1969 and 2009 was used to determine a percentage of parks within a 1500 m buffer zone surrounding residence for childhood, adulthood, and later adulthood periods. Linear regressions were undertaken to test for association with age-standardised, residualised change in cognitive function (Moray House Test score) from age 11 to 70 years, and from age 70 to 76 (n = 281). The most appropriate model was selected using the results of a partial F-test, and then stratified by demographic, genetic and socioeconomic factors. The local provision of park space in childhood and adulthood were both important in explaining the change in cognitive function in later life. The association between childhood and adulthood park availability and change in the Moray House Test Score from age 70 to 76 was strongest for women, those without an *APOE* e4 allele (a genetic risk factor), and those in the lowest socio-economic groups.

Greater neighbourhood provision of public parks from childhood through to adulthood may help to slow down the rate of cognitive decline in later life, recognising that such environmental associations are always sensitive to individual characteristics.

1. Introduction

With the global increase in life expectancy, there is an urgent need to identify factors that affect changes in cognitive abilities as people age. Explanatory models of cognitive ageing posit a variety of demographic, genetic, behavioural and environmental factors contributing to cognitive function (Anstey, 2014). The focus of the current research is on how environmental conditions – or more specifically local green spaces - throughout life affect people's cognitive ageing relative to one another. There have been significant advances made in understanding the range of demographic, genetic, and behavioural factors affecting cognitive ageing. For instance, women tend to have greater resilience to age-related decline (McCarrey et al., 2016). The major genetic predictor

responsible for increased susceptibility to non-normative cognitive ageing is the presence of the APOE (apolipoprotein) e4 allele (Davies et al., 2014; Deary et al., 2012b; Schiepers et al., 2012). Behavioural factors, including diet, physical activity, smoking and alcohol consumption, closely related to an individual's socioeconomic status, are often associated with cognitive function in older age, although, apart from smoking, results differ between studies and some associations are prone to confounding by prior cognitive function (Deary et al., 2009; Plassman et al., 2010). Little work has considered specific built, social or environmental features of local areas, with previous research relying on aggregate measures of social deprivation (Lang et al., 2009). Yet cognitive function could be affected by a range of environmental or neighbourhood conditions including: local social capital; residential

segregation; perceived safety and incivilities; availability of community resources such as food shops and other services; walkability; and the availability of public open space or local greenness (Y. T. Wu et al., 2015a).

It is well established that public open space and greenness is often beneficial for the physical and mental health of local residents (van den Berg et al., 2015). It is also feasible that public open space and greenness may help to optimise cognitive function. Several studies with differing population, design and outcome measures are suggestive of a direct positive benefit of natural environments to directed attention (Ohly et al., 2016). Increased support and motivation for social interaction and physical activity, reductions in stress and exposure to higher air quality offer indirect benefits to cognitive capability, evidenced by a large body of research on changes in physiological markers and emotional states (Hartig et al., 2014). Other indirect benefits such as exposure to beneficial microbiota could indirectly affect cognitive processes through facilitating a reduction in blood pressure and boost to immune function (M. Kuo, 2015). Some of these mechanisms have been shown to directly link with change in cognitive function; for example, in participants over 70 years old, low levels of leisure-time physical activity were associated with a decline in cognitive function five years later (Willey et al., 2016). The only previous longitudinal study of area-level greenness and cognitive change focused on children. The authors found that greenness surrounding a child's home, school and commute was correlated positively with improvements in memory and a reduction in inattentiveness (Dadvand et al., 2015a). However, the study only considered these associations over a 12-month period during early life, and therefore the influence of green space on cognitive function over an individual's lifetime remains unknown.

In the present study, we examined whether availability of green space (using a measure of nearby public parks) was associated with age-related changes in cognitive function between age 11 and 70 years, and between age 70 and 76 years. Three life course models (critical periods, accumulation, and effect modification) were used to address three key hypotheses. First, early childhood has been shown to be a critical period for brain growth due to heightened brain plasticity (Lyu and Burr, 2016). Therefore, we hypothesised that greater public park availability during childhood has positive associations with cognitive change in later life (critical period model). Second, we hypothesised that a greater accumulation of park availability over life is required to promote successful cognitive ageing in later life (accumulation model). This was based on the assumption that cross-sectional effects of access to parks on cognitive function are consistent, albeit weaker, over time (Dadvand et al., 2015a) and that for significant cognitive ageing to be observed a threshold must be surpassed (Anstey, 2014). Finally, by combining the critical periods and accumulation models, we hypothesised that availability during adulthood is important for determining the extent of cognitive reserve, with the capacity to modify the effect of exposure on the sensitive childhood period (effect modification model). As mentioned previously, demographic, genetic and behavioural factors will set an individual on a unique cognitive health trajectory. Therefore, with the aim to determine which groups would benefit most from greater park availability, we stratified the life course model by sex, the presence of an *APOE* e4 allele, and occupational social class (as a marker of individual socioeconomic status).

2. Methods

2.1. Study design and setting

A retrospective life course study was designed using data from the Lothian Birth Cohort 1936 (LBC1936) (Deary et al., 2007, 2012a). The participants, who were all born in 1936, were recruited from Edinburgh and the Lothians in Scotland. Most had taken part in a nationwide assessment of their general intelligence in 1947 (Scottish Mental Survey, 1947; N = 70,805) (SCRE, 1949). The cohort participants were re-

contacted in 2004 and, from 2318 responses, 1091 were eligible for wave 1 data collection (Deary et al., 2012a). Cohort participants were subsequently contacted and tested at mean ages of approximately 70 years (Jul 2004–May 2007), 73 (Oct 2007–May 2010) and 76 (Jul 2011–Nov 2013). At mean age 78, a stand-alone questionnaire booklet was posted out with returns received between July 2014 and April 2015.

2.2. Operationalising change in cognitive function

We operationalised the outcome of cognitive ageing using the participant's Moray House Test No. 12 (MHT) scores from mean ages of 11, 70 and 76 years (SCRE, 1949). The MHT is a validated measure of cognitive function, which correlates highly with the current "gold standard" cognitive tests (Deary et al., 2004). The MHT is a general intelligence test that is composed of 71 items, measuring the participant's ability on a variety of mental tasks including verbal reasoning, arithmetic, and following directions. Each score was adjusted for age in days at the time of examination by taking the standardised residuals from a linear regression with age as the independent variable. The score was then standardised to have a mean of 100 and standard deviation of 15. Change was calculated by generating the standardised residual from a linear regression model with previous MHT score (e.g. change from 11 to 70 calculated by taking age 70 score as the dependent and age 11 as the independent variable). This statistical technique to calculate change in score is superior to an arithmetic difference as the outcome is independent of baseline level (Prochaska et al., 2008), and has been used in relation to changes in cognitive function previously (Gow et al., 2005). The procedure above provided two outcomes: residualised change in MHT score from age 11 to 70 and residualised change in MHT score from age 70 to 76.

2.3. Operationalising LBC1936 covariates

During the structured interview as part of the cognitive testing appointment at age 70, respondents provided the information required for all the covariates except for father's social class, which was obtained via a questionnaire, and BMI, which was obtained during the physical examination. Covariates were selected *a priori* based on previous literature (Deary et al., 2009), including sex, Occupational Social Class (OSC) (Office of Population Censuses and Surveys, 1980) of participant's father, people per room in childhood household, childhood smoking status, OSC of participant, smoking status and alcohol consumption (Deary et al., 2007). OSC of the participant's father was used as a measure of socioeconomic status from childhood and dichotomised into Professional-managerial (I and II) and Skilled, partly skilled, unskilled (III, IV and V). Additionally, we used childhood overcrowding as a secondary measure of socioeconomic status, defined as the number of people per household room. Participants were asked at what age they started smoking and were categorised as a childhood smoker if they responded that they had started before age 16, as per convention (Hopkinson et al., 2014). Smoking status at age 70 was dichotomised as smoker or non-smoker. Similarly, alcohol consumption was dichotomised as drinks alcohol or doesn't drink alcohol. BMI at age 70 was calculated as weight divided by height squared. Socioeconomic status during adulthood was defined by OSC of the participant's main job from their career and dichotomised in the same way as their father's OSC. For females, husband's OSC was used if higher than their own. We selected a number of variables as effect modifiers *a priori* including sex, adulthood OSC and *APOE* e4 allele. Sex and adulthood OSC at age 70 were operationalised as above. Blood samples were taken during examination and participants were genotyped for *APOE* allele status using TaqMan technology at the Wellcome Trust Clinical Research Facility Genetics Core (Deary et al., 2012a). Participants were dichotomised into having at least one *APOE* e4 allele or having none. In addition to the variables above, we selected several variables to act as auxiliary

variables in the imputation of missing data. Due to the association with cognitive ageing, these included the Hospital Anxiety and Depression Scale score (Zigmond and Snaith, 1983), history of stroke (Yes or No) and family history of heart disease, stroke, or problems with blood vessels (Yes or No).

2.4. Operationalising public parks information

We identified four open space surveys that recorded public parks in Edinburgh during the 20th and 21st century (Pearce et al., 2016). Public parks were deemed a suitable indicator of urban green space because they promote social interaction and a range of uses, including physical activity, to a greater extent than ambient greenery (such as road side verges or river corridors) (E. Richardson et al., 2010). Public parks data were scanned from paper maps from the Edinburgh Civic Survey 1949 (Abercrombie et al., 1949) and the Open space survey 1969 (Town Planning Department Edinburgh, 1969), georeferenced and converted to geographic information system vector data using ArcMap 10.1 GIS software (ESRI, Redlands, CA). Contemporary public parks data were derived from the Open Space Audit 2009 (The City of Edinburgh Council, 2009). Although descriptions of the parks changed slightly between surveys (e.g. "public parks" and "public recreation grounds"), consistency was confirmed by the continued presence in certain spaces over time. Hereafter we refer to these spaces simply as 'parks'.

2.5. Operationalising lifetime residential address history

The surviving participants of the LBC1936 were re-contacted in 2014 (mean age 78) (n = 704/1091), and asked to fill out a residential (i.e. Life grid) questionnaire (Blane, 1996), with a response rate of 87% (n = 612/704). From these responses, a total of 593 participants had useable life grid data; these participants are referred to as the "Life grid sample". The participants were given the option to recall the dates of personal events in their life, and to fill them in next to a column containing global events such as the Falklands War. These events acted as memory prompts for participants to provide information on their residential address and occupation (of self or father) for each decade from birth. We have utilised contemporary sources to geocode the 7423 participant addresses. We geocoded the participant addresses using Nomatim to query Open Street Map (OSM) (OpenStreetMap contributors, 2017), as the accuracy for addresses in Edinburgh is between 1 and 3 m and the coverage is excellent (Grosso et al., 2015). The output contained the latitude, longitude and the comma separated OSM-derived address string (e.g. 82, Home Street, Edinburgh, United Kingdom). This address string was then compared with what was supplied by the participant, which was recorded in the same format. 15% of the participant addresses were not able to be geocoded or had lost information (i.e. the difference in the number of comma separated 'information bits' was negative). As we hypothesised that this may be due to misspellings or imperfect matches, the Google Maps geocoding API was used as it employs a fuzzy string matching algorithm. We then manually compared the Google maps geocoding API quality output (i.e. 'rooftop', 'range_interpolated', 'geometric_center' and 'approximate') to the address supplied by the participant. 6% of the google-derived geocodes did not contain the same level of information supplied by the participant and were manually geocoded using historic building repositories such as Canmore.org.uk (i.e. using the 8-digit National Grid Reference, 1m resolution). Participants were eligible for the "Analysis sample" (n = 281) if they recorded Edinburgh addresses during the decades when parks were surveyed (i.e. childhood: 1949; adulthood: 1969; later adulthood: 2009). This approach was markedly less restrictive than an analysis sample where participants had to have all of their previous addresses within Edinburgh (n = 174) and only resulted in a modest drop in the mean percentage of the participant's total number of addresses that were within Edinburgh (i.e. from 100% to

94%).

2.6. Determining park availability using lifetime residential address history

Park availability for the LBC1936 participants was calculated by taking the percentage of park area that intersected with a 1500 m buffer zone surrounding the participant's address at each time period (childhood, adulthood, and later adulthood). A 1500 m buffer zone was selected as it corresponds to approximately a 15-25 min walk to the edge of the buffer zone, based upon data on mean walk speeds of between 1 and 1.5 m/s for ages 20-80 (Ferrucci et al., 2016). Also, a 1500 m circular buffer was used as approximately 90% of the 500 people surveyed in the 1969 Open space survey reported travelling up to 1.6 km (as the crow flies) to reach public parks within the city (Town Planning Department Edinburgh, 1969). A sensitivity analysis was undertaken by repeating the analysis using buffer zones of 500 m and 1000 m. The availability of parks metric was analysed as a continuous variable, for each 10% increase in park area within the 1500 buffer zone.

2.7. Main analyses

All statistical analysis was performed in R version 3.3.1. To investigate the relationship between availability of parks measured at three time periods (childhood, adulthood and later adulthood) and cognitive ageing, we adapted an established method to detect the most appropriate life course model (Mishra et al., 2009). The general premise was to build a series of linear regression models that represent the life course models under investigation ("accumulation", "critical periods", and "effect modification"). The model fit was then compared, via the partial F test, with a "saturated" model. The "saturated" model was specified by including all the individual park terms, three two-way multiplicative interactions and a three-way multiplicative interaction (Fig. 1; see Model 1). The saturated model represents the full complexity of combinations of park availability through life. We determined whether parks have an effect on cognitive ageing or not by comparing the fit statistics of the saturated model with a "no effects" model which contained only the intercept (Fig. 1; see Model 5). This "no effects" model crudely predicted an individual's cognitive change as the mean of the cognitive change experienced by all the participants. Thus, if park availability was important for cognitive ageing then the inclusion of all park terms would explain more of the variance in cognitive change than just using the mean. This was established by comparison of the two models using a partial F-test. If the "no effects" model fitted the data just as well as the saturated model, then a p-value above 0.05 was obtained and we could assume that parks did not have an association with cognitive ageing. If the p-value was lower than 0.05, it signified that the "no effects" model was not superior and we could assume that parks had an effect on cognitive ageing. We could also, subsequently, repeat this procedure to compare life course analyses and determine the most appropriate models.

The Accumulation models were categorised into strict and relaxed. The strict model was defined as the park terms summed (i.e. sum of parks from childhood, adulthood and later adulthood), which assumed that parks had an equal association with cognitive ageing, irrespective of the time they were measured (Fig. 1; see Model 2a). The relaxed model contained each of the park terms as individual predictors; i.e. parks from childhood, adulthood and later adulthood were mutually adjusted for one another, which allowed any differences in the strength of association by time of park measurement to be observed (Fig. 1; see Model 2b).

The Critical Periods models were tested by running separate models for each park term from a single point in time. This assumed that the other park terms did not influence cognitive ageing or modify the association of the parks under investigation (e.g. Fig. 1; see Model 3a).

The Effect Modification models were defined at two points in time, early and later, and were specified by including a multiplicative
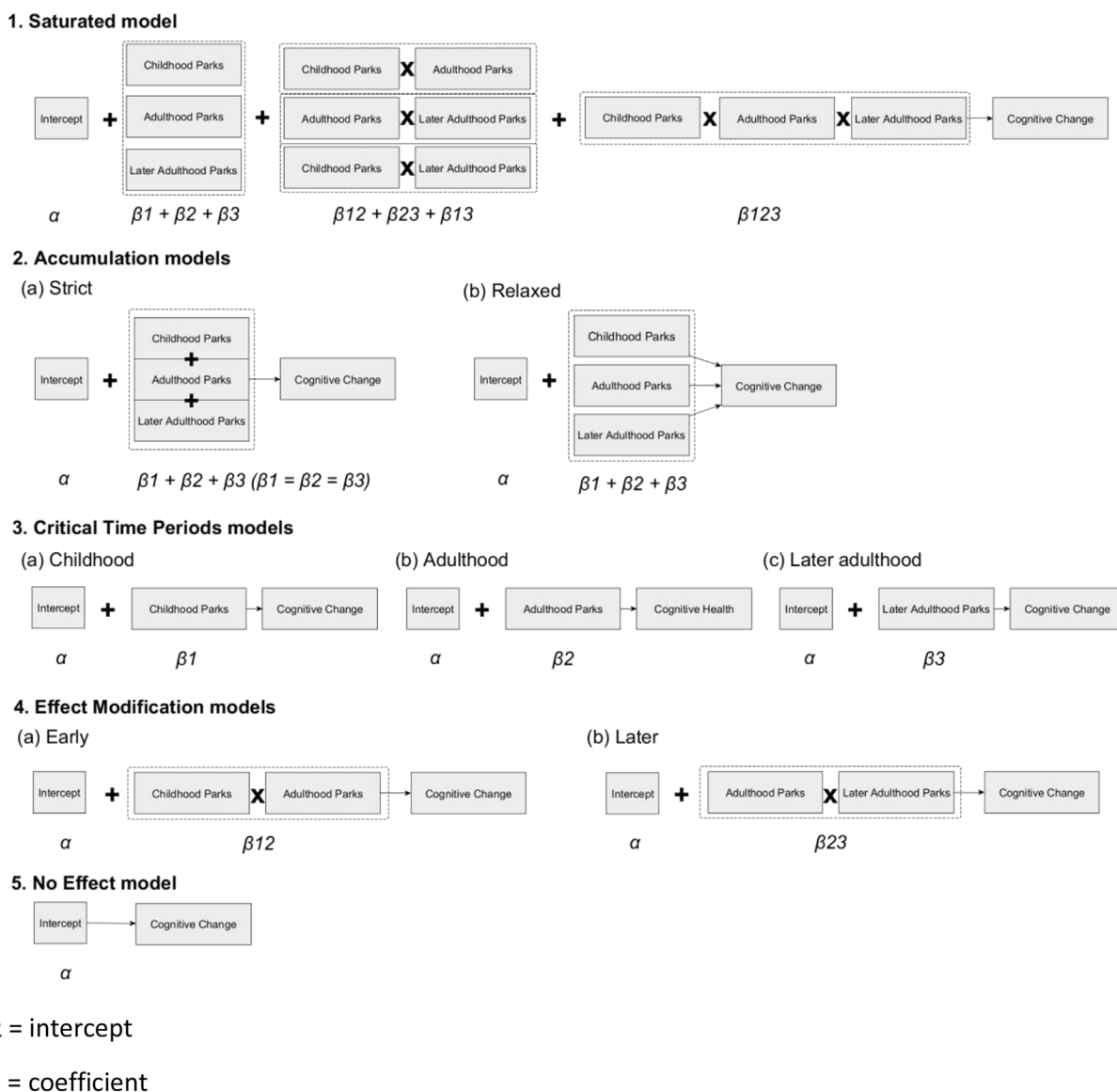
1. Saturated model

Fig. 1. Conceptual model with specifications for life course analysis.

α = intercept

β = coefficient

interaction term between parks from the two successive time periods (i.e. an interaction between childhood parks and adulthood parks) (Fig. 1; see Model 4a). These models emphasised the temporal sequence of exposure during early or later life as being important for the eventual association with cognitive ageing. As before, we compared the partial F-statistics of each life course model with the "saturated" model. A p-value of over 0.05 signified that the life course model fitted the data as well as the "saturated model". The life course model with the highest p-value was deemed the most appropriate as this meant that it not only fit the data as well as the "saturated model", but was more parsimonious. All models were adjusted for sex in a complete-case analysis. A positive regression coefficient represented higher residualised change in cognitive function between the time points (i.e. relatively better cognitive change) whereas a negative regression coefficient represented decreasing residualised change in cognitive function between the time points (i.e. relatively worse cognitive change). The multiplicative interaction regression coefficient was interpreted as the coefficient of one park term being conditional on another.

2.8. Adjusted and stratified analyses

After identifying the most appropriate life course model we continued to the multiple regression analysis, adjusting for childhood and adulthood covariates. Some data were missing for covariates and the two outcomes. These were assumed missing at random and imputed by chained equations using the 'mice' package (van Buuren and Groothuis-Oudshoorn, 2011). We imputed 20 datasets using the following socio-demographic and behaviour variables that were proposed to be related to the missing structure: sex, OSC, smoking, alcohol consumption and BMI; and variables proposed to be associated with cognitive ageing: Hospital Anxiety and Depression Scale total score, history of stroke, and family history of heart disease, stroke or problems with blood vessels. The estimates from the imputed datasets were pooled using Rubin's rules. We then ran a linear regression for three nested models with adjustment for: (i) sex; (ii) father's OSC, number of people per rooms in childhood household, childhood smoking status, (iii) adulthood OSC, alcohol consumption and adulthood smoking status. Finally, using the fully adjusted model we stratified by sex, the presence of the *APOE e4* allele and adulthood OSC.

Table 1
Descriptive statistics of LBC 1936 participants by sample.

Characteristic at age 70[a]	LBC Full Sample at age 70 (n = 1091)	LBC Life grid sample at age 78[c] n=(593)	LBC Analysis Sample at age 78 (n = 281)
Sex			
Women	543 (50)	279 (47)	135 (48)
Age (days)	25,397 ± 303	25,385 ± 306	25,308 ± 252
Family history of Heart Disease			
Yes	672 (62)	377 (63)	167 (59)
NA[b]	7 (0)	5 (1)	2 (1)
APOE e4 allele			
Yes	304 (28)	167 (28)	76 (27)
NA	64 (6)	34 (6)	12 (4)
Father's OSC			
Professional-managerial (I/II)	260 (24)	153 (26)	57 (20)
Skilled, partly skilled, unskilled (III/IV/V)	700 (64)	403 (68)	208 (74)
NA	131 (12)	37 (6)	16 (6)
Childhood smoker (≤16 y)			
Yes	226 (21)	103 (17)	54 (19)
NA	–	–	–
Childhood number of people per room	1.38 ± 0.79	1.32 ± 0.75	1.41 ± 0.78
NA	4 (0)	3 (1)	–
Adulthood OSC			
Professional-managerial (I, II)	592 (54)	354 (60)	133 (47)*
Skilled, partly skilled, unskilled (III, IV,V)	478 (44)	231 (39)	146 (52)*
NA	22 (2)	8 (1)	2 (1)
Adulthood Smoker (> 16 y)			
Yes	125 (11)	39 (7)	23 (8)
NA	1 (0)	1 (0.2)	–
Alcohol consumption			
Yes	947 (87)	533 (90)	248 (88)
NA	1 (0)	1 (0.2)	–
Adulthood History of Stroke			
Yes	54 (5)	22 (4)	11 (4)
NA	1 (0)	1 (0.2)	–
Adulthood HADS Score	7.68 ± 4.52	7.37 ± 4.41	7.52 ± 4.33
NA	6 (0)	5 (1)	2 (1)
Adulthood BMI	27.78 ± 4.36	27.22 ± 4.15	27.76 ± 4.37
NA	2 (0)	1 (0.2)	–

Chi-square test for independence for categorical data and Welch two sample *t*-test for continuous data with significance presented as follows: *P < 0.05.

[a] Number and percentages for categorical data; mean and standard deviation for continuous variables.

[b] "NA" is missing.

[c] Descriptions of samples as follows: Full sample-participants at age 70; Life grid sample-participants with complete address history at age 78; Analysis sample-Participants had at least one Edinburgh address during the decade of park measurement (childhood: 1949; adulthood: 1969; later adulthood: 2009).

3. Results

We found few discernible differences between the Full sample and the Analysis sample for most of the selected characteristics, as shown by chi-square and two sample t-tests (Table 1). The Analysis sample had significantly higher levels of individuals recorded as Skilled, partly skilled, unskilled OSC during the adulthood period. The frequency of missing data was low at below 6% for all the variables. We found similar rates of missing data in the outcomes, with 6.7% for MHT change from 11 to 70, and 4.6% for change in MHT score from 70 and 76. On average, MHT scores increased from 11 to 70 and decreased from 70 to

76. There were differences in age standardised MHT scores by the selected characteristics (Table 2). Men had lower scores at age 11, but were similar to women at age 70 and 76. Those in the skilled, partly skilled, unskilled OSC and carriers of the *APOE* e4 allele also performed worse at each age. We compared the availability of parks at the three measurement periods using Pearson correlation coefficients and found the highest correlation between adulthood and later adulthood parks (0.63) compared to the lowest between childhood and later adulthood parks (0.19) (See Supplementary material; see Fig. S1). Median percentage of parks surrounding participant residence increased with measurement period: from childhood at 7.0%, to adulthood at 7.7%, and later adulthood at 8.4%. This mirrored the increase in parks in Edinburgh during these periods (See supplementary material; see Fig. S2).

3.1. Associations between availability of parks and cognitive change

There was no significant association between the availability of parks and cognitive change from age 11 to 70, as shown by the comparison between the "no effects" model and the saturated model yielding a p-value of over 0.05 (p = 0.780) (Table 3). However, there was an association between park availability and cognitive change from age 70 to 76, with the same comparison yielding a p-value below 0.05 (p = 0.027) (Table 3). The life course model with the best fit was the "early effect modification" model (i.e. the interaction between childhood and adulthood parks), given that this model recorded the highest p-value (p = 0.071) and the lowest AIC (758.1). The coefficient for the interaction term was positive and statistically significant (β = 0.31; 95% CI 0.02–0.59) (Fig. 2). Fig. 2A shows the marginal effects of childhood park availability on cognitive change from age 70 to 76, conditional on the percentage of parks in adulthood. This shows that childhood park availability had an increasingly positive/advantageous association with cognitive change from 70 to 76 years as the person's adulthood park availability increases. This was found predominantly at the highest levels (i.e. top tertile) of adulthood park availability (Fig. 2B).

3.2. Moderating role of demographic, genetic and socio-economic factors

As the most parsimonious model, we undertook further analysis using the early effect modification model with adjustment for childhood (i.e. father's OSC, childhood smoking status, people per room in childhood home) and adulthood covariates (i.e. adulthood OSC, adulthood smoking status and adulthood alcohol consumption status). In the adjusted models, the coefficient was attenuated, to the extent that in the fully adjusted model (i.e. model 3) the association was no longer significant (β = 0.26; 95% CI -0.06–0.57) (Table 4). In analyses stratified by these variables we found that the "early effect modification model" was moderated by sex, the presence of the *APOE* e4 allele and adulthood OSC. We found the association to be strongest in women (β = 0.64; 95% CI 0.24–1.05), those without an *APOE* e4 allele (β = 0.29; 95% CI -0.05–0.63) and in a Skilled, partly skilled, unskilled OSC during adulthood (β = 0.66; 95% CI 0.15–1.18) (Table 5).

3.3. Sensitivity analyses

We found similar results when we used a stricter definition for the Analysis sample (See Supplementary material; see Table S1). We also tested how sensitive the results were to the buffer zone size. In the sensitivity analysis, we found that the results for the 1000 m buffer zone were similar to those using the 1500 m buffer zone, but no association between parks availability and cognitive change was found using the 500 m buffer zone (see Supplementary material; see Table S2). A case-complete analysis was undertaken to test our assumptions of data being missing at random and we found that the coefficients varied marginally. As we found that the interaction was most significant at the highest

Table 2

Descriptive statistics by Moray House Test Score at ages 11, 70 and 76 for LBC Analysis sample.

Characteristic at age 70[a]	Age standardised MHT Score at age 11	Age standardised MHT Score at age 70	Age standardised MHT Score at age 76
Sex			
Men	99.7 ± 15.0	100.8 ± 14.8	99.2 ± 12.5
Women	102.1 ± 13.7	100.2 ± 13.0	100.0 ± 12.5
APOE E4 allele			
No	101.4 ± 14.7	101.1 ± 13.7	100.7 ± 15.6
Yes	98.9 ± 14.0	98.6 ± 15.0	95.8 ± 13.5
Father's OSC			
Professional-managerial (I, II)	104.2 ± 13.5	103.7 ± 10.4	102.6 ± 12.6
Skilled, partly skilled, unskilled (III, IV,V)	99.6 ± 14.5	99.4 ± 14.9	98.7 ± 14.5
Childhood smoker (≤16 y)			
No	101.6 ± 13.6	101.2 ± 13.2	100.5 ± 13.2
Yes	97.6 ± 17.0	97.3 ± 16.5	95.6 ± 16.9
Childhood number of people per room			
< 2	101.6 ± 14.7	101.5 ± 12.9	100.5 ± 13.5
> 2	98.3 ± 12.5	96.5 ± 16.9	96.1 ± 15.7
Adulthood OSC			
Professional-managerial (I, II)	–	103.7 ± 15.1	102.4 ± 23.7
Skilled, partly skilled, unskilled (III, IV,V)	–	97.0 ± 15.1	96.3 ± 15.1
Adulthood Smoker (≥16 y)			
No	–	100.8 ± 13.8	99.9 ± 14.0
Yes	–	98.1 ± 15.0	96.2 ± 14.2
Adulthood Alcohol consumption			
No	–	101.2 ± 11.9	101.3 ± 13.6
Yes	–	100.5 ± 14.2	99.4 ± 14.1
Adulthood Adiposity			
Normal (BMI < 30 kg/m^2)	–	100.8 ± 14.0	100.1 ± 13.8
Obese (BMI ≥30 kg/m^2)	–	99.5 ± 13.7	97.8 ± 14.7
Parks availability[b]			
Childhood			
Low (0.34–7.01%)	99.2 ± 15.5	98.1 ± 16.3	98.0 ± 15.6
High (7.01–31.3%)	100.3 ± 13.4	100.8 ± 12.0	98.7 ± 13.2
Adulthood			
Low (0.73–7.74%)	–	98.6 ± 14.2	98.1 ± 13.8
High (7.74–30.7%)	–	100.3 ± 14.4	98.6 ± 15.0
Later Adulthood			
Low (0–7.07%)	–	99.1 ± 14.7	97.9 ± 14.7
High (7.07–40.9%)	–	99.8 ± 14.0	98.8 ± 14.2

[a] Mean and standard deviation presented.
[b] Residential parks availability dichotomised by median.

Table 3

Association between park life course model and cognitive change from age 11-70 and 70-76.

Park life course model[a]	Outcome[c]									
	MHT Score change 11-70					MHT Score change 70-76				
	AIC	P[b]	β	95%CI LL	95%CI UL	AIC	P	β	95%CI LL	95%CI UL
a) Accumulation										
- Strict	728.466	0.711	−0.018	−0.100	0.063	761.454	0.016	−0.010	−0.094	0.075
- Relaxed	731.475	0.628				762.036	0.018			
Childhood			0.024	−0.181	0.230			−0.149	−0.340	0.041
Adulthood			0.060	−0.204	0.323			0.006	−0.293	0.305
Later adulthood			−0.096	−0.265	0.072			0.112	−0.121	0.346
b) Critical Time Period										
- Childhood	728.624	0.692	0.020	−0.172	0.212	759.368	0.034	−0.130	−0.305	0.045
- Adulthood	728.666	0.687	0.002	−0.220	0.224	761.488	0.016	0.014	−0.210	0.238
- Later adulthood	727.689	0.799	−0.074	−0.223	0.074	760.605	0.022	0.089	−0.097	0.275
c) Effect modification										
- Early	732.511	0.453	−0.019	−0.313	0.274	758.135	0.071	0.308*	0.024	0.591
- Later	731.291	0.621	−0.007	−0.210	0.195	763.304	0.010	0.114	−0.124	0.352
No effect	726.619	0.780	−0.037	−0.155	0.080	759.458	0.027	0.017	−0.102	0.137

*p < 0.05.
[a] Per 10% of parks within 1500 m residential buffer zone.
[b] *P*-value for partial F test in comparison with the saturated model.
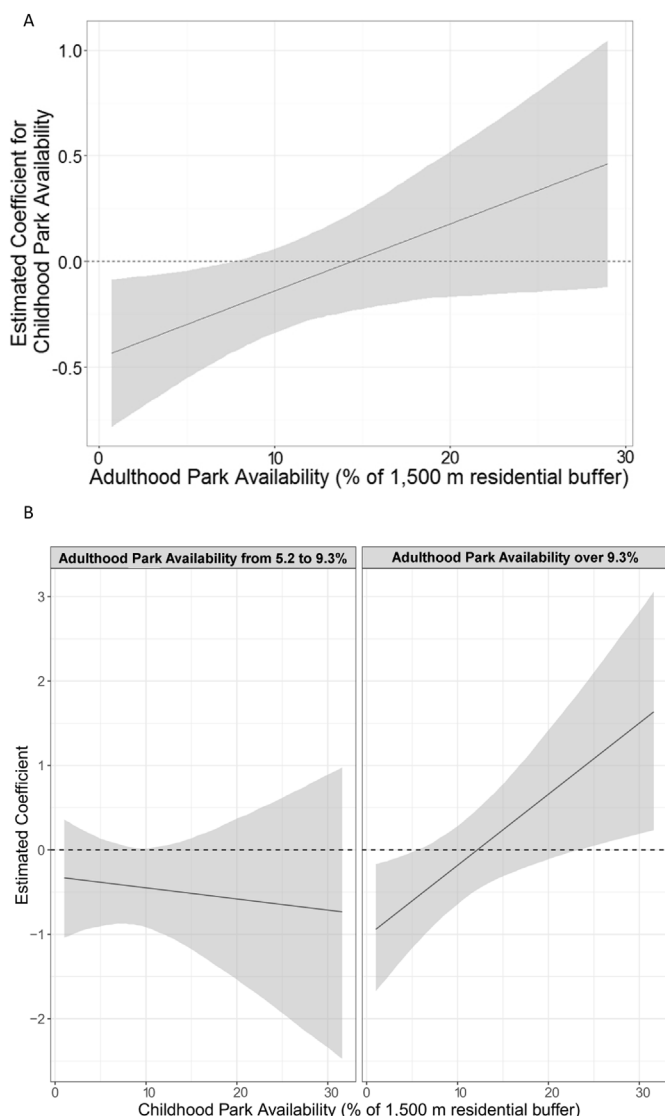[c] MHT score change is residualised on previous MHT score and standardised for age.

Fig. 2. Marginal effects of park availability, conditional on parks availability from adulthood on cognitive change from age 70-76, presented continuously (A) and in tertiles (B).

Table 4
Association between childhood and adulthood park availability, as modelled by an interaction term, and cognitive change from age 70-76.[a]

Covariate model[c]	Model term[b]	
	Childhood*Adulthood	
	β	CI (95%CI)
Model 1	0.31*	0.02–0.59
Model 2	0.26	−0.05–0.58
Model 3	0.26	−0.06–0.57

*p < 0.05.
[a] MHT score change is residualised on previous MHT score and age.
[b] Per 10% of parks within 1500 m residential buffer zone.
[c] Model 1 adjusted for sex; Model 2 additionally adjusted for father's Occupational Social Class (OSC), childhood smoking status and people per room in childhood home; Model 3 additionally adjusted for adulthood OSC, adulthood smoking status and adulthood alcohol consumption status.

levels of adulthood park availability, we present the adjusted and stratified results using tertiles of adulthood park availability (Table S3 and Table S4). Finally, in the current analysis, we acknowledge that the

Table 5
Stratified analysis on the association between childhood and adulthood public park availability, as modelled by an interaction term, and cognitive change from age 70-76.

Effect modifier[a]	Model term[b]	
	Childhood*Adulthood Parks	
	β	CI (95%CI)
Sex		
Male	0.06	−0.42–0.54
Female	0.64**	0.24–1.05
APOE e4 allele		
Yes	−0.02	−0.78–0.74
No	0.29	−0.05–0.63
Adulthood OSC		
Professional-managerial (I, II)	0.02	−0.38–0.44
Skilled, partly skilled, unskilled (III, IV,V)	0.66*	0.15–1.18

*p < 0.05 **p < 0.01.
[a] Additionally adjusted for childhood OSC, people per room in childhood home, childhood smoking status, adulthood smoking status and adulthood alcohol consumption status.
[b] Per 10% of parks within 1500 m residential buffer zone.

meaning and purpose of public parks may differ depending on level of urbanity (see Supplementary material; see Fig. S3). As a proxy for degree of urbanity we have extracted the population density from the Edinburgh Civic survey 1947 (for 1941) and 1951/1961 censuses and appended this information to the participant addresses. In the fully adjusted model (model 3), the early effect modification model coefficient for participants residing in areas with greater population density (27.4–76 people per hectare) was 0.43 (95% CI; 0.00–0.86) compared with −0.03 (95% CI; −0.52-0.47) for those residing in a lower population density area (3.06–27.4 people per hectare).

4. Discussion

This research is the first to consider the role of green space in influencing cognitive ageing, and identifies an important new line of enquiry for understanding the factors promoting successful cognitive ageing. We examined the association between combinations of park availability over an individual's lifetime and cognitive ageing. Our key finding was that greater availability of parks in both childhood and adulthood were associated with successful cognitive ageing in later life. Although the effect size is modest, the result makes a valuable contribution to understanding how aspects of physical environment may be protective against poorer cognitive ageing. These findings are amongst the first to suggest that environmental conditions in childhood might have significant implications for health outcomes much later in life. The work is also novel because it is the first to examine the role of green space over a participant's lifetime in influencing any health outcome; examining a wider set of health outcomes and environmental characteristics are important next steps for researchers in this field.

We observed greater park availability in childhood to have a positive association with the stability of cognitive functioning in older adulthood, conditional on early adulthood environment. Previous work on children pre-post home relocation have shown cognitive function to be highest amongst children who moved to greener neighbourhoods (Wells, 2000). Other studies have found the school environment to be important for childhood cognitive development, with significant positive effects on academic performance with higher surrounding greenness of schools (Dadvand et al., 2015b; C. D. Wu et al., 2014). In addition, objective measures of a child's residential neighbourhood and self-reported greenness of their activity spaces have been associated with fewer symptoms of social, emotional and behavioural difficulties (F. E. Kuo and Taylor, 2004; E. A. Richardson et al., 2017).

Parks may represent a feature of the urban environment that are more stimulating cognitively than other kinds of green spaces,

including those found in rural environments (Cassarino et al., 2016). Whilst it has been shown that a lower percentage of surrounding green space and private gardens is associated with a higher likelihood of cognitive impairment and dementia (Y. T. Wu et al., 2015b), this is not uniformly the case (Clarke et al., 2012). Conflicting results in these previous studies may be due to the age of participants. As the majority of the participants in the Clarke et al. study were under 70 years old, null findings may be because there were smaller variations in cognitive ageing trajectories.

While we hypothesised that adulthood park availability modifies the influence of childhood park exposure due to childhood being a sensitive period for brain development, the reverse may also be true. It is feasible that modification of park availability during adulthood by childhood exposure relates to the theory of the "childhood factor", whereby the frequency of visits and positive experiences with natural spaces in childhood predicts use in adulthood (Thompson et al., 2008). Those who participated in nature-based recreation when they were children may be better able to mitigate any constraints they face to participation in adulthood (Asah et al., 2012). Other researchers stress the importance of unstructured play for infants and structured support from the family, school and social clubs thereafter strengthening the link with nature-based recreation in adulthood (Lovelock et al., 2016; Wang et al., 2013). Both interpretations emphasise the importance of childhood exposure and the associated opportunity for brain development and acculturation, which, if not realised, could result in much lower accumulated benefits from green space throughout life.

We found that associations were strongest in those without the *APOE* e4 allele, women and those with skilled, partly skilled and unskilled occupations; these results may be explained by differences in outcome subtype and interaction with parks. The presence of the *APOE* e4 allele has been shown as the single biggest predictor of older age cognitive change using the LBC1936 (Ritchie et al., 2016). Ritchie et al., found that women in the LBC1936 were more likely to retain cognitive functions, in particular under the specific domain of acquired knowledge, as they aged (Ritchie et al., 2016). Previous studies have found that biomarkers of inflammation consistently associate with cognitive ageing (Marioni et al., 2010; Rafnsson et al., 2007), but in some cases, associations have also only been found in women and those without the APOE e4 allele (Metti et al., 2014). These results could be due to differences in the pathology of cognitive ageing. The presence of APOE e4 alleles is mainly associated with Alzheimer's dementia (Corder et al., 1993) and women experience cardiovascular health problems 7-10 years later than men (Maas and Appelman, 2010). Taken together, our result may suggest that park availability, through the potential mechanism of inflammatory biomarker variability, could have a greater impact on vascular dementia, thus explaining heightened significance in these groups. Our finding of a stronger association for lower socioeconomic individuals is consistent with previous evidence showing that the greenest areas have the lowest inequality in mortality (R. Mitchell and Popham, 2008) and mental wellbeing (R. J. Mitchell et al., 2015). This may be because those in a lower socioeconomic status have less resource to take advantage of spaces outside of their immediate environment, and therefore spend more time closer to home.

A major strength of the study is the availability of childhood measures of cognitive function and repeated measures in older age from the LBC1936 study, thus reducing the issue of reverse causality associated with cognitive testing being undertaken within older age only. We have used change in cognitive function rather than level at one point in time, thus avoiding cohort-specific differences in ageing and measurement error (Liu et al., 2010). Our outcome is complemented by our environmental exposure being the most consistently used measure of historical natural space currently available (Pearce et al., 2016). We have also considered parks throughout life, decreasing differential assessment error which can occur from using an address from a single point in time (e.g. birth or last known address) (Brokamp et al., 2016). However, given the lengthy time frame of exposure we were unable to classify subtypes of green space (e.g. golf courses, allotments) or the quality of green space, which has been shown to be important in contemporary analyses (Wheeler et al., 2015). The life course method we applied has been validated (Mishra et al., 2009). We used continuous variables in the life course models, hence slight modifications to the specifications presented elsewhere. Namely, we did not constrain the effect modification models to have fixed effects to be 0, which would have resulted in a decrease in the model degrees of freedom and therefore errors in the nested model comparison. We conducted a sensitivity analysis dichotomising the variables, based on being within the highest quartile for public park availability with the fixed effects constrained to 0, and the results were congruous to the continuous analysis. Findings from the sensitivity analysis suggest that level of urbanity, defined by residential population density in childhood, has an impact on the effect size and significance of the associations. The non-significant relationship in suburban areas may be in part due to the differences in use of public parks, whereby suburban residents have lower reliance on public parks, as private gardens and other types of green space (e.g. river/canal corridors and forests) may be used more often (Mitchell and Popham, 2007). We did not perform sensitivity analyses with different buffer methods as we would expect the same results regardless of whether a circular or network buffer was used (Bodicoat et al., 2014).

A weakness of this study is the retrospective data collection of residential address history, which can be prone to recall bias. We were also limited by the numbers available for the analysis sample due to the criteria for eligibility being based on continued lifetime residence in a small geographic area. It was necessary to dichotomise OSC as to provide greater statistical power for stratified models (i.e. to keep cell sizes to an appropriate size). This dichotomisation was also appropriate when this variable was used as a covariate, as previous research found that significant differences in health outcomes were only found between "professional or managerial occupations" compared to the rest (Gale et al., 2016). We dichotomised other covariates (e.g. smoking status) as they were not recorded in the same way for childhood and adulthood and therefore dichotomisation was used to aid interpretation of change over time. The analysis sample was broadly similar in terms of selected characteristics compared with the full cohort at age 70, but selection bias may have caused a higher number of participants from lower socioeconomic groups being included. The issue of selection bias was partly addressed by running the sensitivity analysis using a sample with different assumptions. For addresses within the Edinburgh area, the precision of the addresses supplied varied and therefore, for a small number of addresses that did not have a house number, the error between actual participant residence and geocoded address was larger as we took the centre of their street. In addition, by geocoding using contemporary sources, we have assumed that the street layout was the same as it is today for the majority of the addresses, with only minor changes to the street content. However we acknowledge that these small changes could have affected the precision of the park exposure estimate for the earlier time periods. Given that we were geocoding a relatively small number of addresses, we were able to employ a system to detect information lost compared with what was supplied, so that if the results were unsatisfactory they would be geocoded manually. This ensured that addresses that had changed significantly (e.g. demolished) would be geocoded to the same accuracy as those that were able to be geocoded with contemporary sources (< 3m). Given the complexity of the existing analysis, with multiple exposures from different time points, we were unable to include the examination of non-linearity. However, we would encourage this in future analyses, especially using the forthcoming cognitive data waves in the LBC1936.

Availability of parks represents a 'cumulative opportunity' indicator of urban green space, which was shown recently to represent the sum of intentional and incidental interactions to a greater extent than proximity based measures (Ekkel and de Vries, 2017). However, we were still unable to distinguish how the space was being used and therefore the

specific mechanisms by which green spaces were beneficial to health. It has been argued that the sum of a range of mechanisms could have a large effect on health through the pathway of enhanced immune function (M. Kuo, 2015). Even though the effect of individual mechanisms may only contribute slightly to this effect, the ability to define the function of specific green spaces, and use these individual function-based accessibility metrics to examine the association with mechanisms via responses or biomarkers from cohort participants is still warranted to determine their relative importance. The challenge for future research will be to collect accurate information on historical function and use of public parks and green space by individuals over time.

This is the first study to consider the association between area-level green space on long-term cognitive ageing but, unlike recent studies over shorter time frames (Dadvand et al., 2015a), we did not estimate the effect of school, work or commuting green space. Due to the longitudinal nature and complexity of the analysis, we concentrated on one feature of the residential environment (green space) that may affect cognitive ageing; however, in cross-sectional analyses, multiple features have been examined (Clarke et al., 2012). In addition, we have tested multiple temporal combinations of one feature of the urban environment, as advised previously (Mishra et al., 2009), but this may have led to significant results by chance using conventional p-value thresholds of 0.05; therefore, we recommend the replication of these results in further studies. Future studies in other settings can learn from the approach used in this study in collecting and harmonising historical green space data (Pearce et al., 2016). Comparable green space surveys are available in other large urban areas of the UK and could be linked to cohorts with longitudinal health outcomes in later life. Further automation, using techniques such as Optical Character Recognition on paper maps (e.g. those produced periodically in the UK by the Ordnance Survey), offers significant analytical promise for extracting historical environmental information for larger areas up to the national level. Temporal environmental data collected at this spatial scale can then be integrated with nationwide cohorts (e.g. the various British birth cohort studies). This approach is contingent on the availability of participants' residential addresses over time, which are increasingly being made available for studies of health and place over the life course.

5. Conclusions

This study has demonstrated that environmental circumstances in early life, in particular the availability of local parks, may have life-long impacts on cognitive ageing, particularly for women, people without an *APOE* e4 allele, and those in lower socioeconomic groups during adulthood. The findings are not only novel but also have relevance for policymakers. The results emphasise the need to ensure a good level of access to parks throughout the life course, but particularly during childhood. Encouraging parents to help their children's use of parks become regular and frequent may also be warranted, as this can inspire lifelong green space usage as well as providing continued positive effects for the parent (Refshauge et al., 2012). Future research could usefully investigate the geographic nature of availability of parks (e.g. accounting for movement from home to work and school) and which features (e.g. safety, number of amenities) are important for both children and adults to encourage lifelong use for health-promoting behaviours, as well as considering how exposure to a wider set of environmental features across the life course affect health and wellbeing in later life.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2017.10.038.

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