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A national examination of neighborhood socio-economic disparities in built environment correlates of youth physical activity

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ABSTRACT

Adolescents in the U.S. do not meet current physical activity guidelines. Ecological models of physical activity posit that factors across multiple levels may support physical activity by promoting walkability, such as the neighborhood built environment and neighborhood socioeconomic status (nSES). We examined associations between neighborhood built environment factors and adolescent moderate-to-vigorous physical activity (MVPA), and whether nSES moderated associations. Data were drawn from a national sample of adolescents (12–17 years, N = 1295) surveyed in 2014. MVPA (minutes/week) were estimated from self-report validated by accelerometer data. Adolescents' home addresses were geocoded and linked to Census data from which a nSES Index and home neighborhood factors were derived using factor analysis (high density, older homes, short auto commutes). Multiple linear regression models examined associations between neighborhood factors and MVPA, and tested interactions between quintiles of nSES and each neighborhood factor, adjusting for socio-demographics. Living in higher density neighborhoods (B(SE): 9.22 (2.78), p = 0.001) and neighborhoods with more older homes (4.42 (1.85), p = 0.02) were positively associated with adolescent MVPA. Living in neighborhoods with shorter commute times was negatively associated with MVPA (−5.11 (2.34), p = 0.03). Positive associations were found between MVPA and the high density and older homes neighborhood factors, though associations were not consistent across quintiles. In conclusion, living in neighborhoods with walkable attributes was associated with greater adolescent MVPA, though the effects were not distributed equally across nSES. Adolescents living in lower SES neighborhoods may benefit more from physical activity interventions and environmental supports that provide opportunities to be active beyond neighborhood walkability.

1. Introduction

The U.S. Physical Activity Guidelines for adolescents recommend 60 min of moderate to vigorous physical activity (MVPA) daily, yet only 26% of adolescents currently meet the guidelines (Center for Disease Control and Prevention (CDC), 2020). These statistics are concerning given that low physical activity in youth is associated with childhood obesity and other health conditions (e.g. diabetes, cardiovascular disease) and contributes to unhealthy lifestyles in adulthood (Johnson et al., 2019; Masoumi, 2017; Rhodes et al., 2018; Hallal et al., 2006).

Abbreviations: BMI, body mass index; FLASHE Study, Family Life, Activity, Sun, Health, and Eating Study; GED, General Educational Development; MVPA, moderate to vigorous physical activity; NCES, National Center for Education Statistics; NCI, National Cancer Institute; nSES, neighborhood socioeconomic status; PCA, principal component analysis; SE, standard error; SES, socioeconomic status; TEAN, Teen Environment and Neighborhood; YAP, Youth Activity Profile.

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Ecological models of physical activity posit that factors across multiple levels, such as individual, psychosocial, environmental, and policy levels influence physical activity behaviors (Molina-García et al., 2017; Perez et al., 2017). At the environmental level, favorable built and social attributes of the home neighborhood offer opportunities to be physically active and have been associated with youth physical activity (D'Angelo et al., 2017; Ding et al., 2011). However, few studies have examined associations between objectively measured neighborhood walkability and physical activity among adolescents at a national scale (Masoumi, 2017; Ding et al., 2011).

Among the studies that have used objective neighborhood measures of attributes supportive of youth physical activity, findings show that neighborhood measures were positively associated with physical activity outcomes in adolescents (Perez et al., 2019; Sallis et al., 2018; Loh et al., 2019). Studies with adults point to other objective environment factors linked to health, but they have not been examined in studies with youth. These include housing density, neighborhood age, and commute time (the latter which may be affected, e.g., by the availability of high pedestrian street connectivity and public transportation stops) (Rhodes et al., 2018; Hoehner et al., 2011; McGrath et al., 2016). In one Texas study with adults, living in neighborhoods with greater population and housing density, older median home age (i.e., a proxy measure for urban design representing greater pedestrian-oriented sidewalks and street connectivity), and shorter commute times to work (which may support bicycling and walking) were significantly associated with increased cardiorespiratory fitness and lower body mass index (BMI) (Hoehner et al., 2011). However, these findings on walkability among adults cannot necessarily be extrapolated to adolescents. For example, a national study conversely found that shorter commute times were associated with reduced active transport to school among adolescents, highlighting the need for more research in this population (Perez et al., 2019).

Further, a key principle of ecological models is that factors across levels interact to influence behavior. Such interactions can provide evidence of the conditions in which some correlates are related to physical activity. In particular, neighborhood socioeconomic status (nSES) may be an important moderator of built environment and physical activity associations, as shown in studies focused on adults (Sallis et al., 2011). Youth studies show that living in a neighborhood of low socioeconomic status (SES) is associated with lower levels of MVPA (Masoumi, 2017; Molina-García et al., 2017; Ding et al., 2011; Sallis et al., 2018; Villanueva et al., 2016; Janssen et al., 2006). This may be due to unequal distributions of physical activity resources. For example, recreational facilities, YMCAs, walking trails, and parks are often more readily available or of higher quality in neighborhoods of higher SES than those of lower SES (McGrath et al., 2016; Gordon-Larsen et al., 2006; Koohsari et al., 2017). However, how interactions between nSES and the built environment contribute to adolescent MVPA is not well understood. Studies testing such interactions with adolescent samples are limited and findings have been mixed (Molina-García et al., 2017; Perez et al., 2019; Sallis et al., 2018). Further, there is limited evidence from national adolescent studies, which can offer greater heterogeneity in population and environmental characteristics and power to detect associations and moderating effects.

Thus, the purpose of this study was to examine associations of home neighborhood environmental factors (built environment factors and nSES) with MVPA among a national sample of adolescents from the National Cancer Institute's (NCI's) Family Life, Activity, Sun, Health, and Eating (FLASHE) Study. The aims were to examine 1) the association between neighborhood built environment factors and adolescent MVPA and 2) the moderating effects of nSES on these associations.

2. Materials and methods

2.1. Sample and weights

Data were obtained from the NCI's FLASHE Study, including survey data from adolescents and data on objectively measured home neighborhood characteristics (GeoFLASHE) (Perez et al., 2019; National Cancer Institute (NCI), 2017; Westat, 2018). The FLASHE study design and measures development are described in detail in prior publications (Nebeling et al., 2017; Oh et al., 2017). In brief, FLASHE was a cross-sectional survey administered to dyads of parents and adolescents (aged 12–17) between April and October 2014. Parents were recruited through the Ipsos Consumer Opinion Panel, a national market research firm, and were eligible if they were aged $\geq$ 18 years and lived with at least one child aged 12–17 years for at least 50% of the time. During screening, one eligible adolescent from the household was randomly selected for the study. FLASHE dyad participants resided in all states except Alaska (Oh et al., 2017). FLASHE was reviewed and approved by the U.S. Government's Office of Management and Budget, the National Cancer Institute Special Studies IRB, and the Westat IRB. Among the 1,737 adolescents in FLASHE, 1,358 had complete data for MVPA. An additional 63 adolescents were excluded from analyses owing to missing data on demographics or neighborhood variables, leaving a final sample of 1,295 participants for these analyses. Statistical sample weights calculated for adolescents who completed the FLASHE physical activity survey were applied to help account for biases due to the use of a sample drawn from an online panel (National Cancer Institute, 2017).

2.2. Measures

Adolescent physical activity was defined as estimated weekly minutes of MVPA. Physical activity was assessed using the self-reported Youth Activity Profile (YAP), a 15-item questionnaire that assessed activity patterns both during and out of school the previous week. The YAP is a validated web-based self-report instrument (consistent with the survey mode) that could be calibrated with objectively measured physical activity (Saint-Maurice et al., 2015) and divided by during school and out of school times in the week. The school section includes items about activity while commuting to/from school, at physical education, recess/study breaks, and at lunch. The out-of-school section includes activity before school, after school, in the evening, and each Saturday and Sunday. The YAP was scored and calibrated to convert raw YAP scores to estimated minutes of MVPA. A calibration model was developed using data from a subset of FLASHE adolescents who participated in accelerometry data collection (Saint-Maurice et al., 2017). Adolescent demographics used as covariates in the regression models included age, gender, race/ethnicity, and parent education level.

Adolescent home addresses were geocoded, and neighborhoods were defined by a 400-meter street network buffer around the adolescent's home, representing an approximate 5-minute walk from each participant's home. A 400-meter buffer was chosen to be consistent with prior work in FLASHE (Patel et al., 2018) and its association with youth activity in past studies (Yin et al., 2013; Kontou et al., 2020); sensitivity analyses further revealed that nSES and each home environment walk factor were highly correlated across buffer sizes ranging from 400 to 1200 m. Street network buffers included in the publicly available GeoFLASHE data were generated using the Streetmap road network in ArcGIS (Streetmap USA, ESRI, 2014). Data from the US 2010 Census and American Community Survey (2010–2014 Estimates) were linked to each participant's home neighborhood to create a Neighborhood SES (nSES) Index and home neighborhood environment factors.

The nSES Index was calculated based on the Yost SES Index, with a higher score representing greater nSES (Yost et al., 2001). The nSES Index is a factor score created using principal component analysis (PCA) that included the following census tract level measures 1) occupation (% working class), 2) unemployment status (% $\geq$16 years who are unemployed), 3) poverty (% persons below 150% of poverty line), 4) income (median household income), 5) education (education index, weighted in school years), and 6) housing (median house value and median rent). Individual factor loadings for GeoFLASHE had the same direction and a similar order of magnitude compared to a similar national nSES Index (Yost et al., 2001). For neighborhoods spanning more than one census tract, the percentage of buffer area captured by each census tract was calculated and used to create a weighted average of the nSES Index for each buffer.

Home neighborhood environment factors ("neighborhood factors") were created following the methods established by Hoehner and colleagues (Perez et al., 2019; Hoehner et al., 2011). PCA was used to generate three neighborhood factors based on an analysis of 13 census tract measures from the 2010 Census and 2010–2014 American Community Survey (Table 1), including 1) high density, 2) older homes, and 3) shorter commutes (Perez et al., 2019). In our analysis, the three factors accounted for 75.1% of the variance in the walkability measures, compared to 70.5% of the variance in the study by Hoehner and colleagues. The variables contributing to each of the three factors was similar to but slightly modified from Hoehner and colleagues' interpretation (Perez et al., 2019). Neighborhood factors were reverse coded for ease of interpretation. Table 1 shows the factors, interpretation, and Census measures used. Each neighborhood was classified as 1) urban, 2) suburban, or 3) rural. Classification of the urban/rural environment of the buffer was based on 2010 Census data and categorized using the National Center for Education Statistics (NCES) urban-centric categories, with a 90% threshold used to determine when a buffer area had more than one type of development. Similar to nSES, for neighborhoods spanning more than one census tract, the percentage of buffer area captured by each census tract was calculated and used to create a weighted average of the home environment factor within each buffer.

2.3. Statistical analysis

We applied SAS PROC SURVEY procedures to estimate the weighted means or proportions for the socio-demographic, physical activity, and home neighborhood environment variables. Total MVPA data and continuous home neighborhood factors (density, neighborhood age, and commute times) were normally-distributed. We grand mean centered the neighborhood factors for ease of interpretation in the models. We categorized the nSES variable into quintiles for ease of interpretation in the interaction models, where 1 = lowest SES and 5 = highest SES.

We used multiple linear regression to examine associations between the home neighborhood factors and adolescent MVPA, and whether those associations were moderated by nSES. We did not find significant clustering at the neighborhood level (Moran's I (0.03–0.18)), thus we did not conduct a multilevel model; this approach was in line with previous work (Perez et al., 2019). Therefore, we conducted weighted linear regression assessing the associations of the home neighborhood environment variables (neighborhood factors and SES) with total MVPA, adjusting for adolescent age, gender, race/ethnicity, parent education, and neighborhood urban–rural location. To examine the moderating effects of nSES on the associations between the neighborhood factors and total MVPA, we tested two-way interactions between nSES and neighborhood factors (three interactions total). We tested interaction terms simultaneously and then used a backwards elimination approach to remove the least significant term ($p > 0.10$) until only those significant at $p < 0.05$ remained. We plotted significant interactions to show the associations of the neighborhood factors with total MVPA at each nSES quintile. We performed all statistical analyses using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina).

3. Results

The sample was almost evenly split across the three age groups and had an equal balance of boys and girls, and 46.5% of adolescents had a parent with a college degree or higher (Table 2). On average, the sample engaged in approximately 570 min of total MVPA/week (range: 357–915 min/week). Most respondents resided in suburban neighborhoods, followed by urban and rural neighborhoods.

All three home neighborhood factors were significantly associated with MVPA (Table 3). The adjusted main effects model showed that adolescents living in neighborhoods with high density (B(SE) = 9.22 (2.78), p = 0.001) and older homes (B(SE) = 4.42(1.85), p = 0.02) had greater estimated weekly minutes of MVPA. However, adolescents living in neighborhoods with shorter commute times (i.e., higher proportion of

Table 1
Description of the home neighborhood factors and associated measures.[1]

Home neighborhood factor and interpretation	Measures Used
High density area & non-auto commutes	
Higher population density	Population per square mile of area
More attached units (apartments)	% of units ≥ 5 attached
Fewer detached homes	% of units that are 1, detached
Fewer owner occupied homes	% of units/pop owner occupied
Smaller homes	Median number of rooms
Fewer commutes by personal transportation; more commutes by public transportation and walk/biking	% of commutes by car, truck or van; % of commutes by public transportation; % of commutes by walk or bike
Older homes	
More homes built before 1950	% of units built before1950
Fewer homes built after 1970	% of units built in 1970 or later
Earlier median year structure was built	Median year structure built
Short auto commutes	
More short commutes; fewer longer commutes	% of commutes < 20 min
	% of commutes ≥ 35 min
Fewer commutes by public transportation	% of commutes by public transportation
Lower population density	Population per square mile of area

[1] Population per square mile was from the U.S. Census, 2010. All other measures were from the American Community Survey, 2010–2014 Estimates

Table 2
Weighted characteristics of the adolescent sample (N = 1295). FLASHE, 2014[1].

Characteristic	Mean (SE) or %
Socio-demographics	
Age, years	
12–13	32.0
14–15	32.9
16–17	35.1
Female	50.4
Race/ethnicity	
Non-Hispanic White	55.1
Non-Hispanic Black	13.7
Non-Hispanic Other	14.0
Hispanic	17.2
Parent highest education	
High school degree/GED or less	18.9
Some college, no degree	34.6
College degree or higher	46.5
Total MVPA, minutes/week	569.45 (3.29)
Home neighborhood environment[2]	
Neighborhood factors	
Higher density	−0.17 (0.02)
Older homes	−0.20 (0.03)
Shorter commute time	−0.09 (0.03)
Socioeconomic status index	0.16 (0.03)
Urban-rural location	
Urban	38.7
Suburban	44.1
Rural	17.3

[1] FLASHE, Family Life, Activity, Sun, Health, and Eating study; GED, General Educational Development; MVPA, moderate to vigorous physical activity; SE, standard error.
[2] 400-meter network buffer around home location.

Table 3
Multivariate associations of home neighborhood factors and socioeconomic status (SES) with adolescents' total moderate to vigorous physical activity (N = 1295). FLASHE, 2014.[a]

Variable	B	SE	*p*-value
Home neighborhood environment			
Neighborhood factors			
Higher density [b,c]	**9.22**	**2.78**	**0.001**
Older homes [b,c]	**4.42**	**1.85**	**0.02**
Shorter commute times [b,c]	**−5.11**	**2.34**	**0.03**
Neighborhood SES			
Q1, lowest quintile	ref		
Q2	8.11	6.15	0.19
Q3	−0.37	6.22	0.95
Q4	8.04	6.53	0.22
Q5 (highest)	−4.23	7.42	0.57
Home urban–rural location (ref = Urban)			
Suburban	−0.05	4.29	0.99
Rural	−1.34	5.29	0.80
Socio-demographics			
Age, years (ref = 12–13)			
14–15	**−110.95**	**4.50**	**<0.0001**
16–17	**−226.02**	**4.30**	**<0.0001**
Male (ref = female)	**7.90**	**3.48**	**0.02**
Race/ethnicity			
Non-Hispanic white	ref		
Non-Hispanic Black	2.85	4.95	0.56
Non-Hispanic Other	1.61	6.02	0.79
Hispanic	5.07	5.96	0.39
Parent highest education			
College degree or higher	ref		
High school degree/GED or less	−4.04	5.26	0.44
Some college, no degree	−3.57	3.88	0.36

Bolded values are statistically significant. FLASHE, Family Life, Activity, Sun, Health, and Eating study; GED, General Educational Development; MVPA, moderate to vigorous physical activity; SE, standard error; SES = Socioeconomic Status.

[a] Model is weighted using four raking variables from the 2014 Current Population Survey Annual Social and Economic Supplement: age, gender, race/ethnicity, and Census region (National Cancer Institute, 2017).

[b] Variables are grand mean centered.

[c] To aid in interpretation of the neighborhood factor results, the standard deviations are 0.80 for higher density, 0.98 for older homes, and 0.91 for shorter commute time

working adult residents with short commutes, and fewer proportion of commutes by public transit) had lower estimated weekly minutes of MVPA (B(SE) = −5.11(2.34), p = 0.03). Neither nSES nor urban–rural location were significantly related to total MVPA.

The interaction models showed significant interactions of nSES with the neighborhood high density factor (interaction p = 0.02) and older homes factor (interaction p = 0.04). After probing the interactions at each nSES quintile, the positive association between living in a neighborhood with higher density and MVPA was only significant for those living in neighborhoods at the 3rd (B(SE) = 13.9(5.6), p = 0.02) and 4th (B(SE) = 19.1(4.1), $p < 0.0001$) nSES quintiles, compared with those in the lowest SES neighborhoods (quintile 1) (Fig. 1).

After probing the second interaction, the positive association between living in a neighborhood with older homes and MVPA was significant only for those residing in neighborhoods at the 2nd quintile of nSES (B(SE) = 16.2(4.1), p = 0.0001) (Fig. 2). The estimated slope for this interaction was significantly different compared to all other nSES quintiles.

4. Discussion

Guided by the social ecological model, this study first sought to examine the associations between neighborhood built environment indicators of walkability – high density, older homes, and shorter commutes – and adolescent MVPA. We then investigated whether the social environment, specifically nSES, had a moderating effect on these relationships. In this national sample of adolescents, our main effects model showed that residing in neighborhoods with higher population density and more older homes were each positively associated with MVPA, while shorter auto commute times were inversely associated with MVPA. Examination of interactions showed that nSES was a significant effect modifier of the associations of high density and older homes with MVPA, with significant associations found among those in the middle-to-high SES neighborhoods.

4.1. Associations between the home neighborhood environment and adolescent MVPA

From our main effects model, we found positive associations between MVPA and living in neighborhoods with higher density and older homes. This result is in line with findings from a study with adults (Hoehner et al., 2011), which found that older median home age was significantly associated with increased cardiorespiratory fitness and lower BMI and a higher density of homes was associated with lower BMI (Hoehner et al., 2011). Studies among Australian (Loh et al., 2019) and Spanish adolescents (Queralt and Molina-García, 2019) from the International Physical Activity and the Environmental Network (IPEN) Adolescent study also found residential density to be positively associated with MVPA. However, in subsequent analyses, we found that the positive associations of density and older homes with MVPA were only significant for those residing in middle-to-higher SES neighborhoods.

The main effects model also showed an inverse association between the short auto commutes factor and MVPA, contrary to what we expected. A study with adults found a positive association between shorter commute time and increased cardiorespiratory fitness (Hoehner et al., 2011). One explanation may be potential differences in behaviors between adults and adolescents, with adults being more likely to benefit from living in neighborhoods located closer to workplaces by providing more time available for exercise due to less commuting time. This association may also be explained by the inclusion of lower population density in the short auto commute factor, which has been associated with lower levels of physical activity among adolescents (Kowaleski-Jones et al., 2017); increased driving among older youth; utilization of public transit; or other factors (e.g., psychosocial or peer-level factors) not assessed in this study.

Other studies conducted among adolescents found positive associations between overall neighborhood walkability and MVPA. For example, in the aforementioned study among Australian adolescents in the NEighbourhood Activity in Youth (NEArbY) study, which is part of the IPEN Adolescent study, walkability was positively associated with MVPA within an even larger (1 km) buffer (Loh et al., 2019). The Teen Environment and Neighborhood (TEAN) study found that walkability was positively associated with MVPA as well as active transport to non-school destinations (Sallis et al., 2018). A study among 98 Mexican American adolescents found a positive association between living in more walkable neighborhoods and MVPA (Kligerman et al., 2007). However, the heterogeneity in the neighborhood walkability measures make comparisons across studies challenging. Future work towards common metrics for measuring neighborhood environment could address this challenge.

4.2. The moderating effects of nSES on the association between the home neighborhood environment and MVPA

The interaction models showed that nSES was a significant moderator of the association between the high density neighborhood factor and MVPA, with significant associations found only among adolescents living in the 3rd and 4th quintiles of nSES. Higher density in these middle-to-high SES neighborhoods may support MVPA by providing opportunities to be active with other neighborhood children. Middle-SES neighborhoods could have more physical activity resources (e.g. parks) than the lowest income neighborhoods, in addition to a built

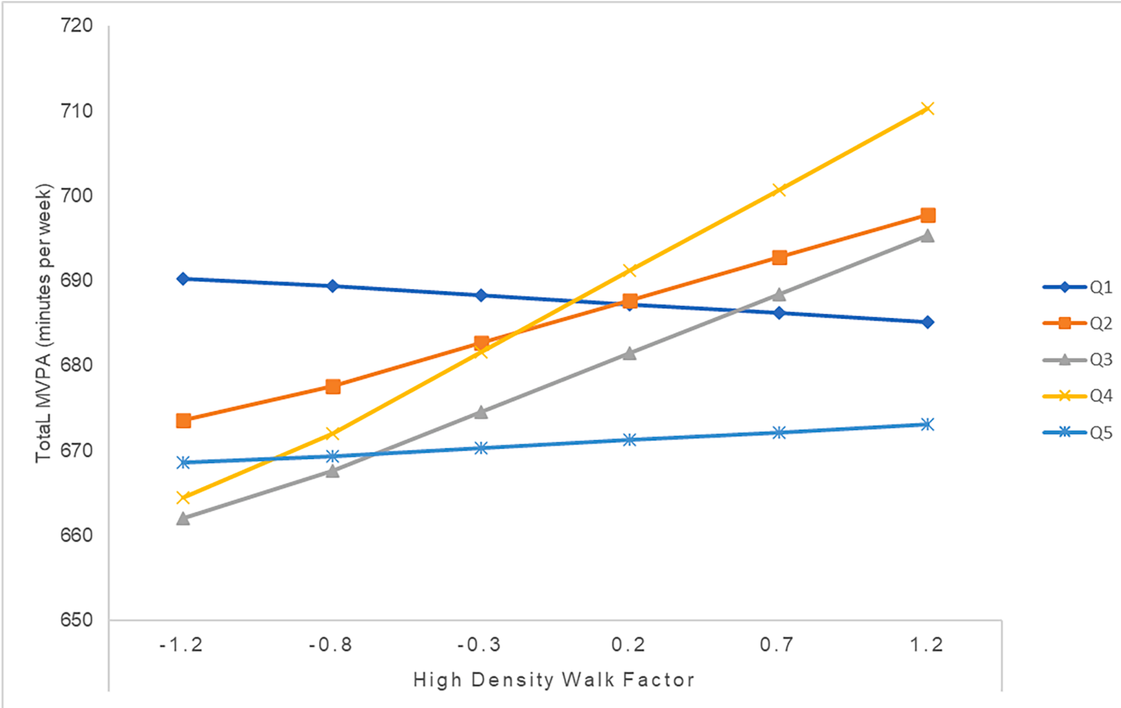

Fig. 1. Moderating effects of quintiles of neighborhood socioeconomic status (nSES) (Q1 = lowest to Q5 = highest) on the association between neighborhood high density factor and total moderate to vigorous physical activity among adolescents in the Family Life, Activity, Sun, Health, and Eating study, 2014. Significant interactions were found for quintiles 3 (B (SE) = 13.9 (5.6), p = 0.02) and 4 (B (SE) = 19.1(4.1), p < 0.0001) of nSES.

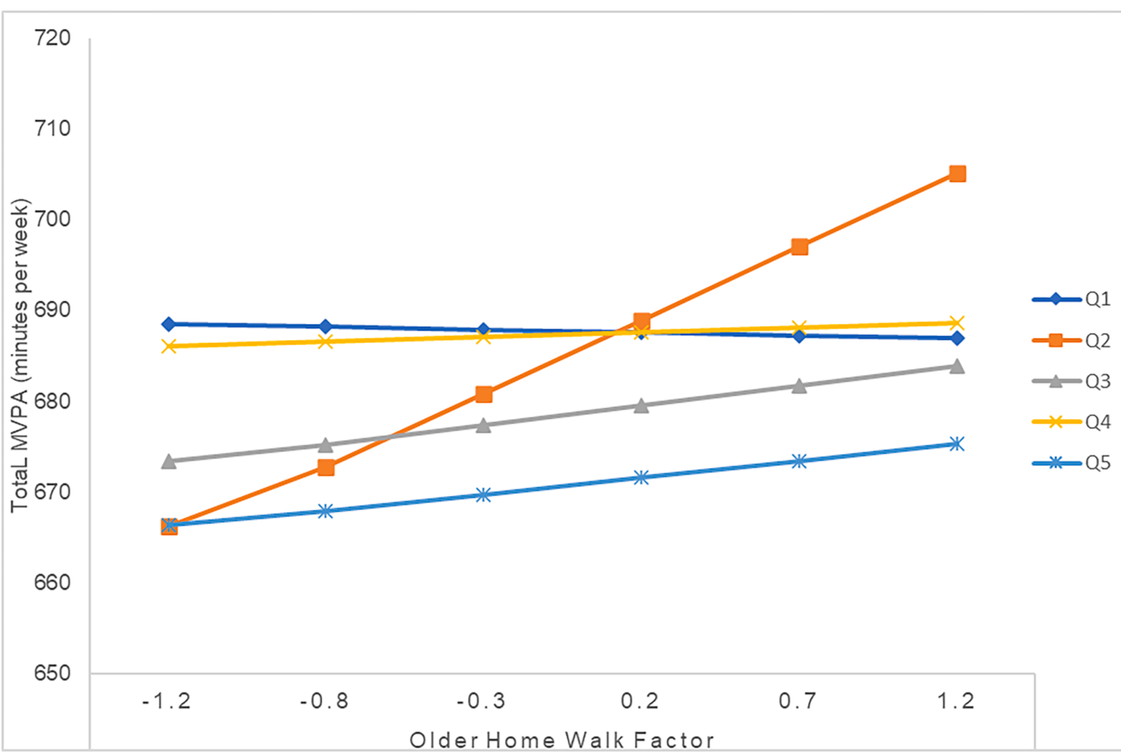

Fig. 2. Moderating effects of quintiles of neighborhood socioeconomic status (nSES) (Q1 = lowest to Q5 = highest) on the association between neighborhood older home factor and total moderate to vigorous physical activity among adolescents in the Family Life, Activity, Sun, Health, and Eating (FLASHE) Study, 2014. A significant interaction was found for quintile 2 of nSES (B (SE) = 16.2 (4.1), p = 0.0001).

environment supportive of physical activity (Gordon-Larsen et al., 2006). A possible explanation for the non-significant association in adolescents living in the highest income neighborhoods may be that they are less dependent on the walkability of their home neighborhood because they have greater access to physical activity resources beyond their neighborhoods (McGrath et al., 2016; Gordon-Larsen et al., 2006;

Koohsari et al., 2017). Further, the non-significant association in adolescents living in the lowest SES neighborhoods suggests that neighborhood density alone may not be sufficient to support physical activity for adolescents living in the lowest income neighborhoods.

The moderating effect of nSES on the association between the older homes neighborhood factor and MVPA showed a significant association only among those in the second quintile of nSES. To our knowledge, no published study has examined such an interaction in youth to help explain this association. However, a study with adults showed that living in older neighborhoods was related to a lower obesity risk in higher income neighborhoods compared to low-income neighborhoods (Zick et al., 2009). Research suggests that neighborhoods with older homes may be more pedestrian-friendly in urban areas and have greater street connectivity to support youth MVPA (Berrigan and Troiano, 2002). One possible explanation for our finding is that in middle-SES neighborhoods, residents of older homes may have more established social ties and social cohesion, which have been found to support youth physical activity (Carroll-Scott et al., 1982; Duke et al., 2012). However, evidence is limited and future studies are needed including data on social ties to examine this hypothesis. It is also possible that other unmeasured geospatial and social environmental factors are confounding this effect, such as neighborhood social capital (Kepper et al., 2019). Neighborhoods are complex and dynamic environments that may be characterized as both low SES and high social capital, where the benefits of social capital may buffer the negative association between low SES and MVPA (Loh et al., 2019; Cradock et al., 2009; Elgar et al., 2010). Future work may consider geospatial and mixed methods approaches to further investigate the mechanisms by which nSES moderates the relationship between neighborhood home age and physical activity in youth.

4.3. Strengths and limitations

A key strength of this study is that it used a national sample and geocoded participant's addresses which allowed for the examination of a greater variety of home neighborhood environments compared with studies of single geographic areas. Additionally, the home neighborhood for each adolescent was defined using GIS data to create unique street network buffers around each home address, and then linked to Census data to determine both neighborhood walkability and nSES. Though MVPA was self-reported, a validated physical activity measure was used to estimate physical activity and was calibrated with objective accelerometry data in a subset of participants.

Though FLASHE includes a national sample, it is not nationally representative such that we cannot generalize our findings to the entire US population. FLASHE is a cross-sectional study and therefore one cannot infer causality from the associations observed between the home neighborhood factors, nSES and MVPA. For this study, we also examined total MVPA, which includes MVPA performed outside of the home neighborhood environment (e.g., school context, sport practices, hiking). Further, there is a level of spatial uncertainty in the objective measures of walkability. We defined the neighborhood as a 400-meter buffer around the home, representing an approximate 5-minute walk. There are varying definitions of neighborhood size in the literature (Molina-García et al., 2017; Perez et al., 2017; Gordon-Larsen et al., 2006; Mitchell et al., 2016; Prins et al., 2011), which can lead to differential findings and raise the question of whether a true relationship exists between the neighborhood-level factor and behavior, or whether it is an artifact of the spatial definition selected. However, we do not believe this affected our findings, given that our sensitivity analysis found buffer sizes ranging from 400 to 1200 m to be highly correlated for both the nSES Index and for each home environment factor, indicating little differences in these measures across buffer sizes. Furthermore, the measures of walkability examined in this study were those available in the public GeoFLASHE dataset; though they are based on earlier work (Perez et al., 2019), we did not have access to personally identifiable information to construct and examine additional neighborhood variables. Lastly, although using a GIS measure offers the benefits of consistency and comparability across participants in this national study, adolescents' perceptions of their neighborhood boundaries may not match the objectively-defined buffers (Villanueva et al., 2016; Colburn et al., 2020). Engaging study participants to help define neighborhood boundaries can aid researchers in understanding what most impacts their decisions on MVPA and can help ground truth the built environment measures of walkability.

4.4. Future directions

Future studies are needed that build on these findings and use geospatial and mixed methods approaches to better understand why adolescents living in lower income neighborhoods with high walkability factors are not benefitting from this built environment feature in the same way as their peers in higher income neighborhoods. Past work also suggests a differential association between home neighborhood environment and MVPA for children and adolescents (McGrath et al., 2016, 2015). Although we could not examine this association due to the categorical reporting of age and limited age range of participants, future studies can consider examining whether associations are different for children compared with adolescents.

5. Conclusions

Our findings suggest that living in neighborhoods with attributes that support walkability is associated with higher levels of MVPA in a national sample of adolescents. However, the benefits of living in walkable neighborhoods were not distributed equally across nSES, with the lowest income neighborhoods showing no association with two home neighborhood factors important for physical activity. Given health disparities in obesity and chronic disease in lower income populations, understanding how neighborhood characteristics contribute to opportunities for adolescents to be physically active is critical for developing targeted MVPA interventions, particularly for those living in the lowest income neighbourhoods.

6. Data statement

FLASHE study datasets are free to the public and available for download at https://cancercontrol.cancer.gov/brp/hbrb/flashe-study/flashe-files.

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CRediT authorship contribution statement

Marissa M. Shams-White: Project administration, Visualization, Writing - original draft, Writing - review & editing. **Heather D'Angelo:** Conceptualization, Methodology, Project administration, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Lilian G. Perez:** Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Laura A. Dwyer:** Conceptualization, Visualization, Writing - review & editing. **David G. Stinchcomb:** Methodology, Formal analysis, Writing - review & editing. **April Y. Oh:** Conceptualization, Methodology, Resources, Visualization, Supervision, 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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