Can Sidewalk and Crosswalk Availability Strengthen Association Between Physical Activity and National Walkability Index

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Abstract

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The majority of U.S. adults do not meet the recommended amount of weekly physical activity. Urban design researchers have studied micro and macro scale features to understand if physical activity, mainly walking, can be bolstered with different initiatives. These studies have resulted in mixed findings. We used a large cross-sectional sample spanning the U.S. from the INSPACE collaborative to quantify the association between neighborhood context, as measured by sidewalk availability, crosswalk availability, and the National Walkability Index, and accelerometer measured physical activity. We set thresholds for moderate to vigorous physical activity and averaged them by day to generate the outcome measure. We estimated the association between context and activity using linear regression to adjust for individual-level age and sex and neighborhood-level income. When using a threshold dependent on age, location of device, and type of device, we found that on average an increase in sidewalk availability by 10% increased mean MVPA per day by approximately 0.63 minutes (95% robust CI: 0.06-1.2). The significance of this relationship held when adjusting for the National Walkability Index. However,

when we performed a sensitivity analysis with an age-agnostic threshold, the association between neighborhood context and physical activity weakened whereas the age parameter strongly predicted physical activity. We uncovered an association between sidewalk availability and physical activity; however this could be an artifact of our age-dependent threshold defining moderate to vigorous physical activity per day. Nonetheless, our findings suggest further research on micro scale features may better illuminate determinants of neighborhood walking.

Introduction

The recommended amount of physical activity (PA) for adults 18 years and older is an average of 21-43 minutes per day of moderate activity (150-300 per week) or 11-21 minutes per day of vigorous activity (75-150 per week) (1). About 80% of adults in the United States fail to meet these criteria. Inactivity could have many negative health consequences, increasing morbidity - PA is shown to protect against obesity, cardiovascular disease, Type II diabetes, and some cancers (2). Several types of interventions, like infrastructure improvement or targeted individual interventions, may encourage physical activity. Policy makers need to know which approaches will have the greatest effect to utilize limited funds wisely.

While PA comes in many different forms, the most common is walking (24). Researchers often study walkability measures when looking to examine environmental correlates of PA, with walkability generally consisting of macro-environmental aspects of urban design thought to promote walking and discourage car use (e.g., density, diverse nearby available destinations, design for walking) (3,4,5). One widely used walkability metric is the National Walkability Index (NWI). This measure is a weighted sum of intersection density, proximity to transit stops, employment mix, and the mix of employment type and occupied housing. The NWI was developed drawing on urban planning theory and frameworks, and does not include microscale features such as the availability and safety of walking infrastructure (sidewalks and crosswalks), which might also affect physical activity behavior such as walking.

In contrast, some studies have used more micro-scale measures to study walkability. A study found individuals recruited near recently improved sidewalks had an increase of weekly accelerometer-measured walking minutes by 1.6 times at one year follow-up (18). Another recent study created and tested a new micro-scale measure of neighborhood infrastructure, the proportion of Google Street View intersection images containing crosswalks and sidewalks (6). The study revealed a significant association between physical inactivity (as survey data derived from the 2016 Behavioral Risk Factor Surveillance System) and crosswalk availability, with less inactivity reported among those living in counties with higher crosswalk proportions. Given these new developments in using micro-scale features for measurement of walkable places, it is imperative to quantify how accurately micro-scale indicators predict PA on their own and in tandem with existing macro-scale measures.

We assessed the association between accelerometer-measured physical activity and the sidewalk and crosswalk availability around the homes of adults who start lifestyle interventions that focus at least in part on increasing physical activity. We further tested whether any association holds when we adjust for the National Walkability Index. Finally, we assessed interaction between sidewalk or crosswalk proportion and walkability in associations with physical activity. The understanding of this interaction could inform planners on how to design neighborhoods to better increase physical activity - that is, do neighborhood-scale walkability and sidewalk availability each play a role, and if so, are their contributions independent or in tandem.

Methods

Study Design and Population

To investigate the relationship between traditional walkability measures, sidewalk presence, crosswalk presence, and physical activity, this cross sectional analysis leveraged data from the Interventions Supporting Physical Activity moderated by Environment (INSPACE) initiative. INSPACE is a consortium pooling data from lifestyle intervention studies including physical activity promotion components, demographics information, and participant-level environmental variables (i.e., the neighborhood/area around where a participant lives). The pooled studies enrolled participants between 2010 and 2020 with physical activity measured both before (baseline) and after (post-intervention) the assigned lifestyle intervention or control condition, although the present analysis only examines the baseline measures of physical activity. The sample for this analysis included participants from 21 different studies from locations across the United States, with variability in racial/ethnic identities, gender, and age.

We limited our analysis to adults 18 years of age and older, expecting that children under the age of 18 have different physical activity patterns (7) and/or could be influenced by different aspects of the environment. We excluded participants with missing exposure or outcome data (physical activity, walkability index, and Google street view data), including those who had less than 3 days of valid accelerometer wear time. Valid days were defined as having 8 hours of wear time based on the Choi algorithm (19). One study called for only 2 days of valid wear time; we did not exclude participants from this study who completed 2 days of valid wear time. We imputed missing data about age and gender using the Multivariate Imputation by Chained Equations (MICE) technique using 10 imputations for 16 participants who otherwise had complete data.

Exposures

The National Walkability Index is a weighted index comprising the following measures: intersection density, proximity to transit stops from population centers, employment mix (such as retail, office, industrial), and the mix of employment type and occupied housing (8). Values for each category are gathered for each block group in the U.S., then each block group is ranked based on their quantile position. The range of this value is from 1-20, with 20 being the most walkable. The measure used in our study is the area-weighted average of the block group scores within the 1000m buffer zone of each individual trial participant's home address.

Nguyen and colleagues developed an algorithm to assess Google Street View (GSV) images captured between December 2017 to July 2018 to identify presence of crosswalk and/or sidewalks (6), and measured the proportion of images within each census tract in the United States showing at least one crosswalk and/or sidewalk. For each 1000m buffer, we computed the proportion of sidewalks and crosswalks present using a weighted aggregation of images with the feature divided by the total images for each census tract within the buffer, weighted by the amount of tract present within the buffer. These will be referenced as the concept they represent in the rest of this paper - sidewalk and crosswalk availability.

In order to gather the exposure measures for InSPACE (built and social environment features, green space, and more, including walkability, neighborhood income, and urban infrastructure), consortium trialists used the Automatic Context Measurement Tool (ACMT). This is a software package that geospatially links publicly available data sources to addresses (in this case participant home addresses), and generates an interpolated estimate for each environmental measure for a given buffer around each individual's home address (9). The ACMT computes a weighted average of each measure within designated buffer areas around a participant's address, which for the InSPACE Project included 500m, 1000m, and 5000m buffer areas. For this study, we chose 1000m given that most MVPA outside of the home often occurs within 1666 m of home (10).

Confounders

Individual-level age and gender and neighborhood level median income were used as confounders. Each trial participant's age and gender were provided by each trial team; gender was grouped into 'Male', 'Female', 'Transgender', and 'Other'. The neighborhood income measure came from the American Community Survey (ACS). To derive this, the proportion of individuals in each income category were estimated for the buffered area. From these estimated proportions, we generated a median neighborhood income measure by taking the midpoint of the income category in which 50% of individuals in the buffer were at or below. For example, if the estimated proportion of individuals in the buffered area were in an income category of $50,000 to $59,999, then the estimated median neighborhood income for that area was $54,999.

Outcome

Physical activity was measured by accelerometer devices managed by the studies contributing to InSPACE. These studies used one of four devices: Actigraph GT1M, Actigraph GT3X, ActigraphGT9X, and activPAL3c. Valid wear time was determined via the standard parameters for the Choi algorithm using the R package PhysicalActivity (17, 19). The accelerometer thresholds that defined MVPA vs lighter activity or inactivity were designated based on a literature review. We chose previously validated thresholds for adults for each accelerometer type and wear location and by age (11,12,13,14). See Figure 1 for more details. For this analysis, our primary outcome was average MVPA per valid wear day at each study's baseline.

Statistical Analysis

We selected potential confounding variables (individual age, individual gender, and median neighborhood-level income) *a priori* through literature review and domain knowledge. Age and gender are associated with differences in physical activity with age also relating to area of residence (15). Research also shows an association between neighborhood income and physical activity (16).

We fit seven pooled linear regression models on a pooled MICE dataset testing significance of all terms of interest at a p-value <= 0.05. These models adjusted for trial, individual age, individual gender, and neighborhood-level income. Since participants in each study are likely correlated given they are recruited from the same geographical region or demographic group, we chose to use trial as a fixed effect variable. This allowed us to account for some association, while not focusing on trial as a parameter of interest. Power calculations (power= 0.8, alpha=0.05, number of covariates=4) showed that a sample size of ~2000-2500 would have sufficient power to detect a small relationship (R^2 = 0.6-0.3%) between the predictors and outcome.

Our descriptive analyses of PA by age suggested, surprisingly, that older adults engaged in more minutes of MVPA than younger adults. Because we were concerned that this was an artifact of applying a lower threshold for the conversion of accelerometer activity counts to minutes of moderate-to-vigorous physical activity among older adults, we conducted a sensitivity analysis using one activity count threshold (i.e. 1952 counts/minute for hip-worn accelerometers) for all ages.

Imputation

16 participants across different trials had complete data for exposure and outcome with at least 3 valid days of accelerometer wear, but were missing age or gender data. Rather than dropping them from the study, we computed MICE imputation utilizing the full dataset. Ideally, we would have imputed by study, but the implementation complexity was too high. Model results show some differences between the complete case and imputed, but validation of the imputation showed no concerning patterns. There is a slight difference in those with complete data and those with missing data (slightly lower mean MVPA and sidewalk availability).

Ethics Approval

The Seattle Children's Research Institute and University of Washington Institutional Review Board through external reliance approved the conduct of the INSPACE consortium.

Results

There were 2055 adults 18 and older with complete exposure and outcome data and 2-3 days of valid accelerometer wear in the final sample for this analysis. The study population skewed towards white and female individuals around middle age (mean age of 52.2, 64.1% Female, 63.1% White) (Table 1). The average MVPA per day was 23.9 minutes, with an average 9.6 valid days. When split by above and below the median NWI, 9.23, there appears to be a slight difference between the populations for all measures except MVPA. This could be due to the differences in recruitment between studies - some targeted certain racial or gender groups living in areas with likely similar levels of walkability. The availability of crosswalk and sidewalk was higher for those above the median walkability index value. Each of the measures had a positive association with each other. The r-value correlations are as follows: NWI~sidewalk = 0.66, NWI~crosswalk = 0.43, crosswalk~sidewalk = 0.62. We can presume that places with higher density have more built infrastructure to manage the safety of pedestrians (i.e., to include sidewalks and crosswalks) and areas without sidewalks likely won't have crosswalks.

Our linear regression analysis found that the availability of sidewalks had a significant positive association with physical activity after confounding adjustment. We estimate the difference in the expected value of mean MVPA per day when comparing INSPACE participants whose sidewalk availability is 10% higher, but are constant in all other variables, to be approximately 0.63 minutes more (95% robust CI: 0.06-1.2). By contrast, crosswalk availability and NWI were not associated with physical activity beyond chance. When modelling sidewalk and crosswalk while accounting for the walkability index, the crosswalk and sidewalk respective significance did not substantively change. The models testing the interaction between crosswalk and sidewalk with walkability showed no significant relationship with physical activity. Examination of the confounders revealed that none, besides some levels of the trial-level effect modifier, held significance.

In our sensitivity analysis, none of our exposure operationalizations were associated with MVPA at an alpha level of 0.05 (i.e., the sidewalk association with MVPA was no longer significant), but the age parameter gained a significant association in every model. We estimate the difference in the expected value of mean MVPA per day when comparing INSPACE participants with the same study, sidewalk/crosswalk/NWI, gender, and area income who differ by one year in age to be approximately 0.33 minutes (95% robust CI: -0.4-0.24), with those older in age participating in less average MVPA minutes per day.

Discussion

In this sample of participants entering physical activity promotion trials, sidewalk availability was associated with baseline MVPA, including after adjusting for NWI. Surprisingly, given their correlation to each other (Figure 2), NWI and crosswalk availability were not associated with baseline MVPA. When we examined if we would get stronger results by examining the intersection of the measures in an interaction model, we found that did not hold. The reason for the difference in findings between our primary models is unclear. The distribution of NWI in our dataset closely reflects what is expected of the general population. By nature of the measure, the average NWI for the U.S. should be around 10.5; our dataset had an average value of 10.0, median of 9.2, and range of 0-19.1. It could be that the data from the studies we recruited may not align with how we are conceptualizing PA in this analysis. For instance, participants may be walking or cycling in their neighborhoods at a pace that isn't considered MVPA or, on the other hand, they could be going to the gym and walking outside their neighborhood (e.g., in a park). The choice to walk nearby one's home versus the ability to do so, which the environment can only partially influence, must be considered when reviewing each of these models, especially for adults recruited for their low activity. We must, lastly, consider random chance and reverse causation that could arise from a cross-sectional study where residents self-select into neighborhoods and into a convenience sample.

That being said, these results did not hold in the sensitivity analysis where we applied the same activity count threshold for accelerometry across all ages. With the consistent threshold applied, the primary result changed to show a significant decrease in PA with older age, and age became a statistically significant confounder. It's difficult to ascertain which threshold is correct - it's plausible that older adults may be more active than younger adults in this population given the differing selection criteria by study. Setting proper thresholds in translating activity counts to estimates of physical activity minutes remains a debate, with researchers inquiring what level of activity produces a meaningful health benefit (20). While we still went with our a priori plan, the results could be an artifact of our decision to categorize PA as moderate to vigorous at lower levels of movement for older adults.

A systematic review examining studies with similar methods to this paper found mixed results (positive, null, and negative associations) between MVPA and sidewalk/connectivity, walkability measures, and the components of the walkability measures (21). Another analysis found that multivariate indexes like, NWI, were more strongly associated with physical activity outcomes than singular environmental variables (22), in contrast to what we found. Lastly, a blog study of walkability measures found the highest NWIs were found in high population urban areas, which may point to some confounding with urban versus rural settings. (23) These results point to the complexity of this relationship, which has surfaced within our results.

Though we have concerns about the validity of the activity count conversion to MVPA chosen to produce these results, for the population described in this analysis, we gleaned an association between PA and availability of sidewalks. We did not find an association with NWI and crosswalks. It is intriguing that sidewalks are more associated with MVPA than NWI in a population of largely inactive people.This analysis explored two newer micro-scale measures and compared them to a widely used macro-scale measure demonstrating their relevance to urban infrastructure research. This analysis also explored the complex space of accelerometer thresholding, building the evidence base to support this discourse and further suggesting the need for deeper investigation of activity count thresholding in older adults.

There are several strengths and limitations to our study. INSPACE uniquely has access to a sizable, diverse nationwide dataset from over 20 studies containing accelerometry, demographic, and harmonized neighborhood characteristic data. With this data, we computed several models with two different thresholding techniques, assessing new metrics on their own, in tandem with an existing metric, and as an interaction. With the assistance of our InSPACE advisory counsel, we were able to gather the most up to date discourse on MVPA thresholds for older adults.

Beyond the discourse on thresholds already discussed in this paper, the limitations include some heterogeneity in accelerometer wear protocols, recruitment methods, and other administrative factors due to the nature of a pooling samples, which was somewhat accounted for with fixed effects modelling. The cross-sectional nature of this analysis can affect the data through reverse causation and a potential for atypical PA behaviors while being monitored (e.g., potentially more PA than usual). Since we are not collecting location data, we are not measuring only the walking that occurs near their home, which doesn't align with the scope of the environmental factors which were limited to being within participants' home neighborhoods. Though we adjust for this with weighting, since we aggregate neighborhood features at a 1000m buffer, there is some potential for skew in areas where census tracts are very large. Lastly, we chose not to include race and ethnicity or other individual or neighborhood level factors as adjustment variables and rather try to capture some neighborhood-level systemic racism effects with neighborhood-level income. We acknowledge that this approach does not adequately capture the effects of racism.

Conclusion

Utilizing a dataset with studies and their samples from different parts of the continental U.S., we found that there was an association between PA and sidewalk availability that held when adjusting for NWI. However, this could be an artifact of our age-dependent threshold to convert physical activity device data to estimates of MVPA per day, since the association disappeared in favor of a strong association between PA and age when using an age-agnostic threshold.

Figures/Tables

Table 1: Physical activity, environment, and demographic characteristics for U.S. adults aged 18 and older from the INSPACE initiative. (N=2055)

Primary threshold: mean_mvpa_by_type_per_valid_day_baseline
Secondary threshold: mean_mvpa_by_accel_type_no_age

Characteristic	Overall N = 2,055[1]	Above Med Walkability N = 1,027[1]	Below Med Walkability N = 1,028[1]
age	52 (13)	53 (14)	51 (12)
Missing	14	8	6
gender_reduced			
Female	1,304 (64%)	587 (58%)	717 (70%)
Male	732 (36%)	426 (42%)	306 (30%)
Other	6 (0.3%)	6 (0.6%)	0 (0%)
Missing	13	8	5
race			
American Indian or Alaska Native	14 (0.7%)	7 (0.7%)	7 (0.7%)
Asian	190 (9.6%)	174 (18%)	16 (1.6%)
Black	432 (22%)	232 (24%)	200 (20%)
Multiple	69 (3.5%)	41 (4.2%)	28 (2.8%)
Native Hawaiian or Other Pacific Islander	3 (0.2%)	0 (0%)	3 (0.3%)
Other	39 (2.0%)	35 (3.6%)	4 (0.4%)
White	1,231 (62%)	495 (50%)	736 (74%)
Missing	77	43	34
median_income_estimate	67,739 (27,852)	64,340 (28,079)	71,135 (27,215)
prop_crosswalk	0.05 (0.04)	0.06 (0.04)	0.04 (0.03)
prop_sidewalk	0.58 (0.25)	0.71 (0.16)	0.44 (0.25)
NatWalkInd	10.0 (3.5)	12.9 (2.3)	7.1 (1.8)
mean_mvpa_by_accel_type_no_age	20 (18)	20 (20)	20 (16)
mean_mvpa_by_type_per_valid_day_baseline	24 (21)	24 (22)	24 (19)
total_valid_days_baseline	10 (6)	11 (7)	9 (4)

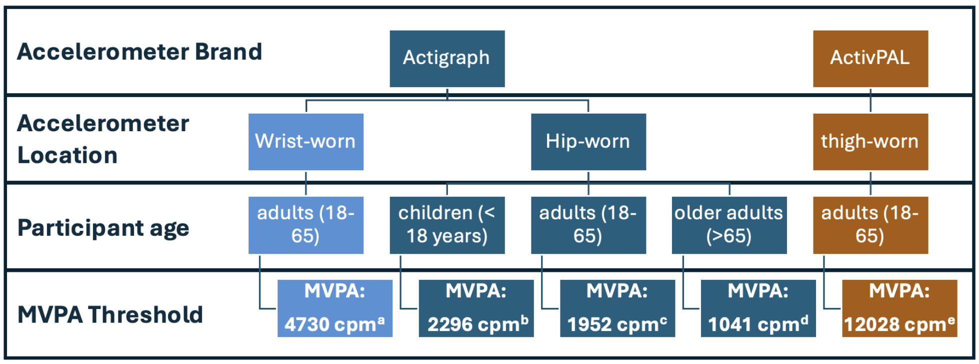
[1] Mean (SD); n (%)

Table 2: Adjusted estimates for coefficients and standard deviations along with corresponding p-values for the association between physical activity and several environmental variables. Adjusted for: age, gender, median neighborhood-level income.

M	Description	Coefficient Name	Primary Threshold[b] Coefficient Estimate[a]	P Value	Secondary Threshold[c] Coefficient Estimate[a]	P Value
1	Association between physical activity and sidewalk availability	Sidewalk Availability	6.327 (0.65 - 12.00)	**0.029***	3.966 (-0.75 - 8.69)	0.099
2	Association between physical activity and crosswalk availability	Crosswalk Availability	16.064 (-15.029 - 47.16)	0.311	12.433 (-13.42 - 38.28)	0.346
3	Association between physical activity and NWI	NWI	0.023 (-0.35 - 0.39)	0.890	0.064 (-0.24 - 0.37)	0.681
4	Association between physical activity, and sidewalk availability, adjusting for walkability	NWI	-0.286 (-0.73 - 0.15)	0.204	-0.109 (-0.48 - 0.26)	0.561
		Sidewalk Availability	8.721 (1.95 - 15.49)	**0.012***	4.872 (-0.75 - 10.51)	0.090
5	Association between physical activity and crosswalk availability, adjusting for walkability	NWI	-0.068 (-0.47 - 0.34)	0.745	0.003 (-0.33 - 0.34)	0.985
		Crosswalk Availability	18.436 (-15.78 - 52.66)	0.291	12.317 (-16.13 - 40.76)	0.396
6	Association between physical activity, NWI, sidewalk availability, interaction between NWI and sidewalk availability	NWI	0.401 (-0.91 - 0.66)	0.754	0.067 (-0.59 - 0.72)	0.840
		Sidewalk Availability	11.308 (-1.21 - 23.83)	0.077	7.723 (-2.69 - 18.14)	0.146
		Sidewalk Availability: NWI	-0.288 (-1.46 - 0.89)	0.630	-0.317 (-1.29 - 0.66)	0.524
7	Association between physical activity, NWI, crosswalk availability, interaction between NWI and crosswalk availability	NWI	-0.103 (-0.59 - 0.38)	0.677	-0.039 (-0.44 - 0.36)	0.849
		Crosswalk Availability	5.493 (-97.17 - 108.16)	0.916	-3.211 (-88.56 - 82.14)	0.941
		Crosswalk Availability: NWI	1.064 (-6.89 - 9.02)	0.793	1.277 (-5.34 - 7.89)	0.705

M: Model number
a: Estimate with 95% confidence interval
b: Model with MVPA threshold set with age
c: Model with MVPA threshold set without age

Figure 1: Accelerometer Threshold Logic



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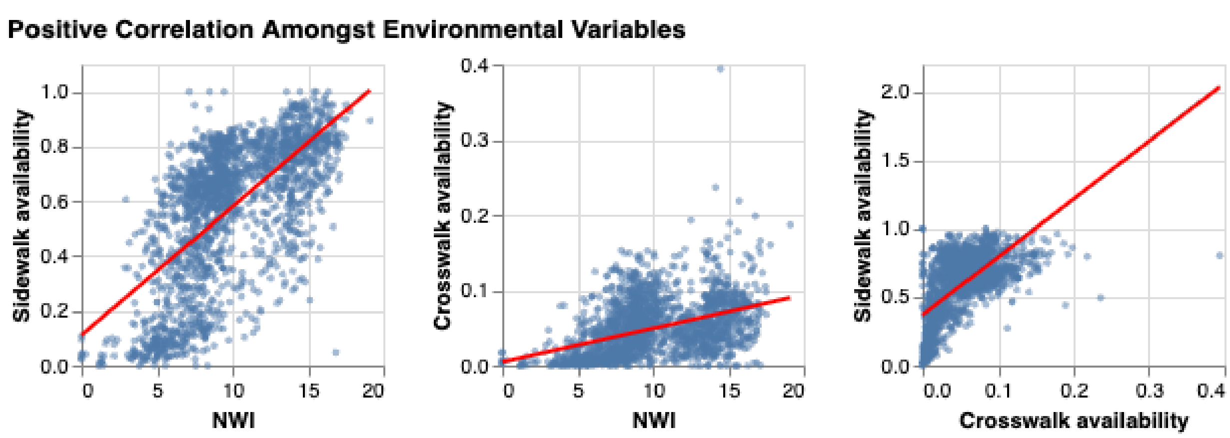
b. Evenson et al., 2008 (calibrated with uniaxial counts on children 5-8 years old)
c. Freedson et al., 1998 (calibration of uniaxial counts)
d. Copeland & Esliger, 2009 (calibrated on uniaxial counts)
e. Powell et al., based on 3007 count per 15-second epoch;

Figure 2: Scatterplot patterns between NWI, sidewalk, and crosswalk
Slope values respectively (0.0468, 0.0044, 4.2274)
R values respectively (0.66, 0.43, 0.62)



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