Journal of Transport & Health 38 (2024) 101855

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Neighbourhood walkability and body mass index in children: Evidence from the Millennium Cohort Study in Wales

Theodora Pouliou [a,*], Rebecca Pedrick-Case [a], Rowena Bailey [a], Anna Rawlings [a], Amy Mizen [a], Jo Davies [a], Gareth Stratton [b], Ronan A. Lyons [a,c], Ben Beck [c], Hayley Christian [d,e], Richard Fry [a], Lucy J. Griffiths [a]

[a] Population Data Science, Swansea University Medical School, Swansea, UK
[b] Research Centre in Applied Sports, Technology, Exercise and Medicine, Swansea University, Swansea, UK
[c] School of Public Health and Preventive Medicine, Monash University, Melbourne, Victoria, Australia
[d] Telethon Kids Institute, University of Western Australia, Perth, Western Australia, Australia
[e] School of Population and Global Health, The University of Western Australia, Perth, Western Australia, Australia

ARTICLE INFO

Keywords:
Children
Obesity
Walkability Index
Active Living Environments
Body Mass Index
Millennium Cohort Study

ABSTRACT

Background: Overweight and obesity in children continues to increase. Yet, the role of active transport, namely walking, in mitigating these trends remains unclear. This study examined the cross-sectional association between walkability and children's Body Mass Index (BMI) and how this varies by socio-economic and lifestyle characteristics.

Methods: We analysed BMI for 14-year-old children living in Wales from the UK Millennium Cohort Study. Children were categorised as healthy weight, overweight or obese using the British 1990 cut-off points. Walkability was assessed using the Wales Active Living Environments (WalALE) database, categorised as 1 (least walkable environments) to 5 (most walkable environments). We applied multinomial logistic regression analysis and adjusted for ethnicity, having a limiting longstanding illness, parental BMI, socio-economic circumstances, and lifestyle characteristics.

Results: Children were more likely to be obese if they lived in areas classed as more walkable in unadjusted analysis [Relative Risk Ratio (RRR) = 1.72 (95%CI = 1.15–2.58)] and following adjustment for ethnicity, limiting longstanding illness and parental BMI [RRR = 1.83 (95%CI = 1.12–3.00)]). Significant associations remained even after further adjustment for lifestyle characteristics and socio-economic circumstances [RRR = 1.76 (95%CI = 1.05–2.96)]. Further, children were more likely to be obese if their parents were overweight or obese and if they were living in poverty. Children were less likely to be obese if they spent 3 or more days per week in moderate-to-vigorous physical activity (MVPA) and if they ate breakfast every day vs. some days or never.

Conclusion: Findings demonstrate that walkable environments are not associated with lower rates of obesity in children, indicating that the relationship between the built environment and child health is complex and requires further study.

* Corresponding author. Swansea University Medical School, Swansea University, Swansea, SA2 8PP, Wales, UK.
E-mail address: T.Pouliou@swansea.ac.uk (T. Pouliou).

https://doi.org/10.1016/j.jth.2024.101855
Received 5 February 2024; Received in revised form 23 May 2024; Accepted 6 June 2024
Available online 21 June 2024

1. Introduction

Overweight and obese populations have become pressing global health concerns contributing to increased morbidity and premature mortality (Abarca-GÃ et al., 2017). The prevalence of overweight and obesity among children and young people aged 5–19 has also risen substantially from just 8% in 1990 to 20% in 2022 (World Health Organisation, 2024). Wales demonstrates the highest rates of childhood obesity in the UK with just over a quarter of children (26%) being overweight or obese in 2020–2021 (Crowther et al., 2022). For the first time in recent history, the increasing prevalence of severe obesity in children may have an impact on life expectancy, with the future youngest generations predicted to live less healthy and ultimately shorter lives than their parents (Olshansky et al., 2005; Daniels, 2006). Being overweight or obese has been linked to several adverse physical and mental health outcomes throughout the life-course. For example, overweight and obesity in children has been associated with increased risk of developing cardiovascular diseases, type II diabetes, cancer, as well as poorer mental health (Lauby-Secretan et al., 2016; Sarwer and Polonsky, 2016; Umer et al., 2017). The rising prevalence of overweight and obesity among children continues to be a persistent public health problem with consequences for physical and mental health, quality of life and life circumstances (Aune et al., 2016; Sarwer and Polonsky, 2016). The negative impacts of obesity also persist into adulthood, further impacting productivity, earnings, morbidity, and mortality (Horesh et al., 2021).

Overweight and obesity in children have complex aetiologies involving a range of factors, such as unhealthy diets, parental influence as well as impact of family as well as social and built environments (Yang et al., 2021). However, empirical evidence on the mechanisms through which the afore-mentioned factors influence obesity in children is lacking, as few studies have been able to control for individual and lifestyle characteristics, as well as socioeconomic and environmental factors. Moreover, it is challenging to untangle the numerous factors in the built environment that impact childhood overweight and obesity. One underexplored measure is walkability. Several measures of walkability have predominantly been used for adults (Paulo dos Anjos Souza Barbosa et al., 2019). The relationship between walkability and overweight and obesity in children remains convoluted as findings are mixed (Daniels et al., 2021; Yang et al., 2021; Malacarne et al., 2022). The main reason for this, is the lack of consensus in the selection of metrics for walkability assessment, despite the influence such a selection could have on the strength or even the consistency of the potential association between overweight and obesity and walkability (Ubiali et al., 2021). For example, Shahid and Bertazzon (2015) used the Walkscore index, while Wilding et al. (2020) adopted the walkability index originally developed by Frank et al. (2010).

More recently, a pan-Canadian measure of the active living environment (Can-ALE) was developed and has been recently applied as a measure of neighbourhood walkability. Can-ALE is readily accessible metric that has been used to study the association between neighbourhood walkability and obesity as well as self-rated health in Canada (Colley et al., 2019) and found a positive association between walkability and both measured obesity as well as self-rated health in adults. However, children may experience their environments, such as the immediate home-social environment as well as their neighbourhood built environment, differently than adults. Particularly, in adolescence, children become more independent in terms of exploring their neighbourhoods with less supervision from parents and therefore what constitutes a walkable environment for an adult might be completely differently from that of a child or young person. Further research is therefore needed to explore the association between walkability and overweight and obesity in children (particularly adolescents), taking into consideration, the individual, lifestyle as well as socio-economic characteristics. Using previously developed walkability metrics would provide further insight into the consistency of the association between walkability and overweight as well as obesity in children and allow us to examine how neighbourhood typologies operate in different regional contexts.

There is also a growing consensus that individual factors alone may be unable to slow and/or reverse current overweight and obesity trends at the population level, as individuals are embedded within social and built environments which play a significant role in shaping health. While the volume of literature exploring the determinants of overweight and obesity is expanding, gaps in research on the association between walkability and overweight and obesity in children, still offer important opportunities for further exploration and reporting of evidence across different geographical as well as social contexts. The aim of this study was to assess the feasibility and potential of linking the Wal-ALE database to Cohort data as well as to examine the association between neighbourhood walkability and children's Body Mass Index (BMI) and how this might be influenced by socio-economic circumstances and lifestyle characteristics. Most importantly, through the lens of the population health perspective (Evans and Stoddart, 1990; Evans et al., 1994), this study investigates overweight and obesity in children by incorporating aspects of the broader environments. Adopting this perspective could further improve our understanding of overweight and obesity in children, allowing us to point in evidence-driven policy directions.

2. Material and methods

2.1. Study design

This was a retrospective, cross-sectional observational study which utilised survey data from the Millennium Cohort Study (MCS) in the UK, linked to routinely collected geospatial data. All data were accessed and analysed via the Secure Anonymised Information Linkage (SAIL) Databank, a Trusted Research Environment (TRE), hosted at Swansea University (Ford et al., 2009; Jones et al., 2019). SAIL Databank does not receive or handle identifiable data. The identifiable or demographic elements (including name, address, and date of birth) are sent by the data provider to the Digital Health and Care Wales (DHCW) who operate as a trusted third party (TTP) to match and anonymise the records. Reliable record matching is important to preserve record integrity and identity in the anonymised datasets in the SAIL Databank. The matching algorithm has been devised with DHCW; it uses deterministic and probabilistic routines sequentially, and as a result of testing and refinement, high rates of matching accuracy (>90%) are regularly attained. At DHCW, the demographic data comprising of commonly recognised identifiers such as name and date of birth, are removed and replaced with an Anonymous Linking Field (ALF). This is an encrypted number unique to each person represented in the dataset, with no attributable meaning or currency outside the system. The ALF along with gender and minimal aggregated demographics (week of birth, Lower Super Output Area (LSOA) of residence) are sent to the SAIL Databank for recombination with the content elements of the dataset to enable linkage of records from various sources (full details of the anonymisation and linkage methodology are described elsewhere) (Ford et al., 2009; Lyons et al., 2009).

2.2. Data sources

The MCS is a UK-wide prospective study of children born between September 2000 and January 2002. The original cohort comprised 18,818 children (72% response rate) whose parents were first interviewed when their child was aged nine months old (Hawkes et al., 2007; Connelly and Platt, 2014). Home interviews were repeated at ages 3, 5, 7, 11, 14 and 17 years, with the latest one in 2023 at 23 years old. Detailed information regarding demographic, social, and health factors relating to the children and their families was obtained through home-based interviews (Connelly and Platt, 2014). Families' consent to link MCS information to routinely collected data was sought when the children were seven years old and is permitted up to the child's 14th birthday (Tingay

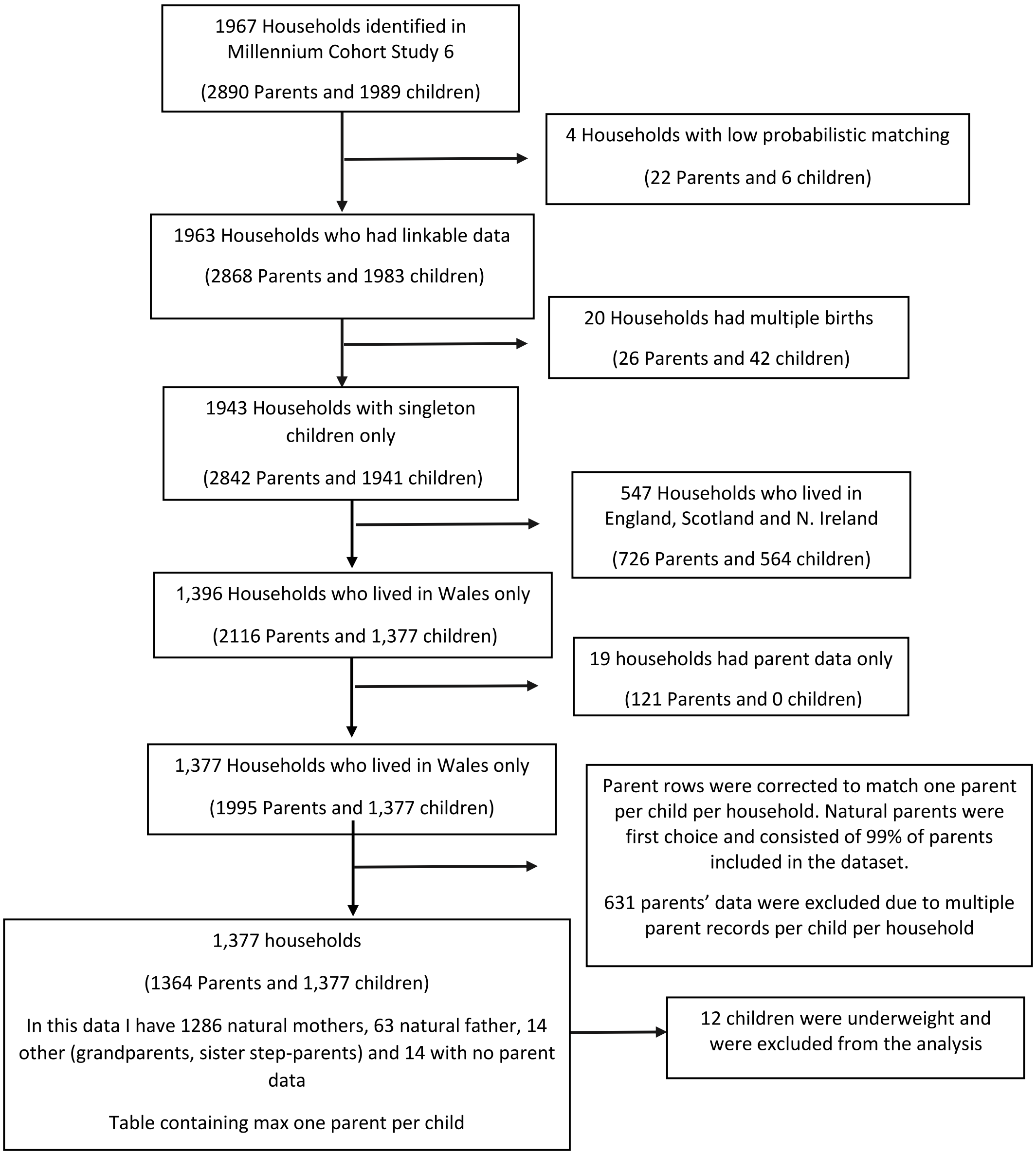

Fig. 1. Cohort consort diagram.

et al., 2019).

The Wales Active Living Environments (Wal-ALE) Database (Fry et al., 2018; Mah et al., 2022) contains data relating to the active living characteristics of the built environment in Wales, UK. A Walkability Index was created using Geospatial Information Systems (GIS) models, applying the identical protocol for the Can-ALE). The methodology for the Can-ALE has been described in detail elsewhere (Herrmann et al., 2019), but briefly, neighbourhoods were delineated using 1-Km Euclidean buffers around the centroids of dissemination areas (DA), which represent 400–700 persons and is the smallest geographic unit for which Canadian census data are released. The Wal-ALE was originally derived for Output Areas (OAs) corresponding to an average population of 300 people (with approximately 125 households) as this is roughly comparable to the Canadian DA. In Wales, the walkability measure was then aggregated from output areas (OAs) to LSOAs, which represent statistical zones equivalent to small neighbourhoods (∼1500 people) to reduce the risk of re-identification and allow linkage with the MCS data within the SAIL Databank.

Data on the road network and footpaths were downloaded from OpenStreetMap (OpenStreetMap Contributors, 2017) and used to calculate the density of ≥3-way intersections within each 1-Km Euclidean buffer to capture how well connected a neighbourhood is. The number of points of interest (e.g., location of schools, parks, and food outlets) within each buffer was also calculated using 2017 Open Street Map data, while dwelling density was calculated using data from the Office for National Statistics 2011 Usual Residents data as these were the earliest available datasets at point of analysis. Points of interest featured categories such as public places (e.g, library, nursing home), health sector (e.g., pharmacy, hospital), leisure (e.g., theatre, park), catering (e.g., restaurant, fast food), accommodation (e.g., hotel, shelter), shopping (e.g., supermarket, mall), tourism (e.g., museum, theme park) (more details can be found at (Geofabrik data, 2022)). Also, source code and documentation for Wal-ALE are freely available at https://envhe.gitlab.io/walkability/.

2.3. Participants

This study used data from the age 14-year MCS 2015–2016 survey (commonly referred to as MCS6) to match the period that environmental data were available as stated above. MCS participants who resided in Wales were selected as the analytical sample, to match the Wal-ALE data at the LSOA level. We restricted our sample to singletons, those matched on all identifiers or with more than 90% probabilistic matching as well as living in Wales. We also excluded children who were underweight and households that had no data relating to children. Our final sample consisted of 1377 households, with 1364 parents/carers (1349 natural parents and 14 carers such as grandparents) and 1377 children. Fig. 1 shows the sample selection process.

2.4. Outcome variable: Overweight/obesity status

At age 14, children were weighed without shoes or outdoor clothing by trained interviewers using Tanita HD305 scales (Tanita UK Ltd, Middlesex, UK). Weights were recorded in kilograms to one decimal place. Heights were also measured with the Leicester Height Measure Stadiometer (Seca Ltd, Birmingham, UK) and recorded to the nearest millimetre. The height and weight measures were used to calculate the BMI of the children (defined as child's weight in kilograms divided by their height in metres squared) and categorised according to the British 1990 growth reference (UK90) BMI cut-off points for overweight and obese and adjusted by sex and age (Cole et al., 1995), as recommended by the Scientific Advisory Committee on Nutrition (Tso, 2011) so, 2011). For the purposes of this study, we categorised children's BMI as healthy weight, overweight (85th centile) and obese (95th centile), using healthy weight category as the baseline for the models.

2.5. Exposure variable: Wales Active Living Environments Class

The Wal-ALE index was calculated from the sum of z-scores of intersection density, points of interest and dwelling density, resulting in either a positive or negative number (Fry et al., 2018; Mah et al., 2022). The selection of points of interest was consistent with the Can-ALE method of selecting amenities based on the relationship (positive or negative) to walking (see (Herrmann et al., 2019)). For the purposes of this study, we used the Wal-ALE class, which is a categorical measure of the Wal-ALE index (Fig. 2). To estimate the Wal-ALE class, raw scores for the three components (intersection density, points of interest and dwelling density) were clustered into

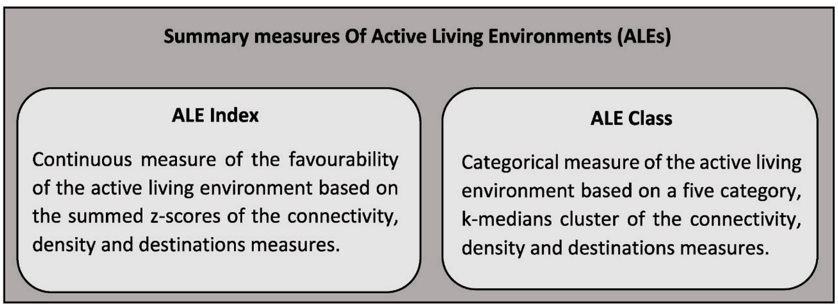

Fig. 2. Summary measure included in the Wal-ALE database based on the Can-ALE protocol (Herrmann et al., 2019; Mah et al., 2022).

five categories using k-medians clustering in R (Herrmann et al., 2019), ordering the categories by very low to very high index, from least favourable active living environments (lowest Wal-ALE class 1) to the most favourable active living environments (highest Wal-ALE class 5). We grouped the 'high' and 'very high' categories due to small numbers and used very low, low, moderate, and high active living, with the 'very low' category as the baseline for the models.

The geographical dispersion of the Wal-ALE class can be seen in the Map 1, which shows that walkability is a measure of urbanicity, and walkability is higher in urban areas.

Map 1. Walkability clusters in wales, UK.

2.6. Explanatory variables

Individual level characteristics included as potential confounders in the analysis were ethnicity (categorised as white; all other groups), and whether participants had a limiting longstanding illness (i.e., parents reported whether their child had any long-term conditions that limited their ability to perform daily activities). Parental BMI (based on parent's BMI) was also included as a confounder, obtained from MCS4 – 2007/08; the last objectively recorded BMI measure for parents. All individual characteristics were selected based on existing literature. We also examined the influence of several lifestyle and socio-economic characteristics that may affect the association between walkability and children's BMI. These were identified a priori from existing literature as covariates associated with BMI in children (Campbell, 2016; Chung et al., 2016; Malacarne et al., 2022). We classified those covariates in the following categories: lifestyle, socio-economic circumstances and environmental characteristics (Fig. 3).

Lifestyle covariates included: the number of days spent participating in Moderate to Vigorous Physical Activity (MVPA) last week (categorised as less than 3 days including no days of MVPA or 3 days or more); use of a bicycle (categorised as several times a week, at least once a month or less often or never); frequency of reading for enjoyment (categorised as most days, once a week, or once a month or less); days per week eats breakfast (categorised as every day or not). Socio-economic covariates included housing tenure (categorised as family owns their home, family rents their home) and numbers of cars in use (categorised as 1 car; and 1+ cars). We also used poverty (defined as those with below 60% of the national weekly median income, which was equal to £284 in 2014 (House of Commons Library, 2023)) and highest level of qualification in education based on National Vocational Qualifications (NVQs) which are practical work-based awards in the UK and are achieved through assessment and training. The NVQs categories were NVQ Level 1: General Certificate of Secondary Education (GCSE) below grade C; NVQ Level 2: GCSE grade A-C; NVQ Level 3: Advanced level qualifications (A levels) or subject-based qualifications; NVQ Level 4: First Degree, Post-graduate diplomas and certificates; NVQ Level 5: Higher Degree and Postgraduate qualifications; other qualifications including overseas). Finally, the environmental variables included were living in an urban area or not (Bibby and Brindley, 2013) and child's perception of neighbourhood safety (very safe; not safe).

2.7. Statistical analysis

Descriptive analysis included summary measures of the outcome presented as a categorical variable (healthy weight, overweight, and obese). We also compared the distribution of children's BMI classification (healthy weight, overweight and obese) by the walkability measure of Wal-ALE class. The lifestyle and socio-economic characteristics of the participants were also described. Categorical variables were presented as numbers and percentages within each group, while continuous variables were summarized using means and standard deviations.

Multinomial regression analysis was applied as the outcome variable being predicted was nominal and had more than two categories (healthy weight, overweight and obese). By keeping all three categories, we were able to quantify differences in the associations between neighbourhood walkability and overweight or obesity separately. As an initial step, univariate multinomial regressions were conducted to evaluate the unadjusted effects of neighbourhood Wal-ALE class on children's BMI categories.

Subsequent, successive multivariate multinomial regression analysis was carried out as follows: model 1 was fitted to examine the effect of Wal-ALE class as the predictor on BMI categories for children (healthy weight, overweight, and obesity) - this model was unadjusted; model 2 was adjusted for the set of confounders (ethnicity, limiting longstanding illness and parental BMI), and; model 3 was further adjusted for all other covariates based on the literature and their significance at univariate analysis.

Model coefficients were exponentiated and model outputs are presented as Relative Risk Ratios (RRRs) and corresponding 95% confidence intervals (90%CI). We interpreted statistical significance using a p-value <0.05. In a sensitivity analysis, we explored differences between urban/rural using an interaction between Wal-ALE index and urban/rural covariate.

3. Results

3.1. Descriptive analysis

The sample consisted of 680 (49%) boys and 697 (51%) girls (Table 1). Over 90% of children were white with all other categories

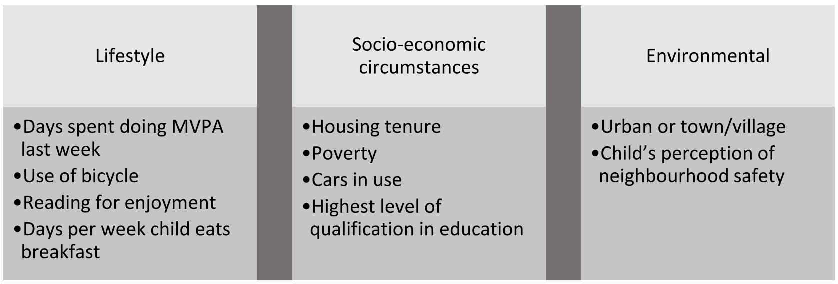

Fig. 3. Categories of covariate variables.

Table 1
Descriptive characteristics of the sample – number of singletons at age 14, living in Wales. Percentage presented in parenthesis.

General characteristics	Number (%)
Sex	
Boys	680 (49.38)
Girls	697 (50.62)
Child's ethnic group	
White	1260 (91.5)
Other	76 (5.52)
Child's BMI	
Underweight	12 (0.87)
Healthy Weight	788 (57.23)
Overweight	207 (15.03)
Obese	289 (20.99)
Child longstanding illness status	202 (14.67)
Parental BMI	
Healthy	598 (43.43)
Overweight	310 (22.51)
Obese	208 (15.11)
Lifestyle	
Days last week spent doing MVPA	
Less than 3 days including none	424 (30.79)
More than 3 days	917 (66.59)
Use of bicycle	
Several times a week	132 (9.59)
At least once a month	313 (22.73)
Less often or never	897 (65.14)
Reading for enjoyment	
Most days	260 (18.88)
Once a week	213 (15.47)
Once a month or less	866 (62.89)
Days per week child eats breakfast	
Never or some days	705 (51.20)
Every day	633 (45.97)
Socio-economic circumstances	
Poverty (<60% median income)	376 (27.31)
Cars in use	
One	457 (33.19)
More than one	857 (62.24)
Housing Tenure	
Own/mortgage	912 (66.23)
Rent, Other	433 (32.19)
Neighbourhood/Environmental characteristics	
Urban/Rural (objective)	
Urban (>10k)	948 (68.85)
Town or fringe	203 (14.74)
Village, hamlet, & isolated dwellings	169 (12.27)
Child's perception of safety	
Very safe/safe	1250 (90.78)
Not very safe/very unsafe	89 (6.46)
Wal-ALE classification (categorical)	
Very Low	369 (27.43)
Low	353 (26.25)
Moderate	358 (26.62)
High	265 (19.70)

Missing: Ethnicity, 41; Adolescents' BMI, 93; Child longstanding illness, 62; Parental BMI, 261; MVPA, 36; Use of bicycle, 35; Reading for enjoyment, 38; Days/week eats breakfast, 39; Poverty, 3; Cars in use, 63; Housing tenure, 32; Urban-Rural, 57; Adolescent's perception of safety in area, 38; Wal-ALE classification, 32.
BMI: Body Mass Index.
MVPA: Moderate to Vigorous Physical Activity.
Wal-ALE (Wales Active Living Environments).

grouped together due to small numbers. Approximately 1 in 7 children had a limiting longstanding illness. Over half of children had a healthy weight (57%), while 15% were overweight and 21% were obese. A little over half (54%) lived in either the 'very low' or 'low' walkability areas and 20% lived in the 'high' walkability areas.

In terms of lifestyle, almost two thirds of children (67%) reported spending more than 3 days participating in MVPA whereas 10% used a bicycle several times per week. In addition, 19% spent most days of the week reading for enjoyment and 46% ate breakfast every day. In terms of socio-economic circumstances, 27% of children were in poverty (<60% median income), 32% lived in rented or other accommodation and 62% were using more than one car in their household. Finally, 69% lived in urban areas with a population of more than 10k and 91% considered their area a safe place to play or live in.

The distribution of children's BMI classification (healthy weight, overweight and obese) by walkability is shown in Fig. 4. Higher obesity rates (26%) were found in high walkability areas compared to very low walkability areas (18%). Also, percentage of overweight children were slightly higher for moderate and high walkability areas compared to very low and low walkability areas. Finally, the percentage of children with healthy weight was lower in high (57%) compared to the very low (67%) and low walkability (60%) categories.

3.2. Unadjusted analysis - model 1

In unadjusted analysis, we found that there was no significant difference between overweight versus healthy weight across Wal-ALE classes (Table 2). Regarding being obese versus having healthy weight, the RRRs were 1.50 (95%CI = 1.03–2.20), 1.52 (95% CI = 1.04–2.23) and 1.72 (95%CI = 1.15–2.58) times higher accordingly, for the 'low', 'moderate' and 'high' Wal-ALE class compared with those in the 'very low' category.

3.3. Adjusted for confounders - model 2

When adjusted for confounders (Table 2) we found that being overweight was not significantly associated with any Wal-ALE classes. Children in the 'low', 'moderate' and 'high' Wal-ALE class categories were more likely to be obese than a healthy weight compared to those in the 'very low' Wal-ALE class category by 79%, 73% and 89% accordingly (all $p < 0.05$). Compared to model 1, when we adjusted for confounders, children's RRRs of being obese increased by 29%, 21% and 11% accordingly. Also, children were respectively 63%, 44% and 35% more likely to be obese than being overweight in the 'low', 'moderate', and 'high' Wal-ALE class categories compared to the reference category.

3.4. Adjusted for confounders and covariates - model 3

When adjusted for both confounders and covariates, children in the 'low', 'moderate', and 'high' Wal-ALE class categories were more likely to be obese by 75%, 70% and 76% accordingly, compared to those in the 'very low' Wal-ALE class category RRRs 1.75 (95%CI = 1.07–2.87), 1.70 (95%CI = 1.04–2.76) and 1.76 (95%CI = 1.05–2.96). Compared to model 2, when adjusted for confounders and covariates, children's RRRs of being obese decreased by 4%, 3% and 7% accordingly. Also, children were respectively 62%, 47% and 35% more likely to be obese than being overweight in the 'low', 'moderate', and 'high' Wal-ALE class categories compared to the 'very low' Wal-ALE class.

In terms of the covariates, as can been seen in Table 3, children were more likely to be overweight or obese if their parents were overweight RRRs 1.55 (95%CI = 1.03–2.33) and 2.08 (95%CI = 1.39–3.12) respectively. In addition, children were less likely (RRR = 0.65; 95%CI = 0.45–0.93) to be obese if they were spending 3 days or more per week on MVPA and ate breakfast every day (RRR =

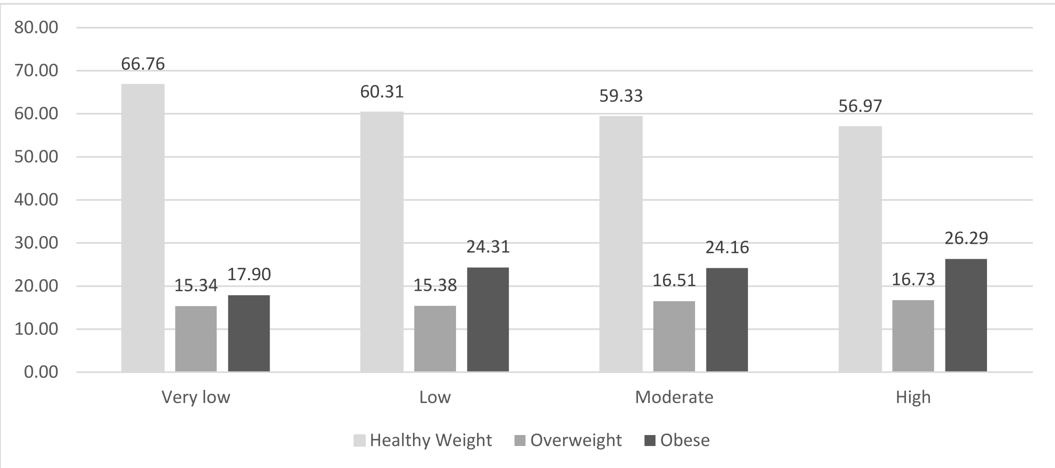

Fig. 4. Children's BMI category by Wal-ALE classification of walkability.

Table 2
Differences in adolescent's BMI status by Wales Active Living Environment classification.

Multi-nomial logit (healthy, overweight, obese)*	Model 1: Unadjusted				Model 1: Unadjusted				Model 2: adjusted for ethnicity, disability, parental BMI and exposure				Model 2: adjusted for ethnicity, disability, parental BMI and exposure			
EXPOSURE VARIABLE	Overweight				Obese				Overweight				Obese			
Wal-ALE Classification (categorical)	RRR	95%CI	95%CI	p-value	RRR	95%CI	95%CI	p-value	RRR	95%CI	95%CI	p-value	RRR	95%CI	95%CI	p-value
Very Low (Baseline category)	–	–	–	–	–	–	–	–	—	—	—	—	—	—	—	—
Low	1.11	0.72	1.70	0.63	**1.50**	**1.03**	**2.20**	**0.04**	1.10	0.67	1.82	0.70	**1.79**	**1.12**	**2.86**	**0.02**
Intermediate	1.21	0.79	1.85	0.37	**1.52**	**1.04**	**2.23**	**0.03**	1.20	0.73	1.96	0.47	**1.73**	**1.08**	**2.76**	**0.02**
High and very high	1.28	0.81	2.01	0.29	**1.72**	**1.15**	**2.58**	**0.01**	1.36	0.81	2.28	0.24	**1.83**	**1.12**	**3.00**	**0.02**

BMI: Body Mass Index.
Wal-ALE (Wales Active Living Environments).
RRR: Relative Risk Ratio.
95%CI: 95 percent confidence interval.
* Optimal is the baseline category.

0.55; 95%CI = 0.38–0.79). Further, children were more likely to be obese if their parent's income was less than 60% of the median income in Wales (RRR = 1.92; 95%CI = 1.29–2.86) or if their parents had more than one car (RRR = 1.47; 95%CI = 1.01–2.14).

Examining the adjusted R^2 statistics suggested that only 8% of children's BMI category could be explained by the environmental exposure, confounders, and covariates. From this, Wal-ALE class explained only 0.4% in the unadjusted model 1 and 4% when adjusted for confounders in model 2. Finally, the results of the sensitivity analysis exploring differences between urban vs rural using an interaction between them showed no significant association.

3.5. Supporting analysis on walkability

Considering the results above, further exploration of the socio-economic circumstances based on the Wal-ALE classification was applied. As can be seen in Fig. 5, higher poverty rates (31%) were found in high walkability areas compared to very low walkability areas (18%). For low and moderate walkability areas, percentages of poverty were 28% and 34% respectively. Differences in poverty rates were significant between very low and high Wal-ALE categories with Pearson chi^2 of 26.41 (p-value<0.05).

We also explored the days each child spent each week on MVPA based on the Wal-ALE classification to explore whether the walkability metric is associated with increased physical activity. Based on Fig. 6, it is shown that approximately 28% of children spent 3 or more days on MVPA in very low walkability areas compared to 19% in high walkability areas. Differences in MVPA were significant only between very low and high Wal-ALE categories.

Table 3
Differences in adolescent's BMI status after adjusting for confounders and covariates.

Multi-nomial logit (healthy, overweight, obese)	Model 3: Adjusted for ethnicity, disability, parental BMI, exposure and covariates				Model 3: Adjusted for ethnicity, disability, parental BMI, exposure and covariates			
EXPOSURE VARIABLE	Overweight				Obese			
	RRR	**95%CI**	**95%CI**	**p-value**	**RRR**	**95%CI**	**95%CI**	**p-value**
Child's ethnic group								
White	–	–	–	–	–	–	–	–
Other	1.05	0.48	2.31	0.90.	1.30	0.64	2.64	0.47
Child longstanding illness status								
Yes	0.84	0.50	1.41	0.51	0.98	0.61	1.58	0.94
Parental BMI								
Healthy	–	–	–	–	–	–	–	–
Overweight	**1.55**	**1.03**	**2.33**	**0.04**	**2.08**	**1.39**	**3.12**	**0.00**
Obese	1.15	0.67	1.99	0.61	**4.31**	**2.82**	**6.61**	**0.00**
Days last week spent doing MVPA								
Less than 3 days including none	–	–	–	–	–	–	–	–
More than 3 days	1.32	0.85	2.05	0.22	**0.65**	**0.45**	**0.93**	**0.02**
Use of bicycle								
Several times a week	–	–	–	–	–	–	–	–
At least once a month	**0.43**	**0.23**	**0.81**	**0.01**	0.80	0.40	1.08	0.54
Less often or never	0.65	0.37	1.12	0.12	1.29	0.70	2.40	0.41
Reading for enjoyment								
Most days	–	–	–	–	–	–	–	–
Once a week	0.65	0.36	1.18	0.16	0.60	0.33	1.08	0.09
Once a month or less	**0.58**	**0.37**	**0.91**	**0.02**	0.66	0.43	1.01	0.06
Days per week child eats breakfast								
Never or some days	–	–	–	–	–	–	–	–
Every day	1.02	0.70	1.49	0.90	**0.55**	**0.38**	**0.79**	**0.01**
Poverty								
(<60% median income)	1.06	0.67	1.70	0.79	**1.92**	**1.29**	**2.86**	**0.01**
Cars in use								
One	–	–	–	–	-	-	-	-
More than one	0.98	0.66	1.47	0.93	**1.47**	**1.01**	**2.14**	**0.05**
Wal-ALE classification (categorical)								
Very Low	–	–	–	–	–	–	–	–
Low	1.08	0.65	1.80	0.78	**1.75**	**1.07**	**2.87**	**0.03**
Moderate	1.16	0.70	1.91	0.56	**1.70**	**1.04**	**2.76**	**0.03**
High	1.30	0.76	2.20	0.34	**1.76**	**1.05**	**2.96**	**0.03**

*Optimal is the baseline category.
BMI: Body Mass Index.
Wal-ALE (Wales Active Living Environments).
RRR: Relative Risk Ratio.
95%CI: 95 percent confidence interval.

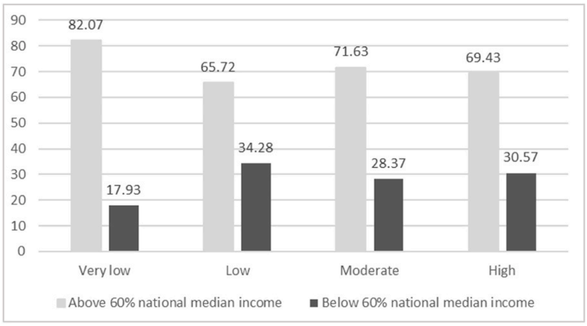

Fig. 5. Poverty indicator based on those above and below the 60% national median income by Wal-ALE classification of walkability.

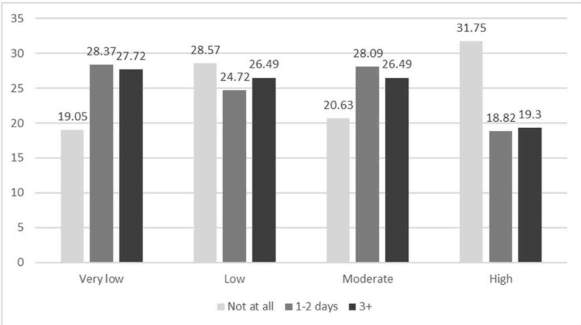

Fig. 6. Moderate to vigorous physical activity in children by Wal-ALE classification of walkability.

4. Discussion

4.1. *Summary of key findings*

This study examined the association between walkability and children's BMI category and how this might be affected by socio-economic circumstances and lifestyle characteristics. Findings demonstrated that children were more likely to be obese if they lived in areas classed as more walkable. Even after adjusting for lifestyle characteristics and socio-economic circumstances, the significant association remained. In addition, after adjustment, children were more likely to be obese if their parents were overweight or obese or if they were living in poverty. Conversely, children were less likely to be obese if they spent 3 days or more per week in MVPA, if they were reading less often for enjoyment or if they ate breakfast every day. On the other hand, there was no association between walkability and overweight.

This is the first study to link MCS data from Wales to an objective measure of walkability to investigate the potential influence of the built and socioeconomic environments as well as lifestyle characteristics on children's BMI category. Further, while the Can-ALE classification was positively associated with obesity in adults in Canada (Colley et al., 2019) this is the first known application of the Wal-ALE to children which demonstrates the feasibility and potential of the Wal-ALE database to study the association between walkability and overweight and obesity in children in Wales.

4.2. *Comparison with existing literature*

Our study demonstrated that obesity was higher in walkable compared to very low walkability areas. There are several insights that may help us understand these results. These findings support earlier evidence by Stowe et al. (2019) who also found that higher walkability (measured using the Walk-Score – a metric similar to the Wal-ALE class) in urban areas was associated with increased BMI z-scores in young people while the association was negative in rural areas (Stowe et al., 2019). This may seem counterintuitive, as one might assume that higher levels of walkability or more favourable active living environments should be associated with lower BMI and thus lower levels of overweight and obesity. However, neighbourhoods could be health-promoting (e.g., supermarkets, healthier school canteen choices, parks, leisure centres) or health-damaging (e.g., fast-food outlets) and this should also be considered as the inundation of unhealthy food provisioning in a neighbourhood can offset the health benefits derived from the walkability of the area (Mizen et al., 2018; Gonçalves et al., 2021). Mizen et al. (2018) have also confirmed this, by finding that homes in urban environments had a greater access and exposure to retail food outlets, which were in turn associated with excess weight in children aged 11–13 years. Further, a systematic review found that the quality of food provided or made available to children, played a crucial role on their BMI status. They found that the availability of healthy food provided by the school significantly decreased the odds of obesity in young people (Gonçalves et al., 2021). In our study, food outlets (fast-food, convenience stores) were included in the points of interest and thus in the estimation of the Wal-ALE class, confirming that the walkability measure could also capture health-damaging aspects of the built environment.

Walkability is fundamentally an urban concept that has been measured either by area-based metrics (i.e., walkability index is based on intersection and dwelling density as well as points of interest within area-level units such as LSOAs) or by network-based metrics that consider walkability as a measure of accessibility to nearby amenities (e.g., walk-score based on distance to food stores and public retail). For example, Ewing et al. (2003) showcased the correlation between obesity in adults and the built environment, using the county sprawl index that was derived with principal components analysis from census and other data and served as the built environment metric. Subsequently, Lopez (2004) explored this connection in US adults by using the urban sprawl index, which gauges the proportion of people residing in low and high-density areas on a scale of 0–100 with higher values indicating more sprawl. Lopez (2004) determined that with each 1-point rise in the urban sprawl index, the likelihood of obesity increased by 0.5%. Later, research has begun to shift towards examining more localized environmental indicators linked to overweight/obesity. For example, Frank et al. (2004) applied a measure of walkability, based on factors such as land-use mix, intersection density, and residential density. Specifically, the authors illustrated that the likelihood of obesity decreased by 4.8% with each additional kilometre walked per day and by 12.2% for every quartile increase in land-use mix. More recently, Stowe et al. (2019) used the Walk-score, a publicly available large-scale walkability database (Walk Score, 2024). Walk Score uses publicly available data to assign a score to a location based on the distance to and variety of nearby commercial and public frequently visited facilities.

Despite the various measures used to capture walkability, there are still challenges in elucidating the effects of walkable environments on childhood obesity, which is confirmed by our findings as well as by the recent review by Yang et al. (2021) who found that while many studies in their review reported that higher levels of walkability were associated with active lifestyles and healthy weight statuses, other studies did not support this association; this indicates that such measures may not capture all features of a walkable built environment. For example, the presence of green-blue space and access to natural environments have been linked with positive health outcomes (Mizen et al., 2019) and are characteristics of many rural neighbourhoods in Wales. Such rural features may contribute to the lower obesity rates we observed for those children living in neighbourhoods we measured as being "less walkable" based on the walkability measure applied.

While the association between children's BMI category and active living environments does not permit us to draw a solid conclusion about the health-promoting effects of living in walkable environments, it emphasizes however, that other features of the built environment could also be considered when attempting to explain the variance in children's BMI and walkability such as pedestrian infrastructure, accessibility to recreational facilities and food outlet density. Applying a methodology for measuring walkability in Wales – based on a metric that was developed and validated for a different country, makes strong assumptions about people interacting similarly in different various built environment contexts. However, findings imply that the combination of street connectivity, points of interest, and dwelling density are not features of health-promoting environments in Wales for adolescents specifically. While recognizing the broad advantages of walkability across diverse geographical settings, many reviews have highlighted the importance of using standardised measures across studies (Daniels et al., 2021; Yang et al., 2021), this could be problematic as location-specific factors may differ across regions or life stages.

Further supporting this, Mah et al. (2022), also using the Can-ALE and Wal-ALE classifications, found that adults in Canada living in high walkability neighbourhoods had lower odds of all-cause hospitalisation compared to Welsh individuals who exhibited higher odds, indicating also that neighbourhoods which promote walkability and potential healthier lifestyles in one geographic context may not do so in another, at least for adults. Colley et al. (2019) also examined the association between walkable neighbourhoods and obesity in Canada using the Can-ALE database and found no association between walkability and measured obesity in children or youth. These differences in findings demonstrate that environments that promote walkability and healthy BMI, differ by geography (e.g., Canada has lower dwelling density compared to Wales) highlighting the need to identify relevant context-specific factors that encourage active living (Colley et al., 2019). That is, we must consider the distinct historical and geographical contexts of Wales and Canada, which have greatly influenced their urban development and how people engage with their communities. Wales, has a population of 3.1 million spread across an area that's around half the size of the Netherlands while Canada has a population of 37.6 million, spanning almost 10 million square kilometres. In addition, the collapse of the coal and steel industries in the late 20th century has left parts of southern Wales facing economic hardships. However, South Wales remains the most densely populated and industrialized region in Wales, oriented toward the highly trafficked Severn estuary. Canadian cities on the other side, have emerged in areas with agricultural land and strategic trade positions near the Canada-United States border. The aforementioned differences in population size, geographic expanse, and historical background between Wales and Canada contribute to distinct patterns of urban density and points of interest across Can-ALE classes compared to Wal-ALE classes. These variations underscore the importance of considering the unique socio-cultural factors that have shaped each country's built environment.

Patterns of associations between overweight and obesity amongst children, and socio-economic as well as lifestyle covariates, were consistent both in direction of effect as well as significance. In terms of socio-economic circumstances, we found that children living in households with low income were more likely to be obese. Evans et al. (2012) also found that household income was inversely related to children's BMI. This adds to current research on the association between lower socio-economic circumstances and increased BMI in children and young people (Wu et al., 2015; Chung et al., 2016). For example, a systematic review by Chung et al. (2016) reported that over half of the included studies observed an increasing prevalence of BMI amongst children with low socio-economic position (SEP) compared to a third of studies among children with a high SEP.

In terms of lifestyle characteristics, our study showed that 67 percent of children spent 3 days or more per week in MVPA –

however, we cannot assume that those MVPA sessions were undertaken in the neighbourhood. For example, children might prefer to exercise indoors (e.g., recreation centre, gym, school physical education) or outside their neighbourhood rather than walking in their neighbourhood or accessing parks and green space for example. Car usage was also found to be positively associated with higher BMI in children; households using more than one car being more likely to be obese compared to households with one car. This, in combination with the negative association found for bike use, indicates that walking could be a mode of transport for the more disadvantaged (Bostock, 2001), supporting further literature on transport poverty and its implications on obesity (Awaworyi Churchill, Koomson and Munyanyi, 2023).

We also found that parental BMI was significantly associated with children's BMI category suggesting that parental influences are more important when investigating family lifestyle. This result supports previous literature which found that parental weight had the strongest influence between socio-economic circumstances and childhood weight when investigating a range of proxies for lifestyle (Lee et al., 2019).

Our results are largely in agreement with existing research, emphasising that BMI is influenced by many factors such as environmental and lifestyle characteristics as well as socio-economic circumstances in complex ways (see foresight and population health perspective (Evans et al., 1994; Butland et al., 2007). Key messages from our study include that the association between walkability and children's BMI categories is convoluted and that walkability metrics may not capture the prevalence of walking or what favours more walkable as well as health-promoting environments as these can be influenced by contextual factors in different geographical settings (Canada vs. Wales). Further, our study emphasizes that children and young people should have the opportunity to engage in MVPA while substantial improvements to underlying family lifestyle (improvement of parental BMI, regular breakfast, increase of bike use) could also have an impact on BMI in children. Recognition of the multilevel nature of obesity supports multi-level interventions that could include behavioural changes at home, comprehensive health education at school, and environmental changes in the community (Vo et al., 2019).

Our study provides a platform for future work that may explore an interaction between social and built environments that can help us gain a better understanding of the association between walkability and obesity in children. Further work is needed to explore walkable metrics as well as identify and understand other built environment characteristics that support healthy lifestyles (e.g., food outlet density, neighbourhood safety and aesthetics). For example, sensitivity analysis of multiple features of the built environment such as proximity as well as accessibility to facilities and services, land-use mix, population density and network design or neighbourhood safety and aesthetics could be considered in future studies. Longitudinal studies focused on children should also be prioritized, especially in disadvantaged areas, to help us develop a better understanding of associations between the built environment and overweight and obesity in children. Findings should be used to inform evidence-based planning policy on how to modify the built environment to promote child health in future generations by increasing better opportunities for diet and activity.

4.3. Strengths and limitations

Our study has several strengths, specifically the linkage of a rich, detailed cohort dataset with objectively measured environmental data, enabled through the SAIL Databank. To the best of our knowledge, this is the first time that MCS data from Wales have been linked to objectively-measured environmental data to examine the potential associations between the physical and socioeconomic environments as well as lifestyle characteristics on children's BMI category. Further, this is the first study to assess the feasibility and potential of the Wal-ALE database in Wales. The Can-ALE classification has been used as a proxy for what is widely referred to as the "walkability" of an area, and our study illustrates the potential of adopting the metric within Wales. The inclusion of objective measurements for both outcome and exposure, (i.e., measured height and weight for BMI as well as the Wal-ALE classification), adds validity to our analysis as these measurements reduce recall and reporting biases commonly associated with self-reported data. In addition, a standardised protocol for measuring height and weight was used, so that measurement error could be minimised. The study also benefits from a substantial sample of children in Wales. Focusing on Wales also provides a geographically specific context, which can be particularly valuable for policymakers and stakeholders in the region. Findings can inform targeted interventions and policies addressing the unique challenges faced by children living in Wales.

Acknowledged limitations include the non-representativeness of the sample and the potential bias this may introduce, especially if certain groups of children are less likely to participate or their families have not consented for their data to be linked, limiting the generalizability of the findings (Ipsos MORI Social Research Institute, 2017).In addition, since this study is for 14 years old singleton children from the MCS6 only, we expect that there were LSOAs with limited or no data, as this is an observational study using survey data and therefore findings should be interpreted with those limitations in mind. This was also a cross-sectional study and further research using a longitudinal study design would be required to identify temporal relationships between variables. In addition, self-reported measures of lifestyle characteristics and socioeconomic circumstances may be subject to recall and social desirability biases. Respondents may underreport unhealthy behaviours and over-report healthy behaviours, affecting the accuracy of the findings. However, patterns of associations between lifestyle characteristics and children's BMI category were consistent, at least in direction of effect in our study. For some variables, such as ethnicity, there was little variability to analyse. Further, while the study provides valuable insights into children's health in Wales, generalising findings to other regions or populations should be done cautiously. Cultural, social, and economic differences may impact the transferability of results. Finally, quantifying walkability using a predefined rubric cannot articulate other important features, such as the aesthetics of the land-scape or the presence of sidewalks that could significantly affect children's willingness to walk and exercise. Points of interest comprised in the walkability measure included amenities that could simultaneously be considered health-promoting or health-damaging (e.g., fast food outlets and supermarkets, leisure centres and convenience stores) or even irrelevant to the age-group of this study (e.g. location of primary schools, gyms etc.).

Aggregating the walkability measure from OAs to LSOAs to reduce risk of re-identification offset some of the impacts of the Modifiable Areal Unit Problem (MAUP) and ecological fallacies which would have been present if measured at LSOA level yet, they still exist. Future studies could examine the association between walkability and childhood obesity at the household-level metrics, as these were not available at the point of analysis. Using the same method of measuring walkability as a standard approach will allow for comparison with other studies as has been highlighted in recent reviews as the way forward in understanding the association between walkability and BMI in children (Daniels et al., 2021; Yang et al., 2021). Finally, we used 2017 OpenStreetMap data for the walkability measure, as this was the earliest available dataset at point of analysis to allow linking with the MCS6 (2015–2016) data within the SAIL databank; however, the difference in years is small and we did not expect any changes in the environment that would impact the findings of this study.

5. Conclusion

Overweight and obesity is a complex public health problem. Professor Dame Sally Davies, Chief Medical Officer for England in her 2019 report "Time to Solve Childhood Obesity: an independent report" stressed that the current obesity crisis is primarily due to children growing up in an obesogenic environment and that, to tackle childhood obesity, changes must be made to create a healthier environment across many different sectors (Independent Report by the Chief Medical Officer and Dame Sally Davies, 2019). The goal of the present study was to examine the association between a walkability measure -applied for the first time in Wales- and children's BMI taking into consideration the potential effects of several socio-economic characteristics and lifestyle behaviours. Findings showed that children were more likely to be obese if they lived in areas classed as more walkable, even after adjusting for socio-economic circumstances and lifestyle characteristics. Moreover, based on our findings, the use of more context specific and age-relevant built environment measures, is necessary (Giles-Corti et al., 2022).

This study provided an opportunity to explore the same metric (adjusted based on data availability) in two different countries. This study is work in progress as it lays the groundwork for more comparisons of walkability measures, pointing to the direction that future research could use multiple metrics to capture walkability at the individual, household or neighbourhood levels to improve methodology. This work confronts the limitations of our current understanding of walkability as well as the generalizability of associations with positive outcomes for health and health-related behaviours. It implies that designating a group of built environment features as determinants of walkable environments could be misguided if these features are not actually correlated with walkability in all areas. As it stands, the combination of street connectivity, destinations, and density does not capture what drives childhood obesity in Wales. While there is great value in acknowledging the widespread benefit of using a composite measure of walkability across a range of different geographies, there remains a need to identify relevant specific factors such as access to green space and neighbourhood safety that encourage active living.

Ethics statement

The MCS study has received ethical approval from the London Central Research Ethics Committee (13/LO/1786). All data within the SAIL Databank are treated in accordance with the Data Protection Act 2018 and comply with the General Data Protection Regulation, 2016 (SAIL, no date).

Statement on conflicts of interest

None to declare.

Data availability

The data sources are thoroughly detailed in the methods section and were accessed and analysed within a Trusted Research Environment (TRE). Due to the conditions of use, extracting data from the TRE is prohibited. Accredited researchers can apply to access the SAIL Databank through a governed approval process, which operates independently of the study authors (https://saildatabank.com/).

Financial disclosure

This work is part of the Built Environment and Child Health in Wales and Australia (BEACHES) project which is a joint initiative between Telethon Kids Institute, University of Western Australia and Swansea University. The BEACHES Project is funded by the UKRI-NHMRC Built Environment Prevention Research Scheme (grant number GNT1192764 and MR/T039329/1). Administrative Data Research (ADR) Wales also supported this research, which forms part of the ADR UK investment that unites research expertise from Swansea University Medical School and WISERD (Wales Institute of Social and Economic Research and Data) at Cardiff University with analysts from Welsh Government. ADR UK is funded by the Economic and Social Research Council (ESRC), part of UK Research and Innovation. Hayley Christian is supported by an Australian National Heart Foundation Future Leader Fellowship (102549) and partially supported by the Australian Government through the Australian Research Council's Centre of Excellence for Children and Families over the Life Course (Project ID CE200100025). Ben Beck was supported by an Australian Research Council Future Fellowship (FT210100183).

CRediT authorship contribution statement

Theodora Pouliou: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Rebecca Pedrick-Case:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Rowena Bailey:** Writing – review & editing, Methodology, Conceptualization. **Anna Rawlings:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Amy Mizen:** Writing – review & editing, Methodology, Funding acquisition, Data curation, Conceptualization. **Jo Davies:** Writing – review & editing, Data curation, Conceptualization. **Gareth Stratton:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Ronan A. Lyons:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Ben Beck:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Hayley Christian:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Richard Fry:** Writing – review & editing, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Lucy J. Griffiths:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

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.

Acknowledgments

We would like to acknowledge all data providers who make anonymised data available for research. We wish to acknowledge the collaborative partnership with the Centre for Longitudinal Studies (CLS) that enabled acquisition and access to the de-identified data, which led to this output. All research conducted has been completed under the permission and approval of the SAIL independent Information Governance Review Panel (IGRP) project number 1001.

References

Abarca-Gã, L., et al., 2017. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet 390 (10113), 2627–2642. https://doi.org/10.1016/S0140-6736(17)32129-3.

Aune, D., et al., 2016. 'BMI and all cause mortality: systematic review and non-linear dose-response meta-analysis of 230 cohort studies with 3.74 million deaths among 30.3 million participants'. The BMJ 353. https://doi.org/10.1136/BMJ.I2156.

Awaworyi Churchill, S., Koomson, I., Munyanyi, M.E., 2023. Transport poverty and obesity: the mediating roles of social capital and physical activity. Transport Pol. 130, 155–166. https://doi.org/10.1016/j.tranpol.2022.11.006.

Bibby, P., Brindley, P., 2013. The 2011 Rural-Urban Classification For Small Area Geographies: A User Guide and Frequently Asked Questions (v1.0).

Bostock, L., 2001. Pathways of disadvantage? Walking as a mode of transport among low-income mothers. Health Soc. Care Community 9 (1), 11–18. https://doi.org/10.1046/j.1365-2524.2001.00275.x.

Butland, B., et al., 2007. Foresight report - tackling obesities: future choices. www.foresight.gov.uk. (Accessed 24 May 2021).

Campbell, M.K., 2016. Biological, environmental, and social influences on childhood obesity. Pediatr. Res. 79 (1–2), 205–211. https://doi.org/10.1038/pr.2015.208.

Chung, A., et al., 2016. Trends in child and adolescent obesity prevalence in economically advanced countries according to socioeconomic position: a systematic review. Obes. Rev. 17 (3), 276–295. https://doi.org/10.1111/obr.12360.

Cole, T.J., Freeman, J.V., Preece, M.A., 1995. Body mass index reference curves for the UK, 1990. Arch. Dis. Child. 73 (1), 25–29. https://doi.org/10.1136/adc.73.1.25.

Colley, R.C., et al., 2019. An examination of the associations between walkable neighbourhoods and obesity and self-rated health in Canadians. Health Rep. 30 (9), 14–24. https://doi.org/10.25318/82-003-X201900900002-ENG.

Connelly, R., Platt, L., 2014. Cohort profile: UK Millennium cohort study (MCS). Int. J. Epidemiol. 43 (6), 1719–1725. https://doi.org/10.1093/ije/dyu001.

Crowther, H., et al., 2022. Child measurement programme 2020-2021. Available at: www.publichealthwales.org/. (Accessed 24 June 2022).

Daniels, K.M., et al., 2021. The built and social neighborhood environment and child obesity: a systematic review of longitudinal studies. Prev. Med. 153, 106790 https://doi.org/10.1016/J.YPMED.2021.106790.

Daniels, S.R., 2006. The consequences of childhood overweight and obesity. Future Child. 16 (1), 47–67. https://doi.org/10.1353/FOC.2006.0004.

Evans, G.W., et al., 2012. Family income and childhood obesity in eight European cities: the mediating roles of Neighborhood characteristics and physical activity. Soc. Sci. Med. 75 (3), 477–481. https://doi.org/10.1016/j.socscimed.2012.03.037.

Evans, R.G., Barer, M.L., Marmor, T.R., 1994. In: Evans, Robert G., Barer, Morris L., Marmor, Theodore R. (Eds.), Why Are Some People Healthy and Others Not?. De Gruyter. https://doi.org/10.1515/9783112421628.

Evans, R.G., Stoddart, G.L., 1990. Producing health, consuming health care. Soc. Sci. Med. 31 (12), 1347–1363. https://doi.org/10.1016/0277-9536(90)90074-3.

Ewing, R., et al., 2003. Relationship between urban sprawl and physical activity, obesity, and morbidity. Am. J. Health Promot. : AJHP 18 (1), 47–57. https://doi.org/10.4278/0890-1171-18.1.47.

Ford, D.V., et al., 2009. The SAIL Databank: building a national architecture for e-health research and evaluation. BMC Health Serv. Res. 9 (1), 157. https://doi.org/10.1186/1472-6963-9-157.

Frank, L.D., et al., 2010. The development of a walkability index: application to the Neighborhood Quality of Life Study. Br. J. Sports Med. 44 (13), 924–933. https://doi.org/10.1136/bjsm.2009.058701.

Frank, L.D., Andresen, M.A., Schmid, T.L., 2004. Obesity relationships with community design, physical activity, and time spent in cars. Am. J. Prev. Med. 27 (2), 87–96. https://doi.org/10.1016/J.AMEPRE.2004.04.011.

Fry, R., et al., 2018. Measuring active living environments: an international comparison between Canada and Wales. International Journal of Population Data Science 3 (2). https://doi.org/10.23889/ijpds.v3i2.523.

Geofabrik data, 2022. OpenStreetMap data in layered GIS format. https://www.geofabrik.de/data/geofabrik-osm-gis-standard-0.7.pdf. (Accessed 15 May 2024).

Giles-Corti, B., et al., 2022. Creating healthy and sustainable cities: what gets measured, gets done. Lancet Global Health 10 (6), e782–e785. https://doi.org/10.1016/S2214-109X(22)00070-5.

Gonçalves, V.S.S., et al., 2021. The food environment in schools and their immediate vicinities associated with excess weight in adolescence: a systematic review and meta-analysis. Health Place 71, 102664. https://doi.org/10.1016/j.healthplace.2021.102664.

Hawkes, D., Hughes, G., Joshi, H., 2007. The Millennium Cohort Study: Technical Report on Sampling 4th Edition Ian Plewis with Contributions from Lisa Calderwood Centre for Longitudinal Studies. Available at: www.ioe.ac.uk/bedfordgroup. (Accessed 12 September 2023).
Herrmann, T., et al., 2019. A pan-Canadian measure of active living environments using open data. Health Rep. 30 (5), 16–25. https://doi.org/10.25318/82-003-x201900500002-eng.
Horesh, A., et al., 2021. Adolescent and childhood obesity and excess morbidity and mortality in young adulthood—a systematic review. Current Obesity Reports 10 (3), 301–310. https://doi.org/10.1007/s13679-021-00439-9.
House of Commons Library, 2023. Poverty in the UK: Statistics.
Independent Report by the Chief Medical Officer, A, Dame Sally Davies, P., 2019. Time to Solve Childhood Obesity.
Ipsos MORI Social Research Institute, 2017. Millennium Cohort Study Sixth Sweep (MCS6) Technical Report - Prepared for the Centre for Longitudinal Studies.
Jones, K.H., et al., 2019. A profile of the SAIL databank on the UK secure research platform. International Journal of Population Data Science 4 (2). https://doi.org/10.23889/ijpds.v4i2.1134. Available at:
Lauby-Secretan, B., et al., 2016. Body fatness and cancer — viewpoint of the IARC working group. N. Engl. J. Med. 375 (8), 794–798. https://doi.org/10.1056/NEJMsr1606602.
Lee, C.Y., et al., 2019. Association of parental body mass index (BMI) with child's health behaviors and child's BMI depend on child's age. BMC Obesity 6 (1), 11. https://doi.org/10.1186/s40608-019-0232-x.
Lopez, R., 2004. Urban sprawl and risk for being overweight or obese. Am. J. Publ. Health 94 (9), 1574–1579. https://doi.org/10.2105/AJPH.94.9.1574.
Lyons, R.A., et al., 2009. The SAIL databank: linking multiple health and social care datasets. BMC Med. Inf. Decis. Making 9 (1), 3. https://doi.org/10.1186/1472-6947-9-3.
Mah, S.M., et al., 2022. An international comparative study of active living environments and hospitalization for Wales and Canada. SSM - Population Health 18, 101048. https://doi.org/10.1016/J.SSMPH.2022.101048.
Malacarne, D., et al., 2022. The built environment as determinant of childhood obesity: a systematic literature review. Obes. Rev. 23 (S1) https://doi.org/10.1111/obr.13385.
Mizen, A., et al., 2018. Linking environment and health data to investigate the association between access to unhealthy food and child BMI. International Journal of Population Data Science 3 (4). https://doi.org/10.23889/ijpds.v3i4.906.
Mizen, A., et al., 2019. Longitudinal access and exposure to green-blue spaces and individual-level mental health and well-being: protocol for a longitudinal, population-wide record-linked natural experiment. BMJ Open 9 (4). https://doi.org/10.1136/bmjopen-2018-027289.
Olshansky, S.J., et al., 2005. A potential decline in life expectancy in the United States in the 21st century. N. Engl. J. Med. 352 (11), 1138–1145. https://doi.org/10.1056/NEJMSR043743/SUPPL_FILE/1138SA1.PDF.
Paulo dos Anjos Souza Barbosa, J., et al., 2019. Walkability, overweight, and obesity in adults: a systematic review of observational studies. Int. J. Environ. Res. Publ. Health 16 (17), 3135. https://doi.org/10.3390/ijerph16173135.
Sarwer, D.B., Polonsky, H.M., 2016. The psychosocial burden of obesity. Endocrinol Metab. Clin. N. Am. 45 (3), 677. https://doi.org/10.1016/J.ECL.2016.04.016.
Shahid, R., Bertazzon, S., 2015. Local spatial analysis and dynamic simulation of childhood obesity and neighbourhood walkability in a major Canadian city, 2(4), pp. 616–637. https://doi.org/10.3934/publichealth.2015.4.616.
Stowe, E.W., et al., 2019. Associations between walkability and youth obesity. Differences by Urbanicity 15 (8), 555–559. https://doi.org/10.1089/CHI.2019.0063. https://home.liebertpub.com/chi.
Tingay, K.S., et al., 2019. Record linkage to enhance consented cohort and routinely collected health data from a UK birth cohort. International Journal of Population Data Science 4 (1). https://doi.org/10.23889/IJPDS.V4I1.579.
Tso, L., 2011. Dietary reference values for energy scientific advisory committee on nutrition 2011. Available at: www.sacn.gov.uk. (Accessed 25 April 2023).
Ubiali, A., et al., 2021. Measures of walkability in the pediatric population: a qualitative review of the literature. Ann. Ig. Med. Preventiva Comunita 33 (1). https://doi.org/10.7416/ai.2021.2409.
Umer, A., et al., 2017. Childhood obesity and adult cardiovascular disease risk factors: a systematic review with meta-analysis. BMC Publ. Health 17 (1), 683. https://doi.org/10.1186/s12889-017-4691-z.
Vo, L., Albrecht, S.S., Kershaw, K.N., 2019. Multilevel interventions to prevent and reduce obesity. Current Opinion in Endocrine and Metabolic Research 4, 62–69. https://doi.org/10.1016/j.coemr.2018.11.002.
Walk Score, 2024. Live where you love. https://www.walkscore.com/. (Accessed 19 May 2024).
Wilding, S., et al., 2020. Are environmental area characteristics at birth associated with overweight and obesity in school-aged children? Findings from the SLOPE (Studying Lifecourse Obesity PrEdictors) population-based cohort in the south of England. BMC Med. 18 (1), 1–13. https://doi.org/10.1186/S12916-020-01513-0/TABLES/2.
World Health Organisation, 2024. Obesity and overweight: fact sheets. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. (Accessed 26 October 2023).
Wu, S., et al., 2015. Socio-economic position as an intervention against overweight and obesity in children: a systematic review and meta-analysis. Sci. Rep. 5 https://doi.org/10.1038/srep11354.
Yang, S., et al., 2021. Walkability indices and childhood obesity: a review of epidemiologic evidence. Obes. Rev. 22 (S1) https://doi.org/10.1111/obr.13096.

Glossary

(BMI): Body Mass Index
(SAIL) Databank: Secure Anonymised Information Linkage
(TRE): Trusted Research Environment
(ALF): Anonymised Linkage Field
(MCS): Millennium Cohort Study
(ALEs): Active Living Environments
(DHCW): Digital Health and Care Wales
(TTP): Trusted Third Party
(Wal-ALE): Wales Active Living Environments
(Can-ALE): Canadian Active Living Environments
(GIS): Geospatial Information System
(ONS): Office for National Statistics
(OAs): Output Areas
(LSOAs): Lower Layer Super Output Areas
(DAs): Dissemination Areas
(UK90): British 1990 growth reference
(MVPA): Moderate to Vigorous Physical Activity
(RRRs): Relative Risk Ratios
(NVQs): National Vocational Qualifications
(GCSE): General Certificate of Secondary Education
(MAUP): Modifiable Areal Unit Problem