Short communication

The association between adverse childhood experiences, neighborhood greenspace, and body mass index: A cross-sectional study

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A R T I C L E  I N F O

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A B S T R A C T

An association between adverse childhood experiences (ACEs) and elevated body mass index (BMI) has been found in previous investigations. ACEs’ effects on BMI have been primarily considered via individual-level physiological and behavioral frameworks. Neighborhood factors, such as greenspace, are also associated with BMI and may merit consideration in studies examining ACEs-BMI associations. This exploratory study examined associations of BMI with ACEs and neighborhood greenspace and tested whether greenspace moderated ACEs-BMI associations. Methods entailed secondary analysis of cross-sectional data. ACEs and BMI were captured from 2012/2013 Philadelphia ACE Survey and 2012 Southeastern Household Heath Survey data; greenspace percentage in participants’ (n = 1,679 adults) home neighborhoods was calculated using National Land Cover Database data. Multi-level, multivariable linear regression 1) examined associations between BMI, ACEs, (0 ACEs [reference], 1–3 ACEs, 4 + ACEs), and neighborhood greenspace levels (high [reference], medium, low) and 2) tested whether greenspace moderated the ACEs-BMI association (assessed via additive interaction) before and after controlling for sociodemographic and health-related covariates. Experiencing 4 + ACEs (β = 1.21; 95 %CI: 0.26, 2.15; p = 0.01), low neighborhood greenspace (β = 1.51; 95 %CI: 0.67, 2.35; p < 0.01), and medium neighborhood greenspace (β = 1.37; 95 %CI: 0.52, 2.21; p < 0.01) were associated with BMI in unadjusted models. Only low neighborhood greenspace was associated with BMI (β = -0.95; 95 %CI: -1.75, 0.89; p < 0.02) in covariate-adjusted models. The ACEs-greenspace interaction was not significant in unadjusted (p = 0.89-0.99) or covariate-adjusted (p = 0.46-0.79) models. In conclusion, when considered simultaneously, low neighborhood greenspace, but not ACEs, was associated with BMI among urban-dwelling adults in covariate-adjusted models.

1. Introduction

Adverse childhood experiences (ACEs) are traumatic events that occur prior to age 18, such as experiencing physical or sexual abuse, witnessing violent crime, domestic violence against a female caregiver, or incarceration of a parent (Cronholm et al., 2015; Felitti et al., 1998). Prior research has demonstrated an association between ACEs and obesity (defined as body mass index [BMI] of ≥30 kg/m²) during adulthood, likely due to immunometabolic, neuroendocrine, psychosocial, and behavioral stress responses that promote higher BMI (Felitti et al., 1998; Wiss and Brewerton, 2020; Hantsoo and Zemel, 2021). Factors at higher levels of ecology, such as aspects of neighborhood environment, are infrequently studied in ACEs research, although exposure to community-level ACEs have been shown to impact health behaviors and outcomes (Wade et al., 2016).

Neighborhood greenspace, defined as space including natural vegetation and used for aesthetics or recreation, is associated with reduced risk of obesity (De la Fuente et al., 2021). Greenspace’s inverse...
Association with BMI is hypothesized to occur through several possible pathways, including increased physical activity, decreased stress, improved mental health, greater social interaction, and beneficial immunometabolic effects of biodiverse microbial input from natural environments (Wendelboe-Nelson et al., 2019; Rook, 2013; Twohig-Bennett and Jones, 2018).

Considered collectively, prior evidence documents that both ACEs and greenspace are associated with BMI. It is plausible that greenspace’s beneficial effects on psychosocial well-being, physical activity, and immunometabolic health could potentially modulate the negative effects of ACEs; thus, previously reported associations between ACEs and obesity may differ based on greenspace exposure. Additionally, ACEs, greenspace, and obesity have all been linked to social determinants of health (SDH), with marginalized communities having higher rates of obesity (Wang et al., 2020) and ACEs burden (Cronholm et al., 2015) and lower amounts of greenspace (Nesbitt et al., 2019; Rigolon et al., 2021). However, prior research is limited in that studies have examined ACEs and greenspace separately, not simultaneously, leaving unanswered questions about concurrent associations with BMI. Thus, this exploratory study reported examined associations of BMI with ACEs and greenspace and tested whether greenspace moderated ACEs-BMI associations, before and after controlling for potential confounders that include common SDH.

2. Methods

Secondary analysis of cross-sectional survey data and publicly available spatial data was conducted. Institutional Review Board approval was received, including waiver of consent. The sample included participants in the 2012 Southeastern Pennsylvania Household Heath Survey (HHS) (Public Health Management Corporation, 2021) and add-on Philadelphia ACE Survey, telephone surveys collected from 11/2012 to 1/2013 with 1,784 randomly selected adults (≥18 years) living in Philadelphia, Pennsylvania in the United States of America. Details are reported elsewhere (Cronholm et al., 2015; Wade et al., 2016). This analysis sample was limited to participants for whom residence census tract (the smallest level of geographic information in the data) was available (n = 1,679).

2.1. Measures

Measures included ACEs, BMI, greenspace, and potential confounders; all are detailed in this section. The Philadelphia ACE survey (Cronholm et al., 2015; Wade et al., 2016) was developed by an expert task force, grounded in prior literature, informed by qualitative research with Philadelphia youth, and adapted from existing tools for assessing ACEs-related health risks (Wade et al., 2016; Hughes et al., 2017). Nine household-level and five community-level ACEs were assessed. The nine household-level ACEs were: physical, emotional, and sexual abuse; physical and emotional neglect; witnessing domestic violence; substance use, incarceration, or mental illness of a household member; the five community-level ACEs were: witnessing community violence; racial/ethnic discrimination; low income; high school dropout rate; and community violence (Cronholm et al., 2015; Wade et al., 2016). This analysis was limited to participants for whom residence census tract (the smallest level of geographic information in the data) was available (n = 1,679).

2.2. Statistical analysis

Analyses include descriptive statistics to examine sample characteristics, chi-square test to examine differences in greenspace by ACE exposure, and multi-level, multivariable linear regression accounting for census tract-level clustering to examine associations among ACEs, BMI, and potential confounders. Unadjusted and adjusted models estimating BMI included the following independent variables: Model 1) ACEs and greenspace; Model 2) ACEs, greenspace, and an ACEs-greenspace additive interaction term with the lowest joint risk group (0 ACEs and high greenspace) as reference. Estimated BMI values were assessed for each level of ACE-greenspace exposure. Standard model diagnostics were assessed for all models, including variance inflation factor to ensure lack of collinearity. Analyses were conducted using RStudio 4.1.0. Survey weights created for the original Philadelphia ACE Survey were not used in this secondary multi-level analysis; instead, variables comprising survey weights (age, sex, race, poverty) were included along with additional potential confounders mentioned above. Therefore, findings should be considered representative of the study sample, not the broader Philadelphia population.

During the peer-review process, two post-hoc exploratory analyses were executed to assess robustness of study findings. The first repeated Model 1, but operationalized ACEs as two separate variables: household-level continuous ACE score (range: 0–9) and community-level continuous ACE score (range: 0–5). The second repeated Model 1, but included fewer confounders (only age, sex, race, and education level).

3. Results

The sample included 1,679 participants. Collectively, 327 (19.5 %) participants experienced 0 ACEs, 803 (37.8 %) experienced 1–3 ACEs, and 549 (32.7 %) experienced 4 + ACEs. Most identified as female (n = 1,218 [72.5 %]), Black (n = 747 [44.5 %]) or White (n = 787 [46.9 %]), and were 36–65 years old (n = 1,017 [60.5 %]). Participants’ mean BMI
was 29.3 ± 6.8 kg/m². Participants’ census tracts included 25.3 ± 25.1 % greenspace. Individuals with higher ACE exposure lived in neighborhoods with lower greenspace (mean neighborhood greenspace 29.1 % for participants 0 ACEs, 25.9 % for 1–3 ACEs, and 22.3 % for 4 + ACEs (p < 0.01)). Full sample characteristics, for the total sample and by ACE exposure category, are presented in Appendix Table A.2.

Unadjusted and adjusted multi-level, multivariable linear regression results are presented in Table 1. In unadjusted models, greater ACE exposure and less greenspace were associated with higher BMI. More specifically, experiencing 4 + ACEs (β = 1.21; 95 %CI: 0.26, 2.15; p = 0.01) versus 0 ACEs and residing in a neighborhood with low greenspace (β = 1.51; 95 %CI: 0.67, 2.35; p < 0.01) or medium greenspace (β = 1.37; 95 %CI: 0.52, 2.21; p < 0.01) versus high greenspace were independently associated with BMI. After adjusting for potential confounders noted above, ACE exposure was no longer associated with higher BMI, but the association between low greenspace and higher BMI remained (β = 0.95; 95 %CI: 0.14, 1.75; p = 0.02). Findings of post-hoc exploratory analyses were consistent with that of primary a priori analyses (Appendix Table A.3-A.4).

Analyses did not demonstrate an additive interaction between ACEs and greenspace (Table 1, Model 2a-2b). Table 2 includes BMI estimates for each ACE-greenspace exposure level after controlling for potential confounders.

### Table 1
Unadjusted and adjusted multi-level, multivariable linear regression models predicting BMI

| Model | Estimate (95 % confidence interval) | p-value |
|-------|------------------------------------|---------|
| Model 1a: BMI = ACE score + greenspace | 0.60 (0.08, 1.13) | 0.19 |
| 4 + ACEs | 1.21 (0.26, 2.15) | 0.01 |
| Greenspace (Reference: High greenspace) | 1.51 (0.67, 2.35) | <0.01 |
| Medium | 1.37 (0.52, 2.21) | <0.01 |
| Model 1b: BMI = ACE score + greenspace + confounders | 0.05 (-0.84, 0.95) | 0.93 |
| 4 + ACEs | -0.12 (-1.10, 0.86) | 0.80 |
| Greenspace (Reference: High greenspace) | 0.95 (0.14, 1.75) | 0.02 |
| Medium | 0.64 (0.15, 1.14) | 0.10 |
| Model 2a: BMI = ACE score + greenspace + ACE score*greenspace | 0.64 (-0.79, 2.07) | 0.38 |
| 4 + ACEs | 0.11 (-0.27, 2.93) | 0.29 |
| Greenspace (Reference: High greenspace) | 1.58 (-0.25, 3.42) | 0.09 |
| Medium | 0.32 (0.32, 3.26) | 0.11 |
| Greenspace tertiles*ACE score (Reference: High greenspace=0 ACEs) | 0.04 (-2.36, 2.27) | 0.97 |
| Low greenspace*4 + ACEs | 0.89 (-1.24, 2.91) | 0.38 |
| Medium greenspace*4 + ACEs | 0.77 (-0.34, 2.63) | 0.02 |
| Medium greenspace*1–3 ACEs | 0.99 (-2.10, 2.14) | 0.38 |
| Model 2b: BMI = ACE score + greenspace + ACE score*greenspace + confounders | 1.45 (-0.38, 3.29) | 0.12 |
| Greenspace (Reference: High greenspace) | 0.45 (-0.72, 2.81) | 0.24 |
| ACE score (Reference: 0 ACEs) | 0.45 (-0.97, 1.90) | 0.55 |
| 4 + ACEs | 0.88 (-1.47, 1.74) | 0.38 |
| Greenspace tertiles*ACE score (Reference: High greenspace=0 ACEs) | -0.33 (-2.63, 1.96) | 0.79 |
| Low greenspace*4 + ACEs | 0.65 (-0.54, 2.98) | 0.32 |
| Medium greenspace*4 + ACEs | 0.46 (-0.63, 2.77) | 0.46 |
| Medium greenspace*1–3 ACEs | 0.68 (-0.46, 2.57) | 0.68 |

Note: ACE = adverse childhood experience, BMI = body mass index. Boldface = statistical significance (p < 0.05).

4. Discussion

The exploratory study is, to our knowledge, the first to examine the association of ACEs, BMI, and greenspace among urban-dwelling adults and to explore BMI differences across levels of ACE-greenspace exposure. Results demonstrated that experiencing 4 + ACEs and low or medium neighborhood greenspace were independently associated with

### Table 2
Estimated BMI for each level of ACEs-greenspace exposure.

| Group | Estimated BMI | Standard error | 95 % confidence limit |
|-------|---------------|----------------|----------------------|
| Model 1b – BMI = ACE score + greenspace + confounders | 27.3 | 0.676 | 26.0, 28.7 |
| 0 ACEs * high greenspace | 27.5 | 0.742 | 26.0, 28.9 |
| 1–3 ACEs * high greenspace | 27.5 | 0.676 | 26.2, 28.8 |
| 4 + ACEs * medium greenspace | 28.0 | 0.657 | 26.7, 29.3 |
| 0 ACEs * medium greenspace | 28.1 | 0.736 | 26.7, 29.6 |
| 1–3 ACEs * medium greenspace | 28.2 | 0.670 | 26.7, 29.3 |
| 4 + ACEs * low greenspace | 28.3 | 0.649 | 27.0, 29.6 |
| 0 ACEs * low greenspace | 28.4 | 0.726 | 27.0, 29.8 |
| 1–3 ACEs * low greenspace | 28.5 | 0.654 | 27.2, 29.7 |
| Model 2b – BMI = ACE score + greenspace + ACE score*greenspace + confounders | 27.2 | 0.850 | 25.5, 28.9 |
| 0 ACEs * high greenspace | 27.3 | 0.778 | 25.8, 28.9 |
| 1–3 ACEs * high greenspace | 27.6 | 0.715 | 26.2, 29.0 |
| 4 + ACEs * medium greenspace | 27.8 | 0.724 | 26.4, 29.3 |
| 0 ACEs * medium greenspace | 28.2 | 0.891 | 26.5, 30.0 |
| 1–3 ACEs * medium greenspace | 28.2 | 0.720 | 26.8, 29.6 |
| 4 + ACEs * low greenspace | 28.3 | 0.699 | 26.9, 29.6 |
| 0 ACEs * low greenspace | 28.5 | 0.715 | 27.0, 29.9 |
| 0 ACEs * low greenspace | 28.6 | 0.920 | 26.8, 30.4 |

Note: ACE = adverse childhood experience, BMI = body mass index.

* Confounders adjusted for include age (categorical: 18–34 [reference], 35–65, 65 + ), sex (categorical: male [reference], female), race (categorical: Asian, Black, Hispanic, other, White [reference]), below 150 % Federal poverty threshold (categorical: yes or no [reference]), marital status (categorical: married/partnered [reference], other, separated/widowed/divorced, single), employment status (categorical: employed [reference], other, retired, unemployed), education level (categorical: less than high school, high school/technical, some or all college, graduate school), chronic disease diagnosis (categorical: yes or no [reference] for hypertension/stroke/asthma/cancer/human immunodeficiency virus/chronic obstructive pulmonary disease/diabetes mellitus), and age at first sexual activity (continuous).
higher BMI in unadjusted models. However, after adjusting for potential confounders identified above, low greenspace but not ACEs, remained associated with higher BMI. Results did not demonstrate a statistically significant additive interaction between ACEs and greenspace.

Prior landmark research by Felitti and colleagues showed a dose response between ACEs and obesity and recent systematic reviews include a number of studies that have explored and often confirmed the ACE-obesity relationship (Felitti et al., 1998; Wiss and Brewerton, 2020; Hughes et al., 2017). We did not find the same association between ACEs and higher BMI after controlling for neighborhood greenspace and potential confounders, which could be due to a number of factors. First, several prior studies used measured heights and weights and/or dichotomized BMI into >30 kg/m² to align with a diagnosis of obesity, whereas we used self-reported heights and weights to compute BMI, and we analyzed BMI as a continuous outcome to maintain the measure's granularity. Second, much early ACE research measured household-level ACEs only, but the field has grown to understand that adversities outside the home can also impact health and behaviors. This study’s 14-item ACE score captures both household and community-level ACEs, some of which are known SDH, such as witnessing community violence, racial discrimination, and perceptions of neighborhood safety (Cronholm et al., 2015; Wade et al., 2016). Of note, our post-hoc analyses examining household and community-level ACEs separately did not change our study findings. However they did demonstrate that community-level ACEs but not household-level ACEs were associated with higher BMI in unadjusted analyses. While not the focus of the current study, the finding does highlight the importance of exploring the differences between household versus community-level ACEs in future work examining ACEs-BMI associations, including how to disentangle their effects from one another and how to disentangle effects of community-level ACEs from SDH. Third, this study also sampled from a more racially diverse and socioeconomically disadvantaged population and adjusted for a broader array of potential confounders than the landmark ACE study that controlled for age, sex, race and educational attainment (Felitti et al., 1998). Interestingly, post-hoc exploratory analyses controlling for only the same variables as the landmark ACE study did not change our study findings. It is unclear why this is the case, though we hypothesize that differences between our study and the landmark studies’ samples (beyond the differences captured in the aforementioned covariates) may have led to the difference in findings. Lastly, greenspace may have served as a proxy for other neighborhood-level SDH in our study, given prior literature that shows under-resourced neighborhoods have less greenspace (Nesbitt et al., 2019; Rigolon et al., 2021). Some of these study differences would reduce bias, while others might increase bias in this study (e.g., safety, quality, accessibility) are salient to how persons who experienced ACEs engage with greenspace. For example, a moderation effect might exist for safe, well-maintained, accessible greenspace, but not all greenspace. These characteristics might be particularly salient in places that demonstrate wide variation in greenspace quality; for example, in many urban areas some greenspaces are lush, well-maintained parks with minimal crime and other greenspaces are poorly maintained grass lots in areas of higher crime with characteristics associated with neighborhood disorder (e.g., litter, blight). Others are privately accessed. Second, specifics of the study, such as its cross-sectional nature or how measures were operationalized, may have limited the ability to detect a moderation effect that might indeed exist. Lastly, a moderation effect may not exist. The associations of greenspace and ACEs with BMI may operate independently, especially after accounting for SDH. The effects of both greenspace and ACEs on BMI are complex, multi-faceted, and modest; hypothesized effects of ACEs and greenspace may be similar but not identical. Thus, it is possible that our findings reveal that they do not interact to influence BMI.

Interestingly, individuals with higher ACE exposure lived in neighborhoods with lower greenspace. Additionally, given that we did not find a significant association between ACEs and BMI in multivariate analyses, but prior research has found a significant association (Felitti et al., 1998; Wiss and Brewerton, 2020; Hughes et al., 2017), it is possible that controlling for greenspace in those prior studies would have reduced or eliminated that association. Therefore, including greenspace in future ACEs-obesity research could help clarify these associations. In addition, future greenspace-ACEs-obesity research should heed attention to measurement issues arising from wide variation in operationalization of both ACEs and obesity. For example, studies that include sensitivity analyses testing how different measures of greenspace (e.g., park access versus greenspace per tract), aspects of greenspace (e.g., safety, quality, access), or different operationalization of ACEs (e.g., continuous versus categorical ACE scores) can further illuminate associations.

4.1. Limitations

Limitations of the study include: being a cross-sectional secondary analysis of existing data, inability to infer causality; using self-reported ACEs and BMI data; and assuming that census tract is an appropriate scale of measurement for neighborhood exposure. Additionally, results may not generalize outside one urban setting or to studies that operationalize ACEs and greenspace differently. Also green space type, features, and quality were not assessed. Finally, it is possible that analyses may be biased due to omission of potential confounders, including...
unmeasured individual- or neighborhood-level SDH, that we were unable to examine given limitations in the data.

5. Conclusions

After accounting for key sociodemographic and health-related factors, low neighborhood greenspace, but not ACEs, was independently associated with BMI. Currently, most efforts to understand and address documented ACEs-obesity associations have focused at lower levels of the socio-ecological model. Future research should examine why the previously observed association between ACEs and BMI was disconfirmed in this study, after accounting for SDH-related potential confounders and greenspace.

CRediT authorship contribution statement

Krista Schroeder: Conceptualization, Methodology, Funding acquisition, Writing – original draft. Christine M. Forke: Conceptualization, Methodology, Writing – review & editing. Jennie G. Noll: Conceptualization, Funding acquisition, Writing – review & editing. David C. Wheeler: Methodology, Writing – review & editing. Kevin A. Henry: Methodology, Writing – review & editing. David B. Sarwer: Conceptualization, Writing – review & editing.

Declaration of Competing Interest

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found on line at https://doi.org/10.1016/j.pmedr.2022.101915.

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