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## Pedestrian-oriented zoning moderates the relationship between racialized economic segregation and active travel to work, United States

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### Abstract

**Objective:** Pedestrian-oriented zoning, including zoning code reforms (ZCR), may be especially beneficial to racially and economically segregated communities, which may lack built environment features that support physical activity. This study examined associations between racialized economic segregation, measured by quintiles of the Index of Concentration at the Extremes, and public transit (PTW) and active travel (ATW) to work, and whether associations were moderated by pedestrian-oriented zoning provisions and ZCR, respectively.

**Methods:** Zoning codes effective as of 2010 representing 3,914 US municipalities (45.45% of US population) were evaluated for the presence of ZCR and eight pedestrian-oriented zoning provisions. These data were linked with American Community Survey 2013–2017 and NAVTEQ 2013 data on the outcomes and relevant covariates. Fractional logit regressions were computed with standard errors clustered on county.

**Results:** Workers from more deprived quintiles were less likely to engage in PTW and ATW (OR=0.22–0.55,  $p<0.01$ ), and tests revealed moderation by zoning ( $p<0.05$ ). ZCR was positively associated with PTW for the three most deprived quintiles (OR=1.53–2.38,  $p<0.01$ ), and with ATW for the two most deprived quintiles (OR=1.42–1.69,  $p<0.01$ ) and the second most privileged

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CRediT author Statement

**Natalicio Serrano:** Conceptualization, Methodology, Software, Formal Analysis, Writing- Original draft preparation, Writing – Review & Editing **Julien Leider:** Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Writing – Review & Editing. **Jamie Chriqui:** Conceptualization, Supervision, Investigation, Writing-Review & Editing, Project Administration, Funding Acquisition

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.

quintile (OR=1.26,  $p<0.05$ ). In the most privileged quintile, the zoning scale score was negatively associated with PTW (OR=0.91,  $p<0.001$ ) and ATW (OR=0.94,  $p<0.01$ ). However, in the most deprived quintiles, the zoning scale score was positively associated with PTW (Q2: OR=1.13,  $p<0.01$ ) and ATW (Q1-Q2: OR=1.07–1.09,  $p<0.05$ ).

**Conclusions:** Pedestrian-oriented zoning can provide opportunities for ATW in the most deprived communities. Work is needed to explore zoning policy implementation in those communities.

### Keywords

Zoning; Physical activity; Active travel; Health equity; Segregation; Built Environment

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### Introduction

The benefits of physical activity for health are far-reaching, including the reduced risk of several chronic diseases.<sup>1</sup> However, only 54% of US adults meet recommended guidelines of aerobic physical activity, with traditionally disadvantaged populations such as persons of lower income and persons of color facing even lower rates.<sup>2</sup> Transportation-related physical activity, including active travel to work (ATW), is a key domain of physical activity to target, with only 7% of US adults participating in any ATW.<sup>3</sup> Findings of previous studies suggest active travel may contribute to better health, such as reduced risk of diabetes.<sup>4</sup> To promote physical activity, the Community Preventive Services Task Force (CPSTF) recommends built environment approaches that combine improvements in transportation systems with changes in land use and community design.<sup>5</sup>

Zoning is a key policy lever governing pedestrian-oriented built environments that make it easier and safer to access neighborhoods by different modes of travel (e.g., walking, cycling, public transportation) through improved transportation infrastructure, increased street connectivity, open space, mixed-use development, and higher density.<sup>6</sup> Pedestrian-oriented zoning strategies, including zoning code reform (ZCR; e.g., SmartCode, form-based codes, transit-oriented development zoning) that is pedestrian-oriented by design, may be especially beneficial to communities that are racially and economically segregated, as they may lack built environment features that support physical activity. Specifically, racially and/or economically segregated neighborhoods have been associated with less green space, more dilapidated buildings, less tree canopy coverage, less access to urban rail systems, and lower walkability.<sup>7–10</sup>

Though studies have highlighted the links between zoning and both physical activity and active travel,<sup>11–15</sup> less is known about potential equity implications of zoning strategies for racially and economically segregated neighborhoods when it comes to ATW. Recent and historic investments for community infrastructure from the federal government (i.e., Bipartisan Infrastructure Law, American Rescue Plan, and Justice40 Initiative) also create a window of opportunity for healthy community design that is sustainable and equitable. These investments aim to promote sustainable and clean transportation including public transportation and passenger rails, mixed use development, and affordable housing, and seek to ensure that overall investments are being made in traditionally disadvantaged

communities. The present study examined whether pedestrian-oriented zoning moderates the relationship between municipal-level racialized economic segregation (RES) and adult public transit use to work (PTW) and ATW.

## Methods

### Sample

The present study utilized data from municipal-level zoning codes effective as of 2010 (to allow a policy lag with the outcomes). Information on the zoning data collection process is presented elsewhere.<sup>11,13</sup> From a sampling frame of 6,438 municipal jurisdictions (49.14% of US population), the final analytic sample of zoning code data represented 3,914 municipalities and 45.45% of the US population. This represents 471 of the most populous counties and 2 consolidated cities located in 48 states and the District of Columbia. Excluded municipalities included: those representing less than 0.5% of their county or consolidated city's population, those with unobtainable zoning code, or those where data could not be linked on relevant covariates. The present study was exempt from ethical compliance as it did not involve human subjects.

### Data sources and measures

**Racialized economic segregation.**—Utilizing data on race and income from the American Community Survey (ACS) municipal-level five-year estimates (2013–2017), we constructed the Index of Concentration at the Extremes for RES. The RES index assesses spatial concentrations of racial/economic privilege versus deprivation and ranges from –1 to 1 based on percentages of the population living at either end of the designated extremes based on race/ethnicity and income. For this study, the designated extremes were considered as persons that are non-Hispanic White and of higher household income (i.e., > \$125,000) versus persons of color and of a lower household income (i.e., < \$20,000). The RES index was then categorized into quintiles as this was established as one of the most widely used categorizations in a recent systematic review, where the lowest quintile (Q1) represents the most deprived municipalities, and the highest quintile (Q5) represents the most privileged municipalities.<sup>16</sup>

**Zoning measures.**—Analyses examined associations with 1) the presence of ZCR (yes/no), as well as 2) the presence of eight pedestrian-oriented zoning provisions in non-ZCR zoning districts, including: sidewalks, crosswalks, bike-pedestrian connectivity, street connectivity, bike lanes, bike parking, bike-pedestrian trails and paths, and mixed-use development. From these pedestrian-oriented zoning provisions a zoning scale score was computed corresponding to the number of provisions addressed (out of 8).

**Outcomes and covariates.**—The ACS data were used to calculate measures of ATW and relevant covariates. Outcomes of interest included the proportion (i.e., percentage) of workers in any given municipality who reported 1) taking PTW, and 2) engaging in any ATW (i.e., walking, biking, or taking PT) to commute. For this analysis, relevant covariates included Census region, tertiles of the percentage of households in poverty, median age, the percentage of occupied housing with no vehicle, and population size tertiles. A walkability

scale was also calculated that utilized data from the ACS, as well as NAVTEQ 2013. The walkability scale was calculated using data on four measures of density, including: 1) the ratio of four-way intersections to all intersections (NAVTEQ 2013), 2) intersection density or the total number of intersections in the municipality divided by the municipal land area (NAVTEQ 2013), 3) housing unit density (ACS), and 4) population density (ACS). This walkability scale was then standardized and adjusted to reduce negative values and is based on the scale created by Slater et al to focus on local urban compactness.<sup>17</sup>

## Analysis

Relevant data were linked using Federal Information Processing Series geocodes. Descriptive statistics were computed for the sample characteristics. Fractional logit regression models examining the association between zoning, RES, and ATW controlled for sociodemographic characteristics and walkability and were clustered on county, with robust standard errors. Fractional logit regression models were used because both outcomes were bounded, i.e., proportions ranging from 0 to 100%. Tests of moderation were conducted to explore whether pedestrian-oriented zoning (i.e., ZCR and the zoning scale) moderates the relationship between RES and both outcomes (i.e., PTW and ATW, respectively). Specifically, all regressions included interactions between RES and the zoning measure, and Wald tests were used to test the joint significance of interaction terms in the model. The odds ratios for RES show the association between the given RES quintile and the ATW outcome without the given zoning measure, relative to the referent (most privileged quintile) (upper portion of regression tables). The odds ratios on the interactions show the difference in the association between the given RES quintile and the ATW outcome with exposure to the zoning measure (used to estimate the lower portion of regression tables). Adjusted prevalence estimates were computed from the models by zoning code reform status (yes/no) or the zoning scale score (at the minimum and maximum possible values of 0 and 8, respectively) and RES. Though not described in the results because of space constraints, these adjusted prevalence estimates are presented in Tables 1 and 2. Statistical significance was tested at a  $p < 0.05$  level. All analyses were conducted in Stata S.E. (v.17.0).<sup>18</sup>

## Results

Descriptive statistics are detailed in Supplementary Table 1. At the municipal level, there were low average levels of PTW [Mean = 3.2% (SD = 6.0%)] and any ATW [Mean = 6.2% (SD = 7.8%)]. Only 14.3% of municipalities had ZCR, with an average zoning scale score of 3.2 (out of 8; SD = 2.1).

### Racialized economic segregation, zoning code reform, and active travel outcomes

Table 1 illustrates that without ZCR, workers in jurisdictions in the more deprived quintiles had significantly lower odds of engaging in both PTW (Q1-Q4: OR= 0.36 – 0.52,  $p < 0.01$ ) and overall ATW (Q1-Q4: OR= 0.31 – 0.55,  $p < 0.001$ ), when compared to the most privileged quintile. The test of moderation was significant when looking at the interactions between RES and ZCR with both PTW and overall ATW ( $p < 0.05$ ). There was no association between ZCR and PTW for the two highest quintiles of RES, but ZCR was positively associated with PTW for the three most deprived quintiles (OR=1.53 – 2.38,  $p < 0.01$ ). For

overall ATW, there was a positive association between ZCR and ATW for the two most deprived quintiles (OR=1.42 – 1.69,  $p<0.01$ ), as well as the second most privileged quintile (OR=1.26,  $p<0.05$ ).

### **Racialized economic segregation, pedestrian-oriented zoning provisions, and active travel outcomes**

Similarly, Table 2 demonstrates that without pedestrian-oriented zoning provisions, workers in jurisdictions in the more deprived quintiles had significantly lower odds of engaging in both PTW (Q1-Q4: OR= 0.23 – 0.35,  $p<0.001$ ) and overall ATW (Q1-Q4: OR= 0.22 – 0.41,  $p<0.001$ ), when compared to the most privileged quintile. The test of moderation was significant when looking at interactions between the pedestrian-oriented zoning provisions and RES with both PTW and ATW ( $p<0.001$ ). In the most privileged quintile, a higher zoning scale score is negatively associated with both PTW (OR=0.91,  $p<0.001$ ) and overall ATW (OR=0.94,  $p<0.01$ ). However, in the most deprived quintiles, a higher zoning scale score is positively associated with both PTW (Q2: OR=1.13,  $p<0.01$ ) and ATW (Q1-Q2: OR=1.07 – 1.09,  $p<0.05$ ).

### **Discussion**

To our knowledge, this is the first study to examine: (1) the relationship between RES and PTW and ATW, respectively; and (2) whether pedestrian-oriented zoning moderates disparities in the relationship between RES and PTW and ATW, respectively. The most deprived communities have low rates of both PTW and overall ATW. However, we found that these disparities in PTW and ATW were mitigated by the presence of ZCR and, to a lesser extent, by pedestrian-oriented zoning provisions. These results are not only statistically but also practically significant, given policies' extensive reach to potentially all workers who commute to work and the fact that we see multiple percentage point reductions in disparities with zoning measures in place. ZCR and pedestrian-oriented zoning provide a unique opportunity for sustainable infrastructure changes that relate to the CPSTF's recommendation for built environment changes to combine improvements in transportation systems with changes in land use and community design.<sup>5</sup> Though studies have highlighted the beneficial impacts of zoning strategies for physical activity and active travel,<sup>11-13,15</sup> these findings for communities impacted by racialized economic segregation also have positive implications for equity when it comes to healthy community design and neighborhood opportunities. More specifically, ZCR in combination with directed investments such as the Justice40 Initiative and the Bipartisan Infrastructure Law can facilitate improvements in public transportation infrastructure, affordable housing access, mixed use development, as well as other pedestrian and cycling infrastructure. These directed investments can help create more equitable community benefits, including the promotion of physical activity and active travel.

Still, our study is not without its limitations. First, the sample was a purposive sample of municipalities in the most populous US counties and consolidated cities. Though these findings are not generalizable to all municipalities nationwide, these findings are relevant to 45.45% of the US population. Additionally, as this is a cross-sectional study, causation

cannot be inferred. Though we did include a policy lag, as zoning predictors were captured in 2010 and relevant outcomes and covariates were captured from ACS 2013–2017 five-year estimates and NAVTEQ 2013 data, longitudinal studies would be helpful in studying the impacts of zoning policies. Another limitation is the use of workers' PTW and overall ATW, which is only a piece of transportation-related physical activity. However, our study used the best available geocoded data to answer our questions. Additionally, this study is the first to investigate the equity implications of zoning strategies for active travel in communities impacted by racialized economic segregation.

## Conclusions

This study adds to the evidence base for the positive implications of zoning strategies in creating pedestrian-oriented environments that are supportive of active travel and beneficial to overall public health. Our findings suggest that zoning strategies, including ZCR and the inclusion of pedestrian-oriented zoning provisions, may help alleviate disparities in ATW in communities impacted by racialized economic segregation. There are potential equity implications, though future work should explore the implementation process of these zoning policies in the most deprived communities.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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**Table 1.**

Multivariable associations between municipal-level racialized economic segregation, zoning code reform, and public transit and active travel use (2013 – 2017)

	Public Transit Use			Active Travel		
	Odds Ratio	95% CI	Adjusted Prevalence Estimates	Odds Ratio	95% CI	Adjusted Prevalence Estimates
<b>Associations with RES, without zoning code reform</b>						
RES Q1	<b>0.52</b>	<b>0.35 – 0.78</b>	2.9	<b>0.31</b>	<b>0.24 – 0.40</b>	4.1
RES Q2	<b>0.36</b>	<b>0.27 – 0.49</b>	2.1	<b>0.37</b>	<b>0.30 – 0.45</b>	4.8
RES Q3	<b>0.36</b>	<b>0.28 – 0.47</b>	2.1	<b>0.44</b>	<b>0.37 – 0.53</b>	5.7
RES Q4	<b>0.48</b>	<b>0.38 – 0.60</b>	2.7	<b>0.55</b>	<b>0.47 – 0.65</b>	6.9
RES Q5 (referent)	1.00	1.00 – 1.00	5.2	1.00	1.00 – 1.00	11.3
<b>Associations with zoning code reform, by RES</b>						
RES Q1	<b>1.72</b>	<b>1.18 – 2.52</b>	4.7	<b>1.42</b>	<b>1.12 – 1.79</b>	5.6
RES Q2	<b>2.38</b>	<b>1.69 – 3.37</b>	4.5	<b>1.69</b>	<b>1.31 – 2.18</b>	7.6
RES Q3	<b>1.53</b>	<b>1.13 – 2.08</b>	3.1	1.19	1.00 – 1.41	6.6
RES Q4	1.30	0.89 – 1.91	3.4	<b>1.26</b>	<b>1.00 – 1.58</b>	8.4
RES Q5	0.90	0.66 – 1.22	4.7	0.96	0.75 – 1.23	10.9

Fractional logit model controlling for municipal-level median age, percent household poverty, region, walkability, percent occupied housing with no vehicle, population size, and interactions between zoning code reform and racialized economic segregation, with robust standard errors clustered on county. Bold indicates a significant association ( $p < .05$ ). Adjusted prevalence estimates were computed from the models, corresponding to the estimated proportions of public transit use and active travel use to work by zoning code reform status and RES. Adjusted prevalence estimates are shown by RES without (top panel) and with (bottom panel) zoning code reform. N=3,914 municipalities representing 45.45% of the U.S. population in 471 of the most populous counties and 2 consolidated cities located in 48 states and the District of Columbia.



**Table 2.**

Multivariable associations between municipal-level racialized economic segregation, pedestrian-oriented zoning provisions, and public transit and active travel use (2013 – 2017)

	Public Transit Use			Active Travel		
	Odds Ratio	95% CI	Adjusted Prevalence Estimates	Odds Ratio	95% CI	Adjusted Prevalence Estimates
<b>Associations with RES, without pedestrian-oriented zoning provisions</b>						
RES Q1 – most deprived	<b>0.32</b>	<b>0.18 – 0.54</b>	2.4	<b>0.22</b>	<b>0.16 – 0.31</b>	3.7
RES Q2	<b>0.23</b>	<b>0.15 – 0.34</b>	1.8	<b>0.25</b>	<b>0.19 – 0.33</b>	4.1
RES Q3	<b>0.25</b>	<b>0.17 – 0.36</b>	1.9	<b>0.34</b>	<b>0.26 – 0.43</b>	5.3
RES Q4	<b>0.35</b>	<b>0.25 – 0.48</b>	2.6	<b>0.41</b>	<b>0.32 – 0.52</b>	6.4
RES Q5 (referent)	1.00	1.00 – 1.00	6.7	1.00	1.00 – 1.00	13.4
<b>Associations with pedestrian-oriented zoning provisions (i.e., zoning scale score), by RES</b>						
RES Q1	1.10	1.00 – 1.21	4.8	<b>1.07</b>	<b>1.01 – 1.12</b>	5.7
RES Q2	<b>1.13</b>	<b>1.05 – 1.21</b>	4.2	<b>1.09</b>	<b>1.05 – 1.14</b>	7.7
RES Q3	1.05	0.99 – 1.12	2.8	1.03	1.00 – 1.06	6.6
RES Q4	1.03	0.96 – 1.09	3.1	1.04	1.00 – 1.08	8.2
RES Q5	<b>0.91</b>	<b>0.87 – 0.96</b>	3.4	<b>0.94</b>	<b>0.90 – 0.98</b>	8.8

Fractional logit model controlling for municipal-level median age, percent household poverty, region, walkability, percent occupied housing with no vehicle, population size, and interactions between zoning scale score and racialized economic segregation, with robust standard errors clustered on county. Bold indicates a significant association ( $p < .05$ ). Adjusted prevalence estimates were computed from the models, corresponding to the estimated proportions of public transit use and active travel use to work by the zoning scale score and RES. Adjusted prevalence estimates are shown by RES with a zoning scale score of 0 (minimum possible value; top panel) and 8 (maximum possible value; bottom panel).  $N=3,914$  municipalities representing 45.45% of the U.S. population in 471 of the most populous counties and 2 consolidated cities located in 48 states and the District of Columbia.