## Title

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# Associations of types of green space across the life-course with blood pressure and body mass index

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## Abstract

Green space has been associated with better health and well-being. However, most studies have been cross-sectional with limited long-term exposure data. Further, research is limited in what type of green space is beneficial for health. We conducted a longitudinal study to assess sensitive periods (birth, childhood or adulthood) of exposure to different types of green space in association with adult blood pressure and body mass index (BMI). Using longitudinal data from the New

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Author's contributions:
MPJ drafted the article, performed the analysis and interpretation of the data. MPJ, GW, PJ, SVS, and EBL made substantial contributions to the concept and design of the study. SB, CE, SEG, and EBL are primary investigators of the New England Family Study. All authors critically revised and commented on the manuscript as it was developed, approve the final version submitted and agree to be accountable for all aspects of the work.

Declaration of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

England Family Study (1960–2000) and multilevel regression analysis, we examined associations between time-varying markers of residential exposure to green space, and adult BMI, systolic (SBP) and diastolic blood pressure (DBP) (N=517). We created three exposure metrics: distance, average area, and green space count in the neighborhood throughout the life-course. In adjusted models, living one mile farther away from a green space at birth was associated with a 5.6 mmHg higher adult SBP (95%CI: 0.7, 10.5), and 3.5 mmHg higher DBP (95%CI: 0.3, 6.8). One more green space in the neighborhood at birth was also associated with lower DBP (−0.2 mmHg, 95%CI: −0.4, −0.02) in adulthood. Finally, average area of green space was not associated with SBP, DBP nor BMI. Analysis by type of green space suggested that parks may be more relevant than playgrounds, cemeteries or golf courses. Our study suggests that the perinatal period may be a critical time-period where living closer to green spaces may lower hypertension risk in adulthood, but not obesity.

## Introduction

Green space has been linked to a wide range of favorable health outcomes including improved mental health,[1] reduced blood pressure,[2] better self-perceived general health,[3] lower risk of adverse pregnancy outcomes,[4] and lower risk of overall and cardiovascular mortality.[5] Exposure to natural environments or green space may benefit human health by reducing harm (mitigating exposures to heat, noise, and air pollution), relieving psychological stress, and/or promoting healthful activities such as exercise.[6] These mechanisms may be particularly relevant in early-life since increasing physical activity levels is a crucial approach to control increases in childhood obesity as well as preventable lifestyle-related diseases, such as hypertension.[7] Moreover, evidence from longitudinal and cross sectional studies suggests that physically active children are more likely to be physically active in adulthood[8] and overweight/obese children are more likely to be overweight/obese adults.[9] However, the cross-sectional nature of most prior studies on green space hampers the ability to identify long-term impacts and sensitive periods in which an exposure may have a larger association than the same exposure during other periods.[10]

In addition, high blood pressure (BP) and obesity are major risk factors for cardiovascular disease (CVD).[11] Adults diagnosed as obese (Body Mass Index - BMI ≥30 kg/m2) or overweight (BMI=25 to 29.9 kg/m2) are at higher risk of CVD, compared with those of a normal weight.[12] In the US, hypertension (defined as systolic blood pressure [SBP] ≥130 mm Hg or diastolic blood pressure [DBP] ≥80 mm Hg) accounts for more CVD deaths than any other modifiable CVD risk factor.[12] Research has shown that atherosclerosis, the leading cause of CVD begins in childhood and that the extent of atherosclerotic change in children and young adults is associated with the presence of atherosclerotic risk in adults.[13] Therefore, it is useful to study the lifelong health impacts of modifiable determinants, such as green space, in early stages of life where public health interventions can be implemented to improve cardiovascular health in adulthood.

We used longitudinal data to evaluate the association between distinct measures of residential exposure to green space at birth, childhood, and adulthood, and two leading CVD risk factors at adulthood, BP and BMI as a marker of obesity. To our knowledge, this is the first longitudinal investigation of critical stages of exposure to green space across the life-course. Our objectives were first to assess which sensitive period (birth, childhood or adulthood) might have larger associations with blood pressure and body mass index, and second to compare three distinct measures of exposure to types of green spaces (closest distance, count or average area of the neighborhood green space).

## METHODS

### Study Population

The New England Family Study (NEFS) is a follow-up study to the National Collaborative Perinatal Project (NCPP). The NCPP was conducted from 1959–1966 in twelve cities throughout the United States. Twelve university-affiliated medical centers participated in this national study, two of which were in New England (Harvard Medical School and Brown University). The Project enrolled approximately 58,000 pregnant women, of which 17,921 were at the Providence, Rhode Island and Boston, Massachusetts sites (United States) between 1959 and 1966. The study evaluated the mothers and their offspring on 12 occasions prenatally through age 8 years. For this analysis, childhood was defined as ages 7–8 years which was the time of the last child assessment.

Between 2005 and 2011 a total of 931 adult offspring (including 113 sibling sets) of NCPP participants living in New England were re-contacted and hypothesized social, behavioral, and biological pathways leading to adult obesity were assessed.[14] Data were merged from two of the sub-samples that comprise NEFS: Longitudinal Effects of Aging Perinatal Project (LEAP) and Pathways Linking Education and Health in Middle Adulthood (EdHealth).[14] Participants' complete addresses were extracted from the interview files, as reported by their parents, from birth to childhood and subsequently later geocoded (assigned latitude and longitude) at each time point. We further restricted the study to participants with a residential address in Massachusetts or Rhode Island throughout the life-course (n=803) and participants with complete geographic information available for all three time-points: birth, childhood and adulthood (n=549). Participants missing additional pertinent covariates including SBP, DBP or BMI (n=22), parental socio-economic status (SES) (n=6), or race(n=2) were also excluded. The final analytic sample included 517 participants (Supplemental Figure 1).

### Exposure

We estimated exposure to green space based on the residential addresses at birth (mean age=1.60 months), childhood (mean age=7.08 years), and adulthood (mean age=44.41 years). Green space was defined as "land that is partly or completely covered with grass, trees, shrubs, or other vegetation",[15] which can include undeveloped spaces, parks, community gardens, and cemeteries,[16] and that is larger than 1 hectare.[17] We created a historical database of green space in 1960 and 1970 by comparing historical topographic maps from the United States Geological Survey[18] to current recreational open space data layers from the Massachusetts Geographic Information Systems (GIS) Department[19] and the Rhode Island Conservation Lands Public Access,[20] and assessing whether existing green areas were formerly present. We further classified green space as follows: (1) Parks (including both undeveloped and developed parks), (2) Playgrounds, (3) Golf-courses, country clubs, and zoos, and (5) Cemeteries. At each time-point and for each type of green space, exposure to green space was evaluated by using three objective measures obtained through GIS methodology: distance (miles) to the closest green space, the average area (hectares) of green space within the neighborhood, and number of green spaces (n) within the neighborhood (or green space count). The distance from the participant's address to the closest green space was calculated using the street network distance based on the current network,[21] which has been shown to be more appropriate in simulating walking behavior than Euclidean distance[22]. Neighborhood was defined as the space circumscribed by a one-mile network buffer built around the geocoded NEFS participants at each time point. Average area and number of green spaces were estimated within the buffer area of each residential address.[16,22] Although no common standard exists for buffer areas, this one-mile buffer was thought to be a reasonable and relevant walking distance used in past studies.[22,23] The average area considered the total area of the green space, and not just the area covered within the buffer.

## Outcomes

The primary outcome variables were (a) systolic blood pressure (SBP), (b) diastolic blood pressure (DBP), and (c) body mass index (BMI) assessed at adulthood. In EdHealth participants, five SBP and DBP measures were obtained over one-minute intervals in participants seated, after 5 minutes rest, in the right arm at heart level, using automated blood pressure monitors (VSMedTech BpTru, Coquitlam, BC, Canada) demonstrated to have good validity and reliability compared with the auscultation method.[24] In LEAP, three BP measures were assessed by certified research nurses using mercury sphygmomanometers in seated participants resting five minutes prior to assessment consistent, with American Heart Association guidelines.[25] SBP and DBP for both samples (LEAP and EdHealth) were computed by taking the mean of the second and third blood pressure readings.[26] Height and weight were directly assessed by trained research technicians, weight was measured using calibrated scales in participants in light clothing without shoes; height was assessed using calibrated stadiometers. BMI was calculated as weight (kg) divided by the square of the height ($m^2$).

## Covariates

Individual-level covariates included age, sex (male, female), and race/ethnicity (White, African-American, other) assessed at birth. In addition, individual SES was assessed as adult attained education (less than high-school, high-school, more than high-school). Parental SES was assessed as mother's education (less than high-school, high-school, more than high-school), and father's education (less than high-school, high-school, more than high-school). All individual-level covariates were assessed at adulthood, except for parental SES which was assessed at birth. Finally, neighborhood level covariates included neighborhood socio-economic status (NSES) measured at the census-tract level at each of the three time points, as a standardized mean score of: % with less than a high school education, % of unemployment, and median household income.[27,28] Census-tract data for NSES were drawn from the National Historical Geographic Information System,[29] and the Bureau of the Census; the final variables were created as previously described.[30]

### Statistical analysis

We used multilevel linear regression models to assess the association between exposure to green space overall as well as by type of green space during the studied age periods (birth, childhood and adulthood), and SBP, DBP, and BMI measured in adulthood. All models accounted for clustering of individuals (level 1) nested within families (level 2) and within neighborhoods (level 3) by including random intercepts for each family and for each census tract. For each model and each age period, we adjusted for age, sex, race/ethnicity, individual SES, and parental SES, as well as neighborhood SES at each time point, and green space and neighborhood SES in all preceding age-periods, but not in subsequent age periods.[31] We further computed Variance Inflation Factors (VIF) to check for multicollinearity.

Multilevel modeling is highly flexible in terms of the inclusion of a variety of complexities including partially missing data and time-varying covariates.[32] However, we further used multiple imputation by chained equations (MICE) to account for missing data of the covariates as a sensitivity analysis. MICE operates under the assumption that data are missing at random (MAR) conditional on the variables used in the imputation procedure. We used imputation by classification and regression trees (mice.impute.cart in R software) with 10 iterations and 10 multiple imputations. Following published guidelines,[33] imputation models included all model variables. Multilevel models were run across 10 imputed datasets (Imputed N=5797), and the pooled estimates were reported. Imputed results were broadly similar to those obtained using observed values; the latter are presented. Statistical significance was assessed at the 0.05 level. Spatial analysis was done using ArcGIS software version 10.4.1., data management was conducted in SAS version 9.4, and statistical analysis was performed in R software version 3.4.0.

## RESULTS

Table 1 summarizes the characteristics of the 517 NEFS participants included in our analyses with complete data through 46 years. The mean age at the time of outcome assessment was 44.2 years. Among included participants, 76.5% were White, 17.7% were African-American, and 2.5% were Hispanic. About 13% of the sample had less than a high-school education, and parental education level was less than high-school for more than half of the sample.

Adult participants had a mean SBP of 117.3 mmHg (SD =16.3), DBP of 76.2 mmHg (SD =10.9), and BMI of 29.9 kg/m$^2$ (SD=7.9). Descriptive characteristics of green space and neighborhood SES measures at the three time points showed that, on average, participants had five to six distinct green spaces in their neighborhoods. The overall average area of green space increased slightly over follow-up, and the standard deviation for childhood and adulthood was large due to state parks included within the neighborhood of some participants in our analysis. Finally, participants lived 0.4–0.5 miles from the nearest green space at all time-points (Table 2). The analysis by type of green space shows that while the average area of parks increased over follow-up, the area for playgrounds seems to have decreased. Participants lived 0.4–0.5 miles from the nearest park at all time-points, but the distance to a golf course was shorter in adulthood than at birth. Moreover, on average, participants did not have golf courses or cemeteries within their neighborhoods at all time-points (Table 2). The correlation between residential distance to closest green space at birth and at childhood was 0.53, decreasing to 0.10 between birth and adulthood, and to 0.08 between childhood and adulthood. The correlation between count of green spaces in the neighborhood at birth and at childhood was 0.72, decreasing to 0.44 at adulthood, and to 0.52 between childhood and adulthood. Lastly, the correlation between average area was close to null for all combination of time-points.

The results of the multilevel models for exposure to green space overall at each studied time-point for SBP, DBP and BMI are presented in Figures 1–2, and the results by type of green space at each time-point are presented in Figures 3–4. Results for SBP suggested that living one mile farther from a green space at birth was associated with an increase of 5.6 mmHg (95%CI: 0.7, 10.5) (Figure 1A). Results for count of green space and average area of green space showed no significant associations with SBP. The analysis by type of green space suggested that living one mile farther from a park at birth was associated with an increase of 1.5 mmHg (95%CI: 0.2, 2.95), and that living one mile farther from a golf course at birth was associated with an increase of 0.4 mmHg (95%CI: 0, 0.7) (Figure 3A). Distance to playgrounds, and cemeteries showed no significant associations with SBP. Similarly, count and average area of parks, playgrounds golf courses and cemeteries at all time-points were not associated to SBP.

Results for DBP suggested that living one mile farther from a green space at birth was associated with an increase of 3.5 mmHg (95%CI: 0.3, 6.8), and that having one more green space at birth was associated with a decrease of −0.2 mmHg (95%CI: −0.4, −0.02) (Figure 1B). Results for the association of DBP and average area were not significant. Analysis by type of green space and DBP suggested that living one mile farther from a park at birth was associated with an increase of 1.5 mmHg (95%CI: 0.5, 2.5), and that having one more park at birth was associated with a decrease of −0.1 mmHg (95%CI: −0.3, 0) (Figure 3B).

Finally, Figures 2 and 4 show that there were no significant associations identified between BMI at adulthood and any of the measures of exposure to green space nor by type of green space throughout the life-course. VIF for all models yielded scores below 3.0 (one of the more conservative recommended thresholds).[34] Model coefficients corresponding to Figures 1–4 are shown in Supplemental Tables 1-2.

The results from MICE for SBP and DBP suggested similar gradient patterns with distance to closest green space (Supplemental Figures 2A and 2B). Lastly, Supplemental Figure 3 shows the BMI results using MICE, where no significant associations were found with any of the measures of exposure to green space throughout the life-course.

## DISCUSSION

This multilevel regression analysis suggested that proximity to green space at birth had a strong association with SBP, while average area and count of green space did not have a significant association with SBP. Moreover, the explicit analysis by type of green space allowed us to identify that this effect was driven by proximity to parks. We observed similar results for DBP, where proximity to green space, and more specifically to parks at birth, was inversely associated to DBP, count of green space also showed an inverse association but to a lesser extent, while average area did not show a significant association with DBP. For BMI, there was no observed association with any of the exposure metrics, which is a common finding in the literature on green space and health.

Our results on BP are similar to a study of adult twins in Belgium which found that among participants living at an address different from their birth address at the time of the measurement, only residential green space exposure in early-life was associated with night systolic blood pressure.[35] Also, a recent study of Australian adults that used a nature dose framework to examine the association between the duration of exposure to nature and health in an urban population, and showed significantly lower odds of high blood pressure when reported green space visits were an average of 30 minutes or more.[1] Another cross-sectional analysis of children from a German birth cohort showed that children living in areas with more green space had lower systolic and diastolic blood pressure, after accounting for temperature, air pollution, noise, and urbanization.[36] The differences found in the association of green space and BP and BMI by life-course stage are unique in the literature. Previous studies have also found mixed associations of green space with different outcomes. For instance, one recent study evaluating associations between the duration of exposure to nature and health outcomes, found that people who made long visits to green spaces had lower rates of depression and high blood pressure, but not greater social cohesion.[1] The absence of association of green space with BMI is consistent with the majority of the literature seeing no association between green space and BMI.[6,37] This might be due to measurement error, cancellation of the total association due to effect modification, or no association of green space with BMI. Previous studies showed that BMI does not differentiate between fat mass and lean muscle mass or their distribution.[38] Lastly, the unique classification of green space and their differential association with BP and BMI are a novel contribution to the field. Information on the composition of green spaces provides a better understanding of exactly what amenities or aspects of nature might influence health.[37]

Our results also reveal new hypotheses that warrant further attention. The relationship between green space and health may be mediated through a number of possible mechanisms including air pollution, noise and heat reduction, physical activity, and social contacts, among others. Some studies suggest that residential green space may be associated with better health during pregnancy. Specifically, higher levels of green space surrounding the maternal residence, have been associated with lower risk of gestational hypertension,[39] a risk factor for higher offspring SBP and DBP in adulthood, compared with offspring of normotensive pregnancies.[40] On the other hand, higher exposure to green space at childhood may set health behaviors such as physical activity that can have long-term consequences for cardiometabolic health. For instance, a recent study of 23,043 Norwegian 8-year-old children found that higher exposure to green space was associated with more leisure-time physical activity.[41] Another study that evaluated green space from birth to age 10 among 900,000+ Danish children, found that living in greener spaces during childhood was associated with lower risk of psychiatric disorders during adulthood.[42] In adulthood, exposure to green spaces may be of importance in managing stress and thus in improving cardiometabolic health. A study of 21,832 Danish adults showed that living farther from a green space was associated to higher levels of stress, and that higher frequency of visits to green spaces was associated to lower levels of stress.[43]

The prospective cohort design and long follow-up period from birth to adulthood (46-years), in addition to the distinctive measures of exposure to green space are strengths of this study. This study is among the first to investigate the impact of green space on BP and BMI. In addition, our examination of the theoretical model of critical periods and the methodology used to evaluate our research question is an improvement on the approaches used in previous studies.[44] These methods allowed us to identify critical life stages during which higher exposure to green space may lower the risk of CVD. Finally, most research on green space has used aggregate measures (e.g. % of green space within 1km radius of residence),[45] which may mask associations with other features, such as type and quality of the green space.[16] Our distinct metrics of exposure to green space and the classification of green spaces are a step further into assessing which aspects are best suited to improve and/or sustain long-term health benefits.[16]

Some limitations in this study also require discussion. First, although we adjusted for individual and neighborhood level characteristics, residual confounding cannot be excluded. Parental history of hypertension, a predictor of blood pressure of the offspring,[46] for example, may also affect exposure to green space as a recent prospective study showed that health problems at baseline (high blood pressure among others) predicted subsequent neighborhood poverty,[47] and thus, lower exposure to green space. Second, exposure misclassification is possible and thus results may be biased. However, any misclassification would likely be non-differential since the measurement errors for the outcome and the exposure would be independent as they come from different data sources. Classification of green space was an performed systematically and our team is working on further analysis to evaluate the differential impact of types of green space on health. Briefly, three research assistants worked together comparing historical topographic maps coupled with open space data layers to categorize green space following standardized procedures established beforehand. After each map was categorized, a final reviewer re-classified the green spaces to compare results. Third, we do not have information of workplace exposure to green space in adulthood (or school exposure in childhood) a possible source of measurement error. Fourth, we lack data on actual use of the greenspace. Fifth, we restricted the analysis to participants who remained in Massachusetts or Rhode Island with complete data which limits the internal generalizability of our results and may potentially induce selection bias. However, we ran sensitivity analysis using MICE (please refer to Supplemental Figures 2-3) and results were similar. Finally, the road network may not reflect change in streets over the decades and thus results may be biased. However, this exposure bias would be non-differential since the errors in the distance measurements would be independent from the outcome.

These results shed light on the potential importance of exposure to green space during early childhood for development of elevated blood pressure in adulthood. Our finding that proximity to green space is associated with BP has potentially important implications for the design of health interventions. These findings, in complement with other related studies, could be taken into consideration in the future planning of green spaces in urban areas. This study included distinct measures of exposure of green space and types of green spaces that suggested that living closer to a park may be more influential in reducing the burden of CVD risk in adulthood than the size or the count of any other green space in a neighborhood. This type of study can support ensuring wise investment in green space provisions, that have important potential to meet current public health challenges. In the US alone, cities invested over $6 billion in 2015 for the provision, management, and enhancement of public green spaces.[1] Although research has suggested that neighborhood interventions to increase exposure to recreation facilities are a cost-effective means to improve health behavior, more information on the necessary features is fundamental, as public parks and shaded areas may become even more important with ongoing climate change, and further urban sprawl.[48]

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## References

1. Shanahan DF, Bush R, Gaston KJ, et al. Health Benefits from Nature Experiences Depend on Dose. Sci Rep. 2016;6:28551. doi:10.1038/srep28551 [PubMed: 27334040]
2. de Blasio B Healthier neighbourhoods through healthier parks. Lancet. 2016;388(10062):2850–2851. doi:10.1016/S0140-6736(16)31579-3 [PubMed: 27671665]
3. Kardan O, Gozdyra P, Misic B, et al. Neighborhood greenspace and health in a large urban center. Sci Rep. 2015;5:11610. doi:10.1038/srep11610 [PubMed: 26158911]
4. Fong KC, Kloog I, Coull BA, et al. Residential greenness and birthweight in the state of Massachusetts, USA. International Journal of Environmental Research and Public Health. 2018;15. doi:10.3390/ijerph15061248
5. Gascon M, Triguero-Mas M, Martinez D, et al. Residential green spaces and mortality: A systematic review. Environ Int. 2016;86:60–67. doi:10.1016/j.envint.2015.10.013 [PubMed: 26540085]
6. James P, Banay RF, Hart JE, Laden F. A Review of the Health Benefits of Greenness. Curr Epidemiol Rep. 2015;2(2):131–142. doi:10.1007/s40471-015-0043-7 [PubMed: 26185745]
7. WHO. Young People: Need to Move for Health and Well-being. 2004.
8. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. Am J Prev Med. 2005;28(3):267–273. doi:10.1016/j.amepre.2004.12.003 [PubMed: 15766614]
9. Starc G, Strel J. Tracking excess weight and obesity from childhood to young adulthood: a 12-year prospective cohort study in Slovenia. Public Health Nutr. 2011;14(1):49–55. doi:10.1017/S1368980010000741 [PubMed: 20392312]
10. Kuh D DSG. The Life Course and Adult Chronic Disease: An Historical Perspective with Particular Reference to Coronary Heart Disease. 2nd edn. New York: Oxford University Press Inc.; 2004.
11. Mokdad AH, Ford ES, Bowman BA, et al. Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001. JAMA. 2003;289(1):76–79. [PubMed: 12503980]

12. Arnett DK, Blumenthal RS, Albert MA, et al. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation. 2019;140(11):e596–e646. doi:10.1161/CIR.0000000000000678 [PubMed: 30879355]
13. Berenson GS, Srinivasan SR, Bao W, Newman WP, Tracy RE, Wattigney WA. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults. The Bogalusa Heart Study. N Engl J Med. 1998;338(23):1650–1656. doi:10.1056/NEJM199806043382302 [PubMed: 9614255]
14. Gilman SE, Huang YT, Jimenez MP, et al. Early life disadvantage and adult adiposity: tests of sensitive periods during childhood and behavioural mediation in adulthood. Int J Epidemiol. October 2018. doi:10.1093/ije/dyy199
15. What is Open Space/Green Space? http://www3.epa.gov/region1/eco/uep/openspace.html. Published 2017. Accessed March 7, 2018.
16. Nieuwenhuijsen MJ, Khreis H, Triguero-Mas M, Gascon M, Dadvand P. Fifty Shades of Green: Pathway to Healthy Urban Living. Epidemiology. 2017;28(1):63–71. doi:10.1097/EDE.0000000000000549 [PubMed: 27525811]
17. Tamosiunas A, Grazuleviciene R, Luksiene D, et al. Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environ Health. 2014;13(1):20. doi:10.1186/1476-069X-13-20 [PubMed: 24645935]
18. Historical Topographic Map Collection. https://ngmdb.usgs.gov/topoview/.
19. MassGIS Data: Protected and Recreational OpenSpace. https://docs.digital.mass.gov/dataset/massgis-data-protected-and-recreational-openspace.
20. Rhode Island Conservation Lands Public Access. https://www.arcgis.com/home/item.html?id=e31d50b387e04b3a9c025856c015923c.
21. HERE Map Data. Harnessing the power of location data. https://www.here.com/en/products-services/map-content/here-map-data.
22. Kaczynski AT, Besenyi GM, Stanis SA, et al. Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. The international journal of behavioral nutrition and physical activity. 2014;11(1):146. doi:10.1186/s12966-014-0146-4 [PubMed: 25480157]
23. Leslie E, Coffee N, Frank L, Owen N, Bauman A, Hugo G. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. Health & place. 2007;13(1):111–122. doi:10.1016/j.healthplace.2005.11.001 [PubMed: 16387522]
24. Mattu GS, Heran BS, Wright JM. Overall accuracy of the BpTRU--an automated electronic blood pressure device. Blood Press Monit. 2004;9(1):47–52. [PubMed: 15021078]
25. Association AH. Monitoring Your Blood Pressure at Home. https://www.heart.org/en/health-topics/high-blood-pressure/understanding-blood-pressure-readings/monitoring-your-blood-pressure-at-home. Published 2017.
26. Pickering TG, Hall JE, Appel LJ, et al. Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Circulation. 2005;111(5):697–716. doi:10.1161/01.CIR.0000154900.76284.F6 [PubMed: 15699287]
27. Halonen JI, Kivimaki M, Pentti J, et al. Quantifying neighbourhood socioeconomic effects in clustering of behaviour-related risk factors: a multilevel analysis. PLoS One. 2012;7(3):e32937. doi:10.1371/journal.pone.0032937 [PubMed: 22427912]
28. Halonen JI, Stenholm S, Pentti J, et al. Childhood Psychosocial Adversity and Adult Neighborhood Disadvantage as Predictors of Cardiovascular Disease: A Cohort Study. Circulation. June 2015. doi:10.1161/CIRCULATIONAHA.115.015392
29. National Historical Geographic Information System (NGHIS): Version 11.0 [Database]. 2016. doi:10.18128/D050.V11.0
30. Logan J MapUSA: A Human-Mapping Project (1940–2000). July 2016.
31. Zhang X, Tilling K, Martin RM, et al. Analysis of “sensitive” periods of fetal and child growth. Int J Epidemiol. April 2018. doi:10.1093/ije/dyy045

32. Curran PJ, Obeidat K, Losardo D. Twelve Frequently Asked Questions About Growth Curve Modeling. J Cogn Dev. 2010;11(2):121–136. doi:10.1080/15248371003699969 [PubMed: 21743795]
33. Sterne JA, White IR, Carlin JB, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ. 2009;338:b2393. doi:10.1136/bmj.b2393 [PubMed: 19564179]
34. Field A Discovering Statistics Using SPSS. 4th ed. Thousand Oaks, CA: Sage
35. Bijnens EM, Nawrot TS, Loos RJ, et al. Blood pressure in young adulthood and residential greenness in the early-life environment of twins. Environmental Health: A Global Access Science Source. 2017. doi:10.1186/s12940-017-0266-9
36. Markevych I, Thiering E, Fuertes E, et al. A cross-sectional analysis of the effects of residential greenness on blood pressure in 10-year old children: Results from the GINIplus and LISAplus studies. BMC Public Health. 2014. doi:10.1186/1471-2458-14-477
37. Fong K, Hart JE, James P. A Review of Epidemiologic Studies on Greenness and Health: Updated Literature Through 2017. Curr Environ Health Rep. 2018;5:77–87. doi:10.1007/s40572-018-0179-y.A [PubMed: 29392643]
38. Gomez-Ambrosi J, Silva C, Galofre JC, et al. Body mass index classification misses subjects with increased cardiometabolic risk factors related to elevated adiposity. Int J Obes (Lond). 2012;36(2):286–294. doi:10.1038/ijo.2011.100 [PubMed: 21587201]
39. Choe SA, Kauderer S, Eliot MN, et al. Air pollution, land use, and complications of pregnancy. Sci Total Environ. 2018;645:1057–1064. doi:10.1016/j.scitotenv.2018.07.237 [PubMed: 30248831]
40. Alsnes IV, Vatten LJ, Fraser A, et al. Hypertension in Pregnancy and Offspring Cardiovascular Risk in Young Adulthood: Prospective and Sibling Studies in the HUNT Study (Nord-Trondelag Health Study) in Norway. Hypertension. 2017;69(4):591–598. doi:10.1161/HYPERTENSIONAHA.116.08414 [PubMed: 28223467]
41. Nordbø ECA, Raanaas RK, Nordh H, Aamodt G. Neighborhood green spaces, facilities and population density as predictors of activity participation among 8-year-olds: a cross-sectional GIS study based on the Norwegian mother and child cohort study. BMC Public Health. 2019;19(1):1426. doi:10.1186/s12889-019-7795-9 [PubMed: 31666049]
42. Engemann K, Pedersen CB, Arge L, Tsirogiannis C, Mortensen PB, Svenning J-C. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. PNAS. 2019;116(11):5188–5193. doi:10.1073/pnas.1807504116 [PubMed: 30804178]
43. Stigsdotter UK, Ekholm O, Schipperijn J, Toftager M, Kamper-Jørgensen F, Randrup TB. Health promoting outdoor environments--associations between green space, and health, health-related quality of life and stress based on a Danish national representative survey. Scand J Public Health. 2010;38(4):411–417. doi:10.1177/1403494810367468 [PubMed: 20413584]
44. Diez Roux AV, Mair C. Neighborhoods and health. Annals of the New York Academy of Sciences. 2010;1186:125–145. doi:10.1111/j.1749-6632.2009.05333.x [PubMed: 20201871]
45. Astell-Burt T, Feng X, Kolt GS. Greener neighborhoods, slimmer people? Evidence from 246,920 Australians. International journal of obesity. 2014;38(1):156–159. doi:10.1038/ijo.2013.64 [PubMed: 23732654]
46. Lascaux-Lefebvre V, Ruidavets J, Arveiler D, et al. Influence of parental history of hypertension on blood pressure. J Hum Hypertens. 1999;13(9):631–636. [PubMed: 10482973]
47. Arcaya MC, Subramanian SV, Rhodes JE, Waters MC. Role of health in predicting moves to poor neighborhoods among Hurricane Katrina survivors. Proc Natl Acad Sci U S A. 2014;111(46):16246–16253. doi:10.1073/pnas.1416950111 [PubMed: 25331883]
48. Heckman CJ. Public Parks and Shady Areas in Times of Climate Change, Urban Sprawl, and Obesity. Am J Public Health. 2017;107(12):1856–1858. doi:10.2105/AJPH.2017.304140 [PubMed: 29116832]

## Research highlights

- We assessed sensitive periods of green space exposure and cardiometabolic health.
- Influence of types of green space on blood pressure and obesity is also examined.
- Proximity to parks at birth was associated with lower adult blood pressure.
- Birth may be a susceptible period for green space exposure and hypertension risk.
- Green space exposure across the life-course was not associated with BMI.

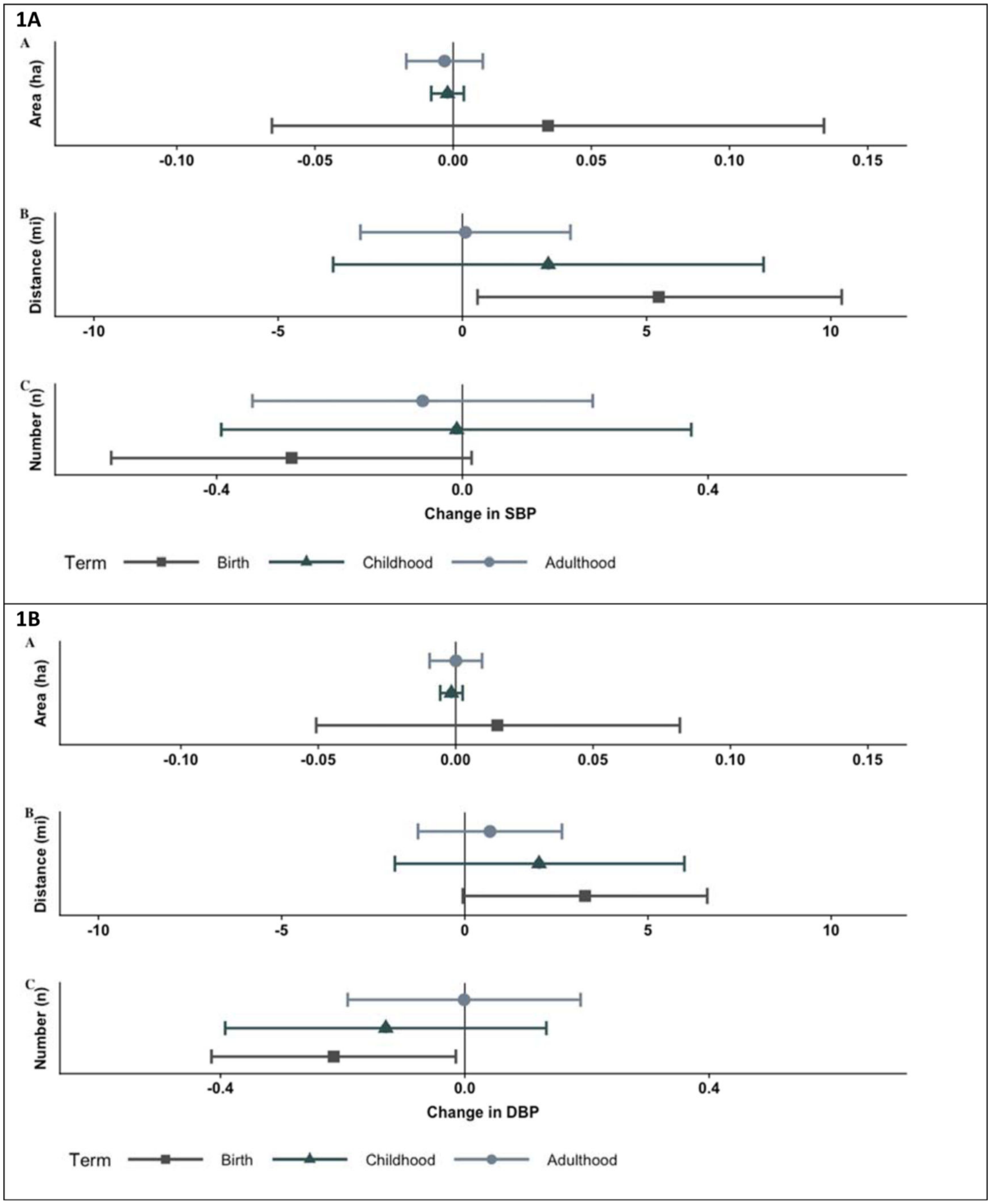


**Figure 1.**

Adjusted Associations between average area of green space, distance to green space and number of green spaces throughout the life-course with **SBP (1A) and DBP (1B)**[b]

[b] Each line with an estimate and confidence interval per term, represents a model fitted adjusted for all covariates (age, sex, race/ethnicity, individual SES, parental SES, and neighborhood SES at each time point), and green space and neighborhood SES in all preceding age-periods, but not in subsequent age periods. The X axis represents the change in SBP (Figure 1A) per one hectare increase (Figure 1A.A), one mile increase (Figure

1A.B), and one more green space in the neighborhood (Figure 1A.C) at birth, childhood, and adulthood, respectively with the corresponding 95% confidence intervals. Similarly, for DBP (Figure 1B).

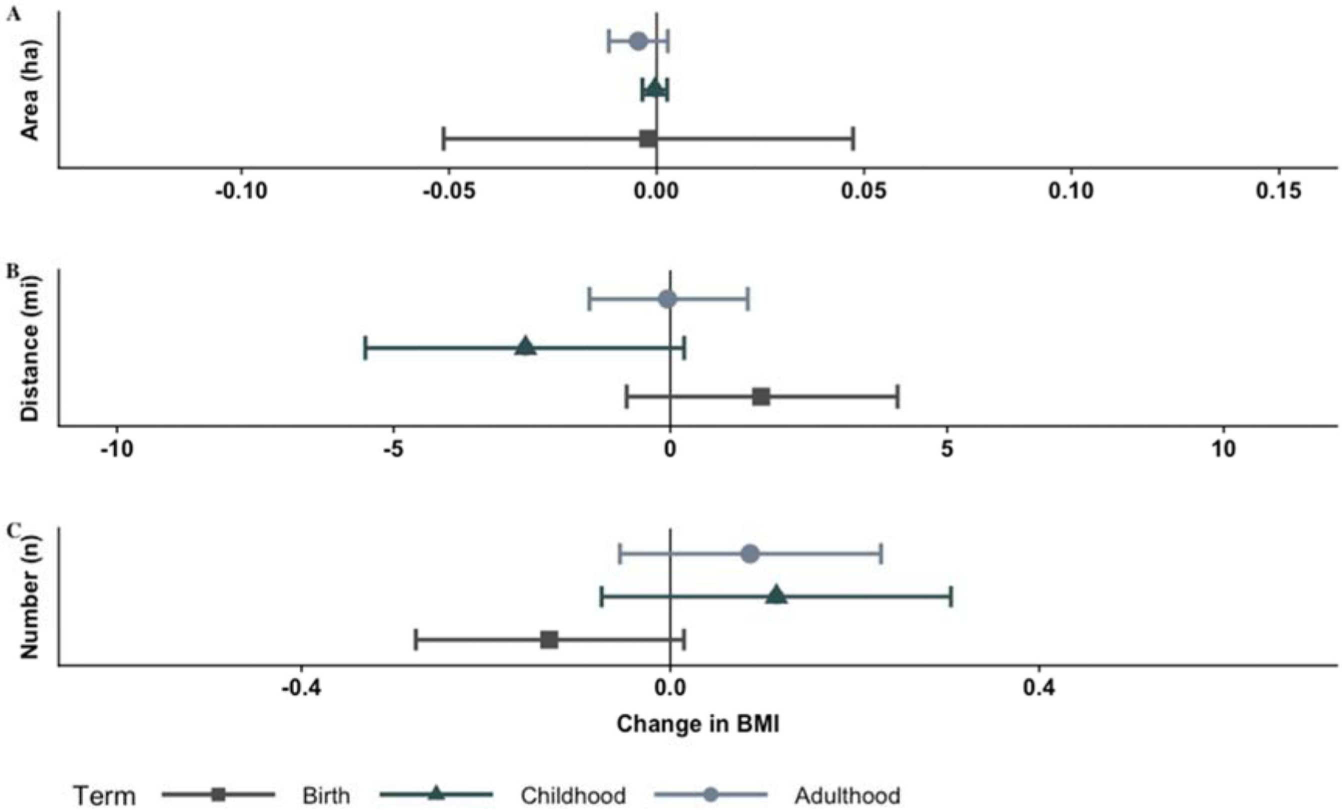


**Figure 2.**

Adjusted Associations between average area of green space, distance to green space and number of green spaces throughout the life-course with **BMI**[c]

[C] Each line with an estimate and confidence interval per term, represents a model fitted adjusted for all covariates (age, sex, race/ethnicity, individual SES, parental SES, and neighborhood SES at each time point), and green space and neighborhood SES in all preceding age-periods, but not in subsequent age periods. The X axis represents the change in BMI per one hectare increase (Figure 2.A), one mile increase (Figure 2.B), and one more green space in the neighborhood (Figure 2.C) at birth, childhood, and adulthood, respectively with the corresponding 95% confidence intervals.

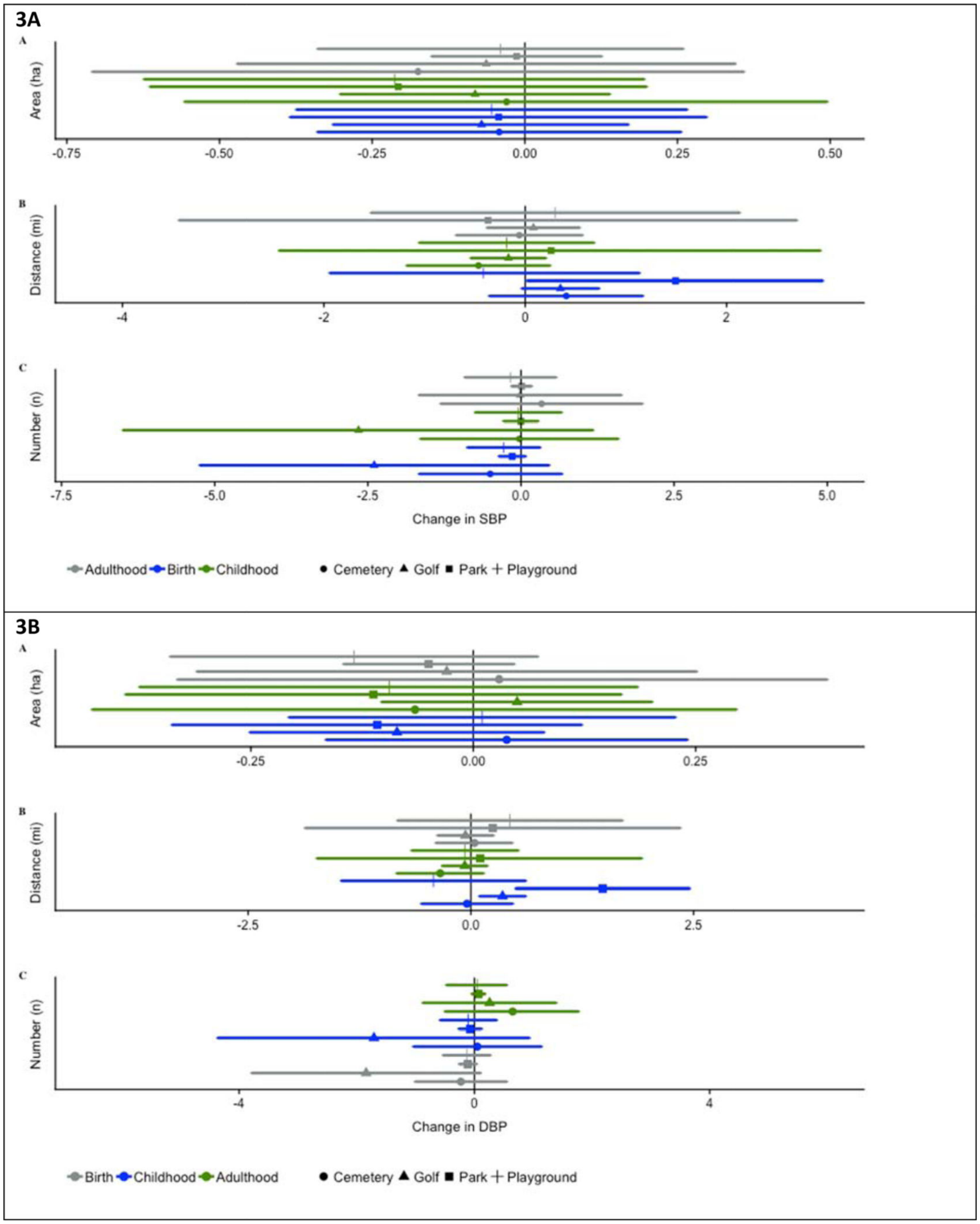


**Figure 3.**

Adjusted Associations between average area of green space, distance to green space and number of green spaces **according to type of green space** throughout the life-course with **SBP (1A) and DBP (1B)**[d]

[d] Each line with an estimate and confidence interval per type of green space and per term, represents a model fitted adjusted for all covariates (age, sex, race/ethnicity, individual SES, parental SES, and neighborhood SES at each time point), and the corresponding type of green space and neighborhood SES in all preceding age-periods, but not in subsequent age

periods. The X axis represents the change in SBP (Figure 3A) per one hectare increase (Figure 3A.A), one mile increase (Figure 3A.B), and one more green space of each type in the neighborhood (Figure 3A.C) at birth, childhood, and adulthood, respectively with the corresponding 95% confidence intervals. Similarly, for DBP (Figure 3B).

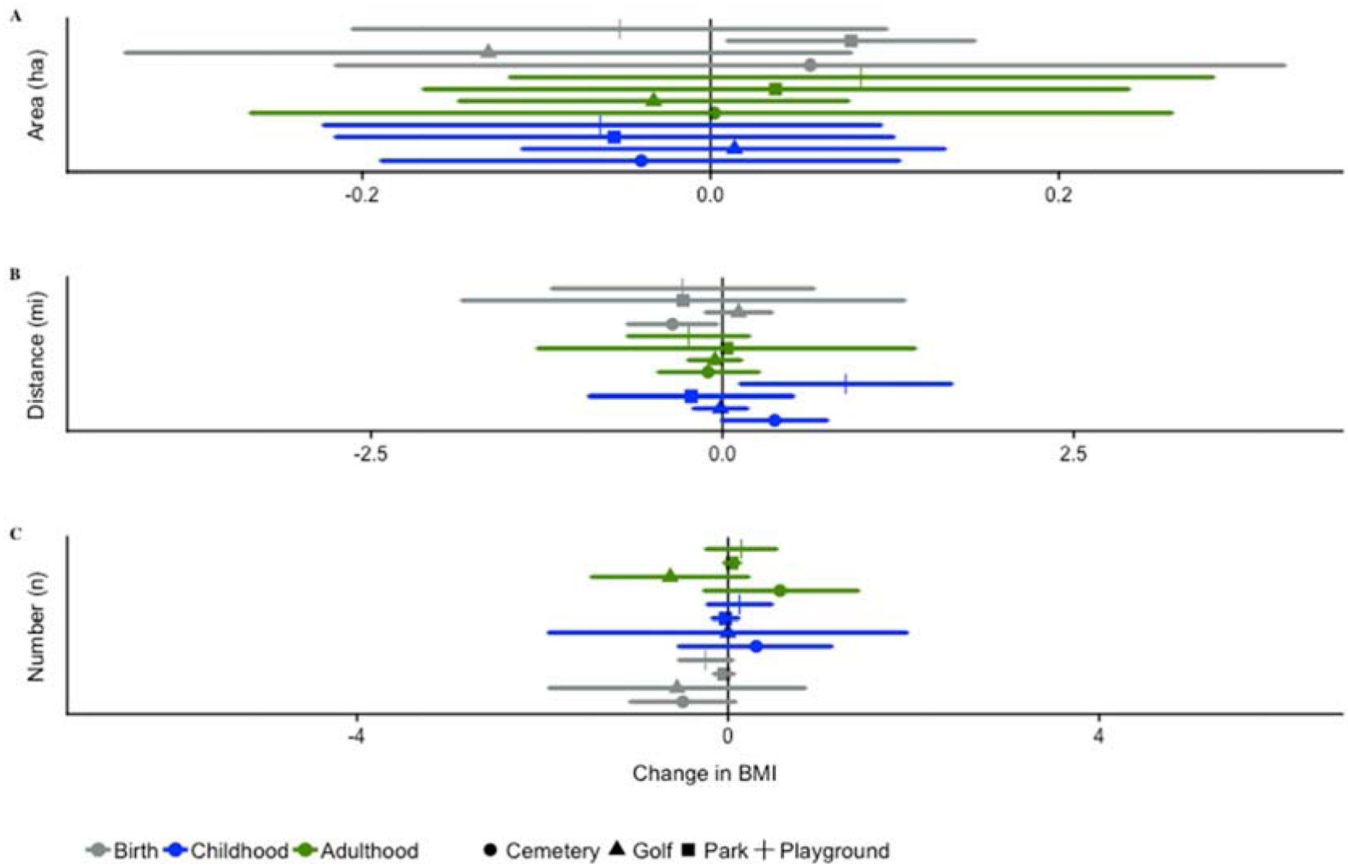


**Figure 4.**

Adjusted Associations between average area of green space, distance to green space and number of green spaces **according to type of green space** throughout the life-course with **BMI**[e]

[e] Each line with an estimate and confidence interval per type of green space and per term, represents a model fitted adjusted for all covariates (age, sex, race/ethnicity, individual SES, parental SES, and neighborhood SES at each time point), and the corresponding type of green space and neighborhood SES in all preceding age-periods, but not in subsequent age periods. The X axis represents the change in BMI per one hectare increase (Figure 4.A), one mile increase (Figure 4.B), and one more green space of each type in the neighborhood (Figure 4.C) at birth, childhood, and adulthood, respectively with the corresponding 95% confidence intervals.

**Table 1.**

Characteristics of the analytic sample, New England Family Study (N=517).

| | N | % |
|---|---|---|
| **Female (%)** | 310 | 59.7 |
| **Race (%)** | | |
| **White** | 397 | 76.5 |
| **African-American** | 92 | 17.7 |
| **Hispanic** | 13 | 2.5 |
| **Other** | 17 | 3.3 |
| **Education level (%)** | | |
| **Less than High School** | 68 | 13.1 |
| **High-school** | 231 | 44.5 |
| **More than High School** | 220 | 42.4 |
| **Mother's Race** | | |
| **White** | 403 | 42.4 |
| **Mother's Education level** | | |
| **Less than High School** | 263 | 50.7 |
| **High School** | 183 | 35.3 |
| **More than High School** | 73 | 14.1 |
| **Father's Education level** | | |
| **Less than High School** | 290 | 55.9 |
| **High School** | 153 | 29.5 |
| **More than High School** | 76 | 14.6 |
| | **Mean** | **SD** |
| **Age at adulthood** | 44.2 | 3.0 |
| **Body Mass Index at adulthood** | 29.9 | 7.9 |
| **Systolic Blood Pressure at adulthood** | 117.3 | 16.3 |
| **Diastolic Blood Pressure at adulthood** | 76.2 | 10.9 |

## Table 2.

Green space characteristics across the life-course

| | Birth | Childhood | Adulthood |
|---|---|---|---|
| | Median (IQR) | Median (IQR) | Median (IQR) |
| All Green Space | | | |
| Closest Distance (mi) | 0.5 (0.4) | 0.5 (0.4) | 0.4 (0.4) |
| Area (Ha) | 4.5 (7.8) | 5.0 (8.3) | 6.0 (9.9) |
| Count (n) | 5.0 (5.0) | 5.0 (5.0) | 6.0 (6.0) |
| Parks | | | |
| Closest Distance (mi) | 0.4 (0.4) | 0.5 (0.4) | 0.4 (0.4) |
| Area (Ha) | 0.5 (1.3) | 0.7 (1.7) | 2.5 (4.5) |
| Count (n) | 3 (7) | 3 (7) | 4 (7) |
| Playgrounds | | | |
| Closest Distance (mi) | 0.8 (0.6) | 0.8 (0.6) | 0.8 (0.7) |
| Area (Ha) | 1 (2.5) | 1 (3) | 0.2 (2) |
| Count (n) | 1 (3) | 2 (3) | 1 (2) |
| Golf courses | | | |
| Closest Distance (mi) | 6.4 (5.4) | 4.3 (3.4) | 2.9 (3.6) |
| Area (Ha) | 0 (0) | 0 (0) | 0 (0) |
| Count (n) | 0 (0) | 0 (0) | 0 (0) |
| Cemeteries | | | |
| Closest Distance (mi) | 1.5 (1.4) | 1.6 (1.6) | 1.9 (2.3) |
| Area (Ha) | 0 (0.7) | 0 (0.7) | 0 (0) |
| Count (n) | 0 (1) | 0 (1) | 0 (1) |
| Neighborhood Socio-Economic Status | | | |
| Income[a] | $27,918 (8,177) | $36,305 (10,433) | $47,309 (20,224) |
| % Unemployed | 6.1 (2.7) | 4.1 (2.1) | 4.3 (3.6) |
| % with High School Degree or less | 91.5 (13.8) | 88.5 (11.2) | 50.3 (15.7) |

[a]Please note that income from 1960s and 1970s were adjusted for inflation rates to the year 2000, and thus are reflective of dollar amount in the year 2000.