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Cycling infrastructure and deprivation: An empirical investigation

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ABSTRACT

Background: Under the Active Travel (Wales) Act 2013, local authorities in Wales must construct new cycling infrastructure and multi-use lanes. Using Cardiff as its geographic focus, this study aims to: (1) examine the distribution of cycling infrastructure across neighbourhoods based on their relative deprivation, (2) assess change in levels of active commuting and cycling frequency among Cardiff residents differ by deprivation group, and (3) identify whether cycling infrastructure is associated with cycling when controlling for sociodemographic and environmental factors.

Methods: This study utilised quantitative methods to analyse linked data across the National Survey for Wales, the Welsh Index for Multiple Deprivation, and geospatial data of cycling infrastructure. The study analysed differences in infrastructure across deprivation groups and change in active travel. Mixed logistic regression models examined associations of cycling infrastructure with active travel after controlling for sociodemographic and environmental characteristics.

Results: Cycling infrastructure has been equally distributed by area deprivation, however, a high percentage of most-deprived area had zero bike lanes. From 2018 to 19 to 2019-20, active commuting increased, and private motorised transport decreased ($\chi^2 = 15.16$, $p < 0.01$), but mainly among people in the middle deprivation group ($\chi^2 = 18.3$, $p < 0.01$). Between 2016-17 and 2018-19, cycling frequency did not change significantly. When controlling for individual socio-demographic factors, the length of cycle lanes was not associated with the odds of active commuting, though access to services and distance to work remained its key predictors.

Conclusions: Findings from this study provide evidence on the equity of cycling infrastructure deployment in Cardiff and offer insights into where and for whom travel behaviours are becoming more sustainable. Results enable city leaders and policymakers to target ongoing and future active travel interventions towards those subgroups and geographic areas in which they will make the most impact, and tailor them to maximise benefit.

1. Background

Improving people's ability to walk or cycle (active travel) has the potential to reduce carbon emissions (Bearman and Singleton, 2014; Elliot et al., 2018), improve air quality (de Nazelle et al., 2010; Keall et al., 2018), improve mental (Porter, 2017) and physical health (Saunders et al., 2013; Woodcock et al., 2009), and reduce inequalities. Additionally, vulnerable populations often feel the negative externalities of cars (e.g., air pollution) disproportionately (Barnes et al., 2019; Fecht et al., 2015), despite lower car

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ownership and use among people in the lowest income brackets (Porter, 2017; SDC, 2011) and lower emissions per capita (Barnes et al., 2019). Therefore, efforts to reduce transport emissions by increasing the proportion of active travel trips can help to reduce inequalities in emissions exposure. Neighbourhoods that are conducive to active travel can also help to bridge socioeconomic divides by removing car ownership as a barrier to access essential resources and services (Lucas, 2012). Understanding how to promote and support active travel effectively and equitably is important for urban planners and city officials to leverage its many benefits to improve public health.

In this paper, we examine these interrelationships and drivers across three themes (Fig. 1): (1) cycling infrastructure and deprivation; (2) active commuting, cycling frequency and deprivation, and (3) the role of cycling infrastructure on active commuting and cycling frequency. The following subsections provide a brief but critical overview of the above three themes.

1.1. *Theme 1 – cycling infrastructure and deprivation*

Several studies draw attention to the importance of ensuring that efforts to promote sustainable development are equitably implemented (Aldred et al., 2019; Braun et al., 2019; Flanagan et al., 2016) and do not exacerbate existing disparities (Kiani et al., 2024). While these studies have increased in the past decade, there remains a paucity of research investigating disparities in access to cycling infrastructure (e.g., bike and pedestrian lanes), particularly in the UK. Those that have examined these disparities have suggested a positive relationship between certain measures of a neighbourhood's socioeconomic status (SES) and access to, or investment in, cycling infrastructure, although mixed findings have been reported as well. For example, a study of 22 US cities found that composite SES (which includes 17 variables from the American Community Survey "related to race and ethnicity, educational attainment, income and wealth, poverty, occupation, employment, and housing") and educational attainment were positively associated with access to bike lanes, while the proportion of Hispanic residents was negatively associated (Braun et al., 2019, pp. 4 & 7). Similarly, a recent systematic review of US studies found larger concentrations of "African Americans, Hispanics, Asians, low-wage employees, individuals with lower education, and older adults" in communities with poor access to bike infrastructure (Sadeghvaziri et al., 2024). However, the proportion of Black residents, median income, and poverty had mixed associations with access to cycling infrastructure in another study (Braun et al., 2019). A longitudinal study from Portland, Oregon and Chicago, Illinois found that neighbourhoods with lower income and lower housing prices, but with incoming wealthier populations, were associated with higher cycling infrastructure investment in both cities (Flanagan et al., 2016). Neighbourhoods with incoming white residents were also associated with higher investment, while those with over 40% minority populations were associated with lower investment. In another study of four US cities, Hirsch et al. (2017) also found increases in cycle lanes to be associated with increases in indicators of socioeconomic affluence (e.g., median household income).

Considering the health and economic benefits associated with active travel, the inequitable distribution of the infrastructure that makes active travel possible could exacerbate existing disparities and is therefore important to monitor. Understanding this relationship is critical to determining whether new infrastructure is being implemented equitably and could help guide future investment and the selection of priority investment areas. It would also address a gap in the literature examining how active travel infrastructure varies by neighbourhood sociodemographic qualities.

1.2. *Theme 2 – active commuting, cycling frequency, and deprivation*

To devise the most effective policy, it is important to understand *who* is and is not adopting active travel behaviours. Associations between indicators of SES and active travel vary by geographic region and type of active travel (e.g., cycling vs. walking), and previous research suggests that in certain contexts, the direction of association is changing. Several studies reported that lower income and higher deprivation were associated with higher likelihood of walking (Agrawal and Schimek, 2007; Brainard et al., 2019; Dėdelė et al., 2020), but two studies suggested that this association was weakening (Goodman, 2013; Yu and Wang, 2020). Yu and Wang (2020), using data from the US National Household Travel Survey, found that the proportion of low-income and minority adults, and those with low education who walked to work, decreased from 2009 to 2017, despite nominally increased levels in the sample. Similarly, a study of trends in travel mode to work in England and Wales found that the gap between high and low affluence decreased in all

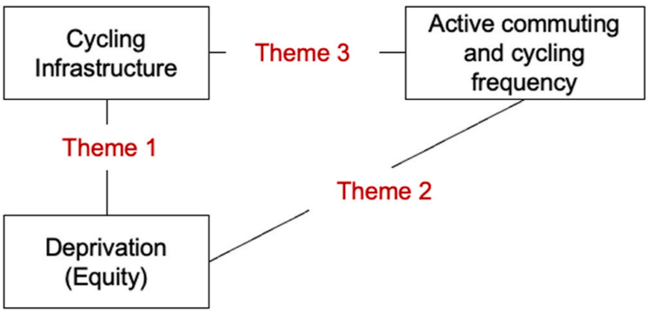

Fig. 1. Cross cutting themes under investigation in this study.

categories of active travel since 2001 (Goodman, 2013). Although similar studies in Lithuania (Dėdelė et al., 2020) and Bangladesh (Jamal et al., 2020) reflect a negative association between cycling and SES, studies across the UK, US, and Canada found that cyclists were more likely to have higher SES (Martin et al., 2021; Goodman et al., 2012) and that cycling was concentrated near universities and in gentrified areas (Pucher et al., 2011).

These findings may correlate with investments in active travel infrastructure skewing towards high-income areas, but more research is needed to understand *where* and *for whom* rates of active travel are increasing. Understanding patterns of active travel among population sub-groups (such as those identified and SES; e.g., Pucher et al., 2011) could lead to more effective active travel interventions. Differences in findings between and within countries also emphasise the need for international active travel research to better understand which interventions would be most effective in each context. Along these lines, Adlakha et al. (2018) stressed caution when applying findings from one country or city to another. For example, a health impact assessment study of Los Angeles neighbourhoods found that although cycling improved health benefits for all, benefits were lower in places with higher percentages of Black and Hispanic residents (Braun et al., 2023). By contrast, a study in the Netherlands found the opposite (Gao et al., 2017).

1.3. Theme 3 – cycling infrastructure, active commuting, and cycling frequency

A systematic review of the effects of built environment on physical activity and active transport stressed that not enough studies have included robust measures of SES or ethnicity (Smith et al., 2017). Including these variables in research studies moving forward is crucial to better understand the role of equity in active travel. Built environment factors (e.g., land use mix, number of destinations, density, and street connectivity) are consistently reported to be positively associated with transport-related physical activity (Bödeker et al., 2018; Christiansen et al., 2016; Hirsch et al., 2014; Kärmeniemi et al., 2018; Wasfi et al., 2016) and active travel (Fraser and Lock, 2011; Hirsch et al., 2014; Kärmeniemi et al., 2018; Wells &Yang, 2008; Yu &Wang, 2020). Previous studies also show a positive association across quality, quantity, accessibility of active travel infrastructure (e.g. sidewalk width, length of bike lane, separation from traffic, etc.) and active travel (Aldred, 2019; Aziz et al., 2018; Buehler and Pucher, 2012; Chapman et al., 2014; Fitzhugh et al., 2010; Fraser and Lock, 2011; Goodman et al., 2013a,b, 2014; Keall et al., 2015; Le et al., 2019; Parker et al., 2011; Pucher et al., 2011) but few have compared the efficacy of different infrastructures. One study that does, using data from 90 US cities, found that two types of bike lanes did not have significantly different associations with cycle commuting, though past findings have been contradictory (Buehler and Pucher, 2012). As the active travel infrastructure continues to be constructed, future research would be necessary to understand the differential effects of different types of active travel infrastructure on active travel.

Finally, a review of policies promoting active travel called attention to the need for research assessing the impacts of specific policies across different settings and population segments (Winters et al., 2017). Although some studies do examine factors impacted by society-level policies, such as speed limit changes, few connect measures to local or national active travel policies. By focusing on the city of Cardiff, Wales, and given the above gaps, this paper aims to answer the following three questions.

1. Is cycling infrastructure distributed equally over space? In other words, do all population groups, according to deprivation, benefit from cycling infrastructure?
2. Are active computing and cycling frequency 'equal' across population groups according to deprivation and do they differ across survey years within each group?
3. Is cycling infrastructure associated with active commuting and cycling frequency when controlling for sociodemographic and environmental factors?

By answering these questions, this paper will help characterise the equality of early roll out of cycling infrastructure since the passage of Active Travel (Wales) Act 2013. Following this section, Section 2 describes the methods used including the study area, data, and analysis plan. Section 3 presents the study findings divided by theme, followed by a discussion of these findings in Section 4. Finally, Section 5 provides a conclusion of the main findings, highlighting their relevance for policymakers and practitioners and identifying possible next steps.

2. Methods

2.1. Study area

The geographic focus of this study is on Cardiff, the capital city of Wales, UK (Fig. 2). At the time of the 2021 Census, the city had a population of 362,310 making it the most populous city in Wales at just under 12% of the country's population (City Population, 2021). Cardiff is the city with the highest levels of nitrogen dioxide and particulate matter in the country; vehicle emissions are the primary source of both pollutants (Welsh Air Quality Forum, 2015), and faces stark disparities, with life expectancy differing by 11 years between its most and least deprived communities (Porter, 2017).

In 2013, the Welsh Assembly passed the Active Travel (Wales) Act with a goal of providing a connected network of functional active travel routes throughout the country (Welsh Government, 2013). The Act came into effect in 2014, and the first network maps were approved in 2016/17 (Welsh Government, 2017). In 2019, while the number of people cycling once per week in Wales hovered around 6% (Welsh Government, 2019a), the number for Cardiff was 22% (Sustrans, 2019). Cardiff has over 30 distinct communities with varying demographics and access to cycling infrastructure suggesting the value of finer grain analysis of cycling behaviour within the city of Cardiff.

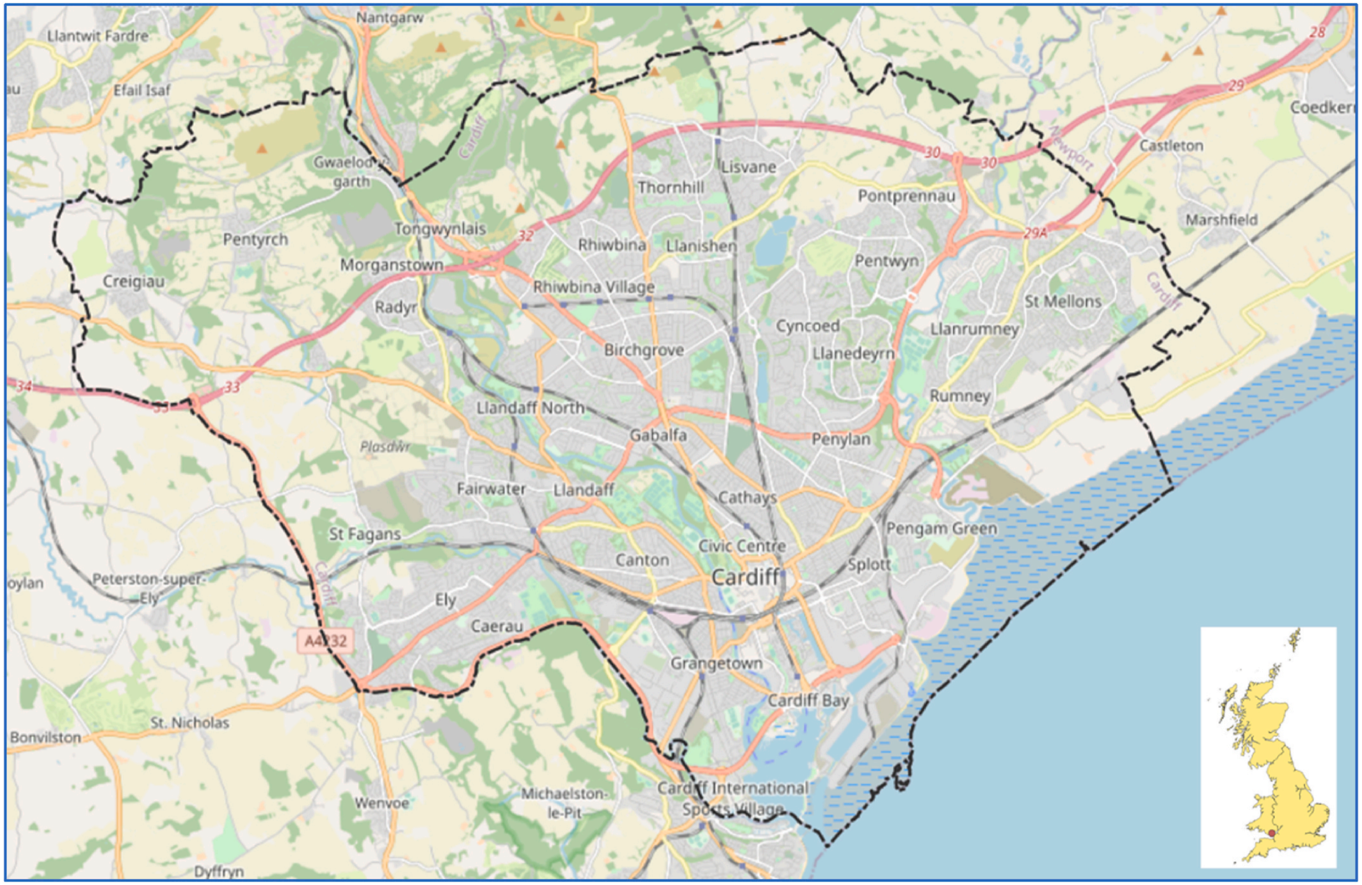

Fig. 2. Study area: Cardiff City (source: Open Street Map).

2.2. Data

The data in this study were drawn from three sources: (1) The National Survey for Wales (NSW), (2) StatsWales, and (3) Cardiff Council. Table 1 provides a summary of the data sources and variables used in this study.

The NSW is a nationally representative, repeated cross-sectional survey of adults aged 16 and older. These datasets are publicly available via the UK Data Service, the UK's largest repository of economic, population, and social research data (UK Data Service, 2021). The place of residence of NSW participants was recorded at the Lower Super Output Area (LSOA) level, a geographic unit of about 1500 people or 650 households, following a data access agreement with the Welsh Government. In this study, the LSOA codes were used to link NSW data with LSOA-level geography including cycling infrastructure and Welsh Index for Multiple Deprivation (WIMD) data.

Each year, over 24,000 households across Wales are selected at random to participate, with one adult from each household randomly selected to be interviewed. Approximately 12,000 participants typically agree to participate in the survey, which is conducted via a 45-min face-to-face interview. Of the over 12,000 annual participants, a little over a thousand are from Cardiff and make up the sample for this analysis. Data from the 2016-17 (N = 1177), 2018-19 (N = 1345), and 2019-20 (N = 1416) waves were extracted from the whole NSW sample with the inclusion criteria being that participants were residents of Cardiff. The samples used in the analysis of the data in this study, however, were further narrowed due to participants needing to have data on all covariates. Notably, only residents who were employed had data on commute mode leading to a smaller sample size than was available for cycling as an outcome. More information on the study procedures used by the NSW can be found in the 2019-20 Data User Guide (Welsh Government, 2020).

Table 1
Summary of data sources and variables.

Data source	Description and variables	Wave/Year
National Survey for Wales	**Active Travel**	
	• Usual mode of travel to work	•2018-19 (retrospective report), 2019-20
	•Cycling at least once a month[a]	•2016-17, 2018-19
	Socioeconomic and distance to work (of primary respondent)	
	•Gender (male, female)	•2018-19, 2019-20
	•Age (continuous)	
	•Ethnicity (white British, white other, and other)	
	•Highest education qualification (levels 4–8, level 3 and below)	
	•Economic status[b] (economically active, economically inactive)	
	•Car access (yes, no)	
	•Limiting long-standing illness, disability, or infirmity (yes, no)	
	•Religion (Christian, no religion, another religion)	
	•Distance to work (<1 mile, 1–3 miles, >3 miles)	
StatsWales: Welsh Index of Multiple Deprivation by Local Super Output Area	**Environment/Deprivation**	
	Physical environment	•2019
	•Proximity to natural greenspace (proportion of houses within 300 m of an accessible natural greenspace)	
	Access to services	
	•Average public travel time (via public transportation) in minutes to food shops, GP surgeries, primary schools, secondary schools, post office, public library, pharmacies, and sports facilities	
	Community safety	
	•Crime incidence (number of incidences averaged over two years divided by the number of people/properties in the LSOA); a combination of police recorded burglary, criminal damage, theft, and violent crime	
	Overall WIMD ranking (used for creating deprivation groups only)	
Cardiff Council: GIS shapefiles	**Cycling Infrastructure**	•2021
	Length in kilometres of:	
	•*Traffic-free* cycle routes completely separated from road traffic, may be segregated or shared with pedestrians	
	•*Shared use* cycle tracks alongside the road, shared with pedestrians	
	•*Segregated* on-road cycle lanes with a physical barrier between road traffic and cyclists	
	•*Non-segregated* painted on-road cycle lanes without a barrier between road traffic and cyclists	
	Total cycle lanes combination of all four lane types	

[a] Pattern reported for the last three months.
[b] Economically active refers to both employed and unemployed, however only 2% of the sample were unemployed, so economically active functions as a proxy for employed.

Data on (relative) neighbourhood deprivation was obtained from the WIMD, "the Welsh Government's official measure of relative deprivation for small areas" (StatsWales, 2021a). The WIMD ranks all 1909 LSOAs within Wales from most to least deprived across eight domains: income, employment, health, education, access to services, community safety, physical environment, and housing. Deprivation rankings for each domain are combined to create an overall index for multiple deprivation, the WIMD. More information on each domain and how they are calculated can be found on the Welsh Government website (StatsWales, 2021b). The Index is updated every four to five years (last updated in 2019), with some indicators updated more frequently.

2.3. Variables

2.3.1. Active commuting and cycling frequency

The Active Commuting variable in this study was derived from the NSW question in which participants reported their usual mode of transport to work in 2019-20 and their usual mode at the same time a year prior (2018-19). Response options included: train, bus, motorcycle or moped, car or van, taxi, bicycle, walk or run, and other. In this study, the responses were re-coded into 'active' (i.e., bicycle, walk or run) and 'non-active' (i.e., train, bus, motorcycle or moped, car or van, taxi, other) commuting. It is worth mentioning that the NSW also captured distance to work in three categories (Table 1).

Participants in the NSW reported their cycling frequency in 2016-17 and 2018-19 in the following question: "In the last three months, how frequently have you used a bicycle as a means of transport?" The response options included: 'less often or never', 'once or twice a month', 'once or twice a week', 'several times a week', and 'every day'. These responses were re-coded to create a binary variable representing 'cycling at least once per month' vs. 'less often or never'. Data from the 2017-18 and 2019-20 survey waves on cycling frequency were only obtained from a subset of participants leaving an insufficient sample size for comparisons within Cardiff, which is why cycling data from these waves was not included.

2.3.2. Environment and deprivation

A set of variables derived from the WIMD included rankings for physical environment, access to services, and community safety at the LSOA level (Table 1). To facilitate comparisons across deprivation groups, participants in the NSW were divided into three groups based on the WIMD ranking of the LSOA at their home location. In addition to ranking each LSOA in Wales, the WIMD splits LSOAs into quintiles ranging from most deprived to least deprived. Using these quintiles, three deprivation groups were created (Table 2). Fig. 3 also shows the spatial distribution of these deprivation groups across Cardiff.

2.3.3. Cycling infrastructure

Total length and length per LSOA, in kilometres, of cycle lanes and mixed-use paths were calculated using the "Summarize Within" function in ArcGIS. Kilometres of lanes were then divided by the area of each LSOA (in km^2) to standardise for different LSOA sizes (Fig. 3).

2.4. Analysis plan

The analysis of the data was aimed at examining the associations across the themes defined in Fig. 1 and the corresponding research questions presented in Section 1.

Firstly, as shown in Table 3, we examined whether active-travel infrastructure has been deployed equally across space in the City of Cardiff (Fig. 1; Theme 1). This analysis involved computing a set of cycling infrastructure related measures including the total and mean length of traffic-free, shared use, segregated, non-segregated, and all-types of cycle lanes at the LSOA level. As previously shown in Table 2, relative deprivation was split into three groups: least-, middle-, and most-deprived. ANOVA tests were conducted across all categories of cycle lanes to compare mean length of cycle lanes across deprivation groups.

The relationship between active commuting and cycling frequency of participants in the NSW by deprivation group was used to answer the second research question (Fig. 1 – Theme 2). As shown in Table 1, the 2019-20 wave of the NSW that included 'usual mode of transport to work' observations (for that year and the previous year) were compared across the three deprivation groups using Chi-square tests. The same approach was used for cycling frequency 'at least once a month' as reported in the 2016-17 and 2018-19 waves of the NSW. Also, Pearson Chi-square tests were computed to examine differences in active travel across deprivation within the same NSW survey wave.

Finally, the analysis concerning Theme 3 focused on the potential association between active commuting and cycling frequency and cycling infrastructure (Fig. 1 – Theme 3) after controlling for factors such as built environment and sociodemographic characteristics as defined in Table 1. Separate regression models were estimated only for the 2018-19 and 2019-20 waves of the NSW because most of

Table 2
Deprivation groups with corresponding WIMD information (source: StatsWales, 2021)

Deprivation Group	Group Name	WIMD Quintile	WIMD Rankings	Map Colour
1	Most deprived	1 = Top 20%	12 to 368[a]	Dark blue
2	Middle deprived	2-4 = Middle 60%	402 to 1527	Lighter blue
3	Least deprived	5 = Bottom 20%	1531 to 1900	Yellow

[a] Note that rankings skip from 368 to 402 and 1527 to 1531 as there are no LSOAs within Cardiff which fall into those ranges.

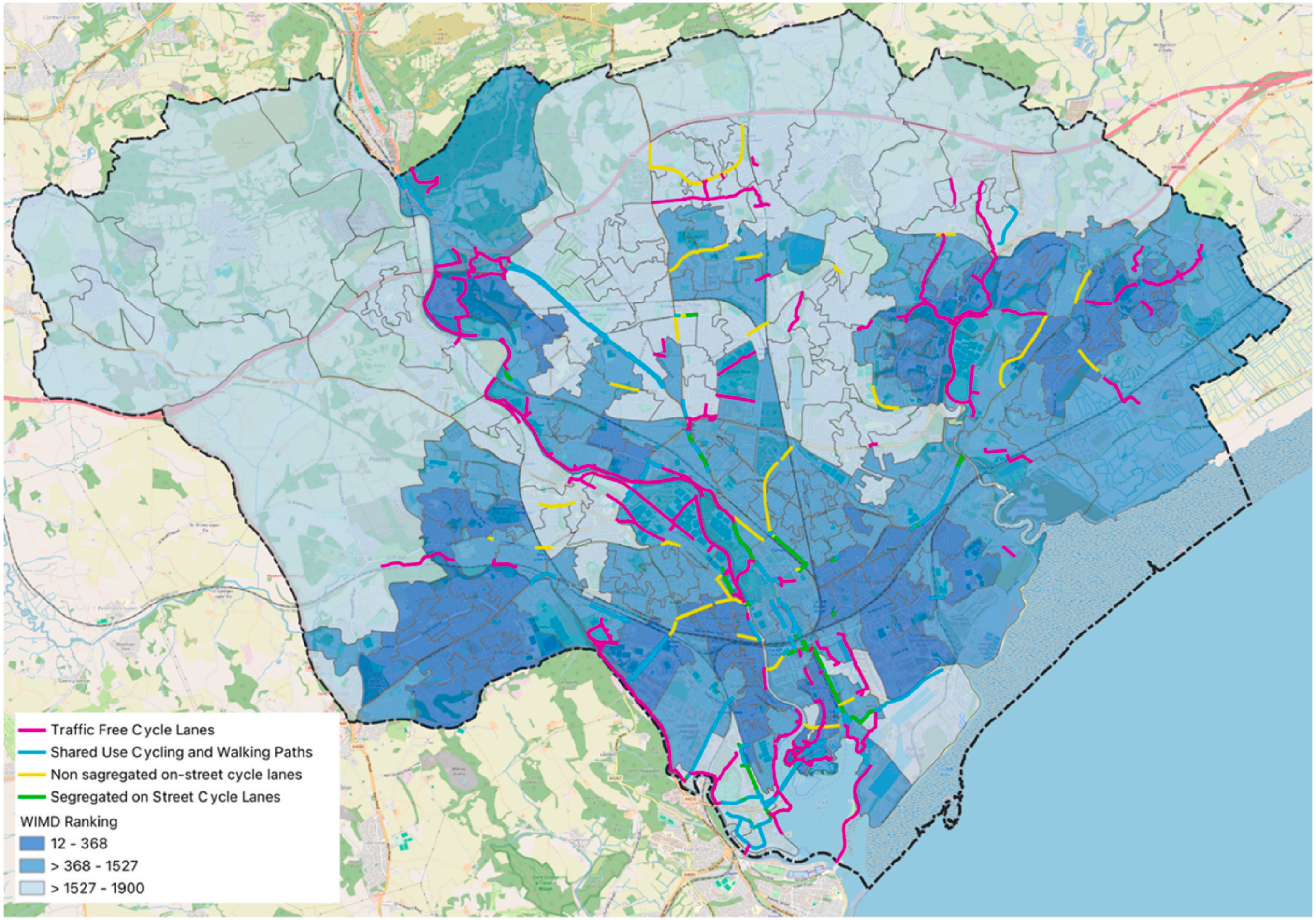

Fig. 3. Cycling and mixed-use paths across Cardiff LSOAs by deprivation group (Sources: Open Street Map; Cardiff Council).

Table 3
Methods of analysis across the three themes in this study.

Theme	Method of analysis
(1) Cycling infrastructure and deprivation • Measures of length of cycling paths vs. Welsh Index of Multiple Deprivation (WIMD)	ANOVA
(2) Active commuting, cycling frequency and deprivation • Cycling at least once a month* • Usual mode of transport to work (walk/bike/run vs. other)	Pearson's chi-square test
(3) Cycling infrastructure, active commuting (active vs. non-active travel to work), and cycling frequency (at least one a month vs. not), and after controlling for environment and sociodemographic variables	Bivariate associations: Independent samples *t*-tests and chi-square Multivariate associations: Simple and Mixed logistic regression models

the cycling infrastructure examined in this study did not exist before 2018.

Independent-sample *t*-tests and Chi-square tests were employed to examine bivariate associations across sociodemographic, environment, and cycling infrastructure variables against active commuting (active vs. non-active) and cycling frequency (cycling at least monthly vs. less often or never) (Tables A1 and A2). Further, logistic regression models examined the association of cycling infrastructure with active commuting (vs. non-active) and cycling frequency at least monthly (vs. less often or never) and after controlling for sociodemographic and environment factors that were significant at a 5% level in preliminary bivariate exploratory analyses. Mixed (or multi-level) models were estimated for both outcomes (active commuting and cycling frequency) to account for serial correlation because of NSW participants' home location 'nesting' within the same LSOAs. The above analyses were conducted using STATA 17 SE (StataCorp, 2021) and the 'melogit' command was used to estimate the mixed logistic regression models.

3. Results

3.1. Sample characteristics

Table 4 shows the NSW participant characteristics of those eligible to provide relevant data on commute mode and cycling frequency. Both samples included about 50% female participants, had a mean age of around 40 years and had about a quarter of respondents reported limiting long-term illness or disability. Respondents in the 2019-20 sample reported higher levels of education qualifications and car access and had a higher proportion of participants reporting no religion and a smaller proportion reporting Christian as their religion. In both samples, over 97% of participants lived in an urban area. A little over half of the 2019-20 sample

Table 4
Sample characteristics across the NSW waves analysed in this study.

Variable	Commute mode[a]	Cycling frequency
NSW Wave	2019–20	2018–19
Active travel to work (%)	117 (24.2)	–
Cycling at least a month (%)	–	132 (15.8%)
Females (%)	214 (48.6)	487 (51.9)
Age (mean ± SD)	39.4 ± 0.67	43.3 ± 0.73
Ethnicity		
White: British (%)	355 (80.6)	773 (82.4)
White: Other (%)	32 (7.4)	27 (2.9)
Other (%)	53 (12.0)	139 (14.8)
Education (%, Levels 4–8)	301 (68.3)	477 (50.7)
Economically Active[b] (%)	–	527 (56.1)
Car access: Yes (%)	399 (90.7)	770 (82.0)
Limiting illness or disability: Yes (%)	99 (22.5)	257 (27.3)
Religion		
No Religion (%)	246 (55.9)	443 (47.1)
Christian (%)	154 (35.0)	402 (42.8)
Another religion (%)	40 (9.1)	95 (10.1)
Living in an urban area (%)	433 (98.5)	915 (97.3)
Distance to work		
<1 mile (%)	45 (10.2)	–
1–3 miles (%)	145 (32.9)	–
>3 miles (%)	250 (56.8)	–
Total Sample Size	440	940

Note: Statistics reflect the characteristics of the analytic sample for each dependent variable.
[a] Commute mode sample only included those participants who commuted to work.
[b] Economic activity was not a variable for commute mode as all participants in this sample were employed. Although both students (N = 47) and people in paid employment (N = 518) reported their commute mode, only people in paid employment had data on distance to work so students were not included in multivariate regressions predicting commute mode.

commuted over three miles to work with about one third commuting one to three miles and 10% of participants commuting less than one mile. Ethnicity was similar across groups with the 2019-20 sample reflecting a higher proportion reporting in the white non-British category.

Table 5 shows the characteristics of all participants in the 2019-20 dataset by deprivation group. All participant characteristics except gender were different across deprivation groups according to Chi-square tests. The most- and middle-deprived groups were younger than the least-deprived group. The most-deprived group had a lower proportion of white (British) participants and over twice the proportion of non-white participants compared to the middle and least. The proportion of people who had access to a vehicle differed by almost 30% from the most to the least deprived group. The proportion of participants identifying as Christian was highest in the least-deprived group, identifying as not religious was highest in the middle-deprived group, and identifying with a religion other than Christianity was highest in the most-deprived group. Participants in the least-deprived group lived further from work on average. The middle deprivation group had the highest proportion living within one mile of work.

3.2. Theme 1 - cycling infrastructure and deprivation

As of early 2021, a total of 105.5 km of cycle lanes had been built in Cardiff. This included 22.8 km in most-deprived, 51.3 km in middle-deprived and 31.4 km in least-deprived areas. Fig. 4 shows how different types of cycle lanes were distributed across the LSOA-based groups of deprivation. Notably, 85 LSOAs (38%) had no cycle lanes at all, accounting for 29 LSOAs in most-deprived (49%), 32 LSOAs in middle-deprived (36%), and 24 LSOAs in least-deprived areas (37%), respectively. This means that about half of the most-deprived LSOAs had no cycle lanes compared to about one third of middle- and most-deprived LSOAs. Traffic-free cycle lanes were the most common type of cycle lanes throughout Cardiff, followed by shared use walk and cycle paths and non-segregated on-street cycle lanes. Segregated on-street cycle lanes were the least common with less than seven (7) km length.

Fig. 5 shows the cycle lane density in terms of length of cycle lanes per square kilometre across Cardiff and across deprivation groups. Cardiff-wide, there were 0.7 km of cycle lanes per km^2. Most-deprived LSOAs had the highest distance per km^2 at 1.16 km/km^2, middle-deprived had 0.96 and least-deprived had 0.41. The most-deprived group had the highest distance per km^2 despite having the lowest total lane distance due to LSOAs in this group having the smallest land area (and higher population density). The most-deprived group had the highest distance per km^2 of all cycle lane types except for segregated cycle lanes, which were the highest in the middle-deprived group. Cycle lane length per LSOA did not differ significantly by deprivation group for any lane type (Table A1) suggesting that overall, cycling infrastructure has been deployed equally across the city.

3.3. Theme 2 – active commuting, cycling frequency, and deprivation

In 2018-19, almost a quarter of participants reported commuting to work by active modes (cycle, walk or run; referred to as active commuting) (Fig. 6). While most participants used private motorised transport (motorcycle or moped, car or van, taxi, other) to travel to work, almost twice as many people commuted to work using active modes in the most- and middle-deprived groups when compared to the least-deprived group. Public transport was the highest in the most-deprived group at almost 20%, and private motorised vehicle use was highest in the least-deprived group at over 70% compared to 60% and 51% in the middle- and most-deprived groups, respectively (see, also Table A1).

Table 5
Participant characteristics by deprivation group (source: NSW, 2019-20).

	Total	Most Deprived	Middle Deprived	Least Deprived
Females (%)	552 (49.8)	149 (51.9)	231 (49.5)	171 (48.4)
Mean Age ± Standard Dev.	44.7 ± 0.68	42.2 ± 1.24	41.6 ± 1.05	51.4 ± 1.05
Ethnicity[a]				
White: British (%)	882 (79.6)	190 (66.0)	384 (82.3)	307 (87.1)
White: other (%)	73 (6.6)	24 (8.4)	32 (6.8)	16 (4.7)
Other (%)	152 (13.8)	74 (25.6)	51 (10.9)	29 (8.2)
Education (% Levels 4–8)	552 (50.6)	99 (35.3)	222 (48.3)	235 (67.0)
Economically Active (%)[a]	659 (59.5)	151 (52.2)	274 (58.9)	278 (66.3)
Car Access: Yes (%)[a]	902 (81.4)	193 (66.9)	378 (80.9)	333 (94.4)
Limiting illness or disability[a]	353 (32.0)	117 (40.5)	145 (31.1)	91 (26.1)
Religion[a]				
No Religion (%)	509 (49.6)	120 (45.0)	243 (56.6)	142 (43.0)
Christian (%)	408 (39.9)	96 (36.0)	151 (35.1)	166 (50.5)
Another religion (%)	108 (10.5)	50 (19.0)	35 (8.3)	22 (6.5)
Living in an urban area (%)[a]	1084 (97.7)	289 (100.0)	467 (100.0)	326 (92.3)
Distance to work[a]				
<1 mile (%)	56 (10.8)	13 (11.1)	31 (13.8)	12 (6.8)
1–3 miles (%)	161 (31.1)	43 (37.0)	75 (33.7)	42 (23.7)
>3 miles (%)	301 (58.1)	61 (52.2)	118 (52.5)	123 (69.5)
Total Sample Size	**1108**	**289**	**467**	**353**

[a] Chi-square test for significance across deprivation groups, p=<0.05.

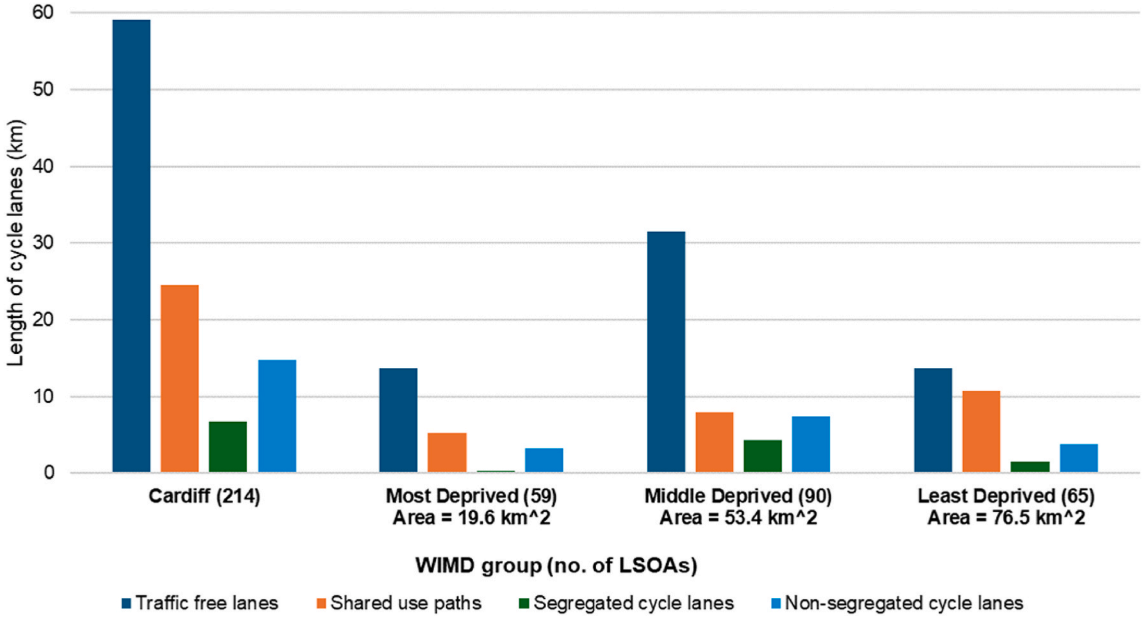

Fig. 4. Length of cycle lanes by deprivation group at LSOA level.

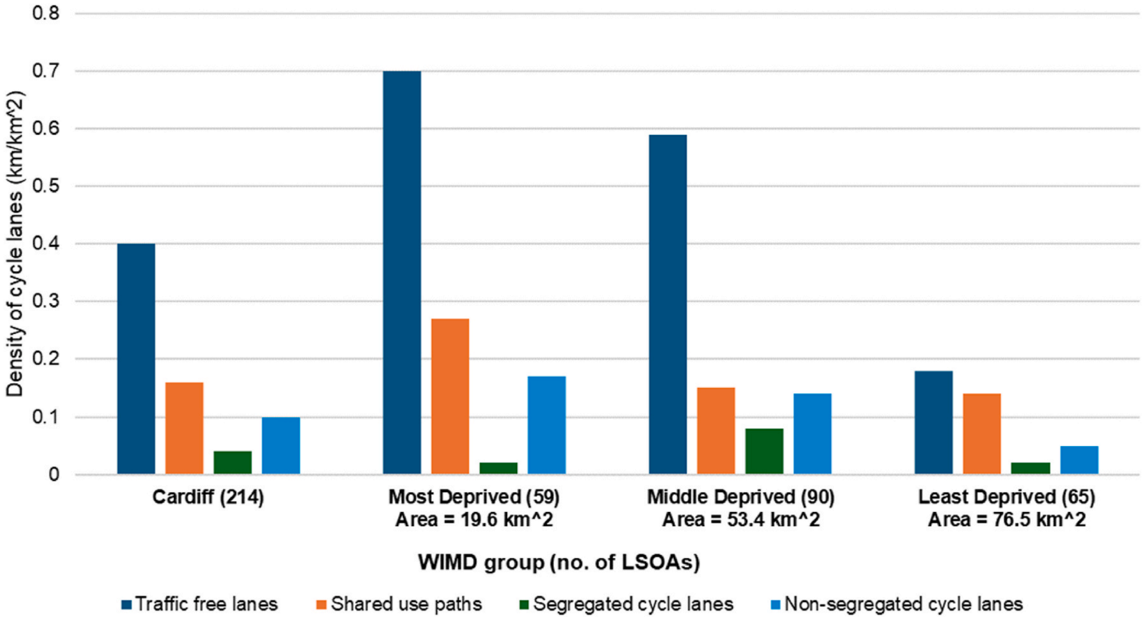

Fig. 5. Cycle-lane density by deprivation group at LSOA level.

Between the NSW waves 2018-19 and 2019-20, the proportion of participants reporting active commuting in Cardiff significantly increased from just below a quarter to a third of commuters ($\chi^2 = 15.16$; $p < 0.01$). Public transport significantly decreased, but only slightly, with private motorised transport decreasing over seven percentage points. When examining change in travel mode across deprivation groups and between the survey waves, significant modal shift towards active travel only occurred in the middle deprivation group ($\chi^2 = 18.30$; $p < 0.01$). In this group, active transport increased from below 30% to almost 45% of the mode share. In the meantime, commuting by public transport decreased by 4% while private motorised transport decreased by 12% (Table A2 in the Appendix).

In 2016-17, 16% of Cardiff respondents cycled at least once per month (Table A3). This proportion was highest in the least-deprived group. This proportion was not significantly different between 2016-17 and 2018-19 across Cardiff or by deprivation group (Fig. 7 and Table A3). However, the proportion of at least monthly cyclists decreased three percentage points in the most-deprived group, while

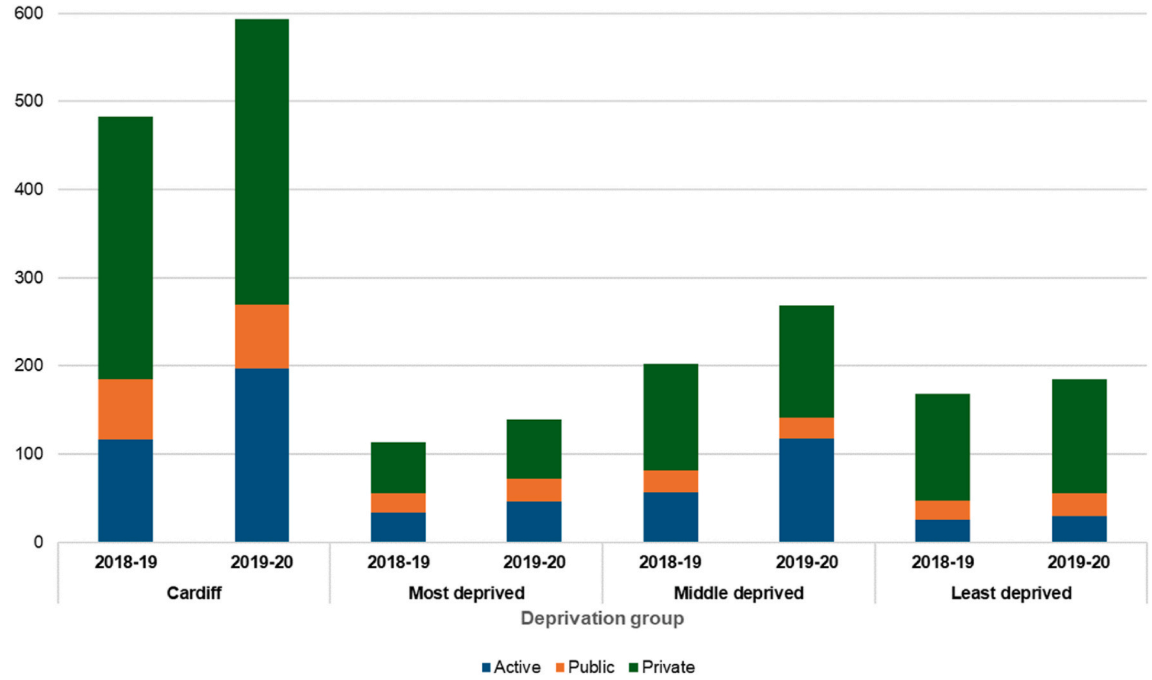

Fig. 6. Frequencies of travel modes to work across deprivation groups in Cardiff, Wales.

the proportion among the least-deprived group increased slightly.

3.4. Theme 3 – cycling infrastructure, active commuting, and cycling frequency

3.4.1. Cycling infrastructure and active commuting

Bivariate analyses showed no association between the length of cycling infrastructure and active commuting. They also showed that active commuters were more likely to be younger, male, more educated, without access to a car, and have no (reported) religion

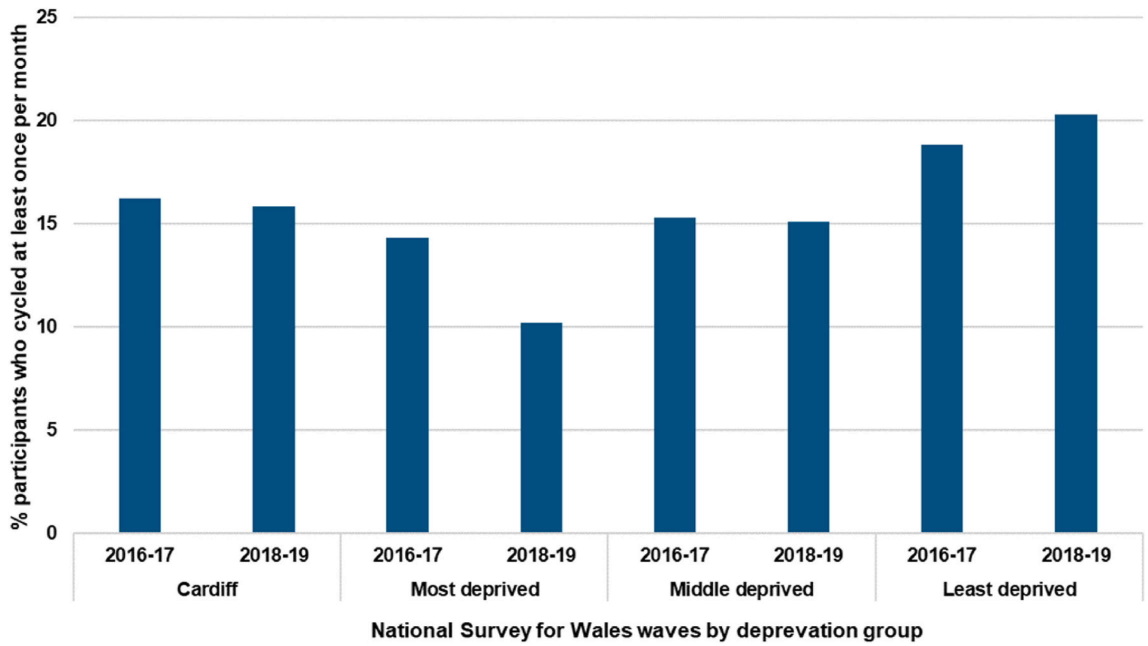

Fig. 7. Percentage participants who cycled at least once per month as reported in NSW.

(Table A4). Active commuters were also more likely to live three or less miles from work and live within a shorter average travel time to services (Table A5). A multivariate mixed binary logistic regression model (Table 6) further confirmed a non-significant association between cycling infrastructure and active commuting after controlling for previously significant socioeconomic and environmental factors in bivariate models. The multivariate model showed that being younger, having no car access, living closer to work, and having better access to services remained significantly associated with higher odds of active commuting.

3.4.2. Cycling infrastructure and cycling frequency

Bivariate analyses also revealed no significant association between cycling infrastructure and cycling frequency (Table A5) but did confirm that those who cycled at least monthly were more likely to be younger, male, more educated, not have a limiting illness or disability, and have no religion (Table A4). None of the environment variables were associated with cycling in bivariate models and therefore were not included in the multivariate model specifications in Table 7 (with the exception of total length of cycling lanes). The multivariate mixed binary logistic regression model further confirmed the lack of association between infrastructure and cycling (Table 7). Car access and having a limiting illness or disability were no longer significant predictors of cycling in multivariate models, while being younger, male, more educated, and having no religion remained associated with higher odds of cycling.

4. Discussion

The purpose of this study has been to examine the relationship across cycling infrastructure, deprivation, and active travel in Cardiff, Wales. Wales presented an interesting case as it is the only country with an active travel law, the Act Travel (Wales) Act 2013.

The analyses in this study led to three key findings (Table 8). Firstly, cycling infrastructure has so far been deployed equally across Cardiff neighbourhoods with differing levels of deprivation. Secondly, comparisons across different waves of the NSW showed that Cardiff residents in middle deprived LSOAs were transitioning to active commuting despite high car access (81%), while those in other LSOAs were not. Finally, when controlling for sociodemographic and environment factors, infrastructure was not a significant predictor of any measure of active travel. Individual sociodemographic characteristics were significant predictors of both measures of active travel, and neighbourhood environment factors were strong predictors of active commuting.

4.1. Theme 1 - cycling infrastructure and deprivation

The first of these findings provides insight into how early infrastructure deployment is associated with neighbourhood deprivation across Cardiff. No significant differences in the amount of infrastructure by deprivation group indicates a relatively even distribution thus far, however, it is noteworthy that almost half of most-deprived LSOAs have zero cycle lanes (compared to around one third for middle- and least-deprived). Least-deprived LSOAs had on average the most shared use paths. This is despite being the only deprivation group with rural residents and the group with the furthest distance to work, both of which are associated with lower odds of active commuting (Quinn et al., 2017). Although lack of deprivation cannot be conflated with affluence (Welsh Government, 2019b), this

Table 6
Logistic and mixed logistic regression for odds of active commuting in 2019-20.

	Logistic		Mixed Logistic	
	OR (95% CI)	p	OR (95% CI)	p
Constant	28.50 (5.67, 143.28)	<0.01	100.10 (8.31, 1205.49)	<0.01
Std. Dev. of Constant	–		3.04 (1.33, 6.94)	–
Sociodemographic				
Female	0.68 (0.35, 1.30)	0.26	0.66 (0.27, 1.66)	0.38
Age	0.96 (0.94, 0.99)	<0.01	0.95 (0.91, 0.99)	0.01
Education (Levels 4–8)	2.04 (0.97, 4.31)	0.06	2.20 (0.79, 6.12)	0.13
No car access	3.50 (1.22, 10.03)	0.02	4.63 (0.95, 22.51)	0.06
Religion	Reference: No Religion		Reference: No Religion	
Christian	0.50 (0.25, 1.00)	0.05	0.54 (0.20, 1.44)	0.22
Another religion	0.35 (0.10, 1.17)	0.09	0.35 (0.07, 1.84)	0.21
Neighbourhood environment				
Distance to work	Reference: Less than 1 mile			
1–3 miles	0.27 (0.11, 0.64)	<0.01	0.15 (0.04, 0.60)	<0.01
>3 miles	0.02 (0.01, 0.05)	<0.01	0.003 (0.00, 0.03)	<0.01
Access to services	Reference: Less than 25 min			
25–29.99 min	0.30 (0.16, 0.58)	<0.01	0.19 (0.07, 0.53)	<0.01
30+ min	0.20 (0.06, 0.70)	0.01	0.18 (0.04, 0.91)	0.04
Total length of cycling lanes (km/km^2)	1.08 (0.90, 1.30)	0.39	1.12 (0.88, 1.43)	0.89
Model statistics				
Observations	440		440 (in 166 LSOA groups)	
Log-likelihood (Model)	−219.25		−232.4	
Log-likelihood (0)	−361.94		−205.0	
AIC	462.5		435.5	
BIC	511.6		488.6	
Pseudo-R^2	0.394		–	

Table 7
Logistic and mixed logistic regression for odds of cycling at least monthly in 2018-19.

	Logistic		Mixed Logistic	
	OR (95% CI)	p	OR (95% CI)	p
Constant	0.35 (0.15, 0.83)	0.02	0.40 (0.13, 1.20)	0.10
Std. Deviation of Constant	–		1.40 (0.78, 2.51)	
Sociodemographic				
Female	0.44 (0.28, 0.70)	<0.01	0.39 (0.23, 0.64)	<0.01
Age	0.99 (0.97, 0.999)	0.03	0.98 (0.96, 0.99)	<0.01
Education (Levels 4–8)	2.08 (1.27, 3.38)	<0.01	2.03 (1.12, 3.69)	0.02
No car access	0.58 (0.27, 1.26)	0.17	0.53 (0.23, 1.24)	0.15
Religion	Reference: No Religion			
Christian	0.46 (0.28, 0.75)	<0.01	0.37 (0.20, 0.69)	<0.01
Another religion	0.34 (0.14, 0.84)	0.02	0.31 (0.10, 1.01)	0.05
Limiting illness/disability (no)	1.62 (0.95, 2.74)	0.07	1.51 (0.83, 2.74)	0.18
Neighbourhood environment				
Total length of cycling lanes (km/km^2)	0.98 (0.83, 1.15)	0.82	0.95 (0.80, 1.14)	0.60
Model statistics				
Observations	940		940 (in 210 LSOA groups)	
Log-likelihood (Model)	−465.89		−443.66	
Log-likelihood (0)	−518.13		−448.34	
AIC	949.8		905.6	
BIC	993.4		949.2	
Pseudo-R^2	0.1008		–	

Table 8
Summary of findings.

Theme 1	• Cycling infrastructure has so far been installed equally across Cardiff neighbourhoods with differing levels of deprivation. •Almost 50% of most-deprived LSOAs have no cycle lanes, compared to around a third of LSOAs in middle- and most-deprived LSOAs.
Theme 2	•On average active commuting increased and private motorised transport decreased •Changes in commute mode were significant only in middle-deprived areas
Theme 3	•Cycling infrastructure was not associated with active travel •Access to services and distance to work were strong predictors of active commuting

finding, along with the higher percentage of LSOAs in the most-deprived group with zero bike lanes, does suggest that residents in Cardiff living in areas with more access to a wider variety of services (a component of deprivation scores) may also have more access to certain types of cycling infrastructure. This pattern is similar to that described by Braun et al. (2019) who found a positive association of access to cycle lanes with overall SES and educational attainment.

4.2. Theme 2 – active commuting, cycling frequency, and deprivation

Few studies examine whether and how intervention or policy impacts differ across demographic sub-groups or geographies (Aldred, 2019). This study's second finding adds to this dearth of literature by examining change in travel mode choices by deprivation group. The change in travel mode only among people living in the middle-deprived LSOAs could be due to the demographics of this group. Participants in this group were younger than the least-deprived group, with higher education qualifications, more likely to be economically active, less religious, and less likely to have a limiting long-term illness or disability than the most-deprived group, all of which were associated with higher odds of active travel in this sample. However, despite these notable differences, the proportion of people in the most-deprived LSOAs who live three or less miles from work was almost equal to the proportion in the middle-deprived LSOAs.

Distance to work remains a strong predictor of active commuting, so the discrepancy in levels of active commuting between the middle- and most-deprived LSOAs suggests that more attention should be given to removing barriers to active commuting among people living in the most-deprived LSOAs. This aligns with research that suggests that lower-income people may face more barriers to biking (McNeil et al., 2017) and that "socio-economic advantage can make car-oriented environments less disabling" (Goodman et al., 2012, p. 1929). The presence of cycle lanes in only about half of most-deprived LSOAs could also be a factor but is unlikely to have made a large impact as infrastructure was not a significant predictor of active travel when controlling for other variables. The finding, however, may well reflect land use patterns that are more conducive to active travel, as access to services was also significantly associated with odds of active commuting (Table 7). One study of adults in the Netherlands found that although levels of walking and cycling were lower among those in lower socioeconomic groups, the health benefits (reduced all-cause mortality) were higher, suggesting that policies focusing on lower socioeconomic groups could not only improve population health but also reduce health disparities (Gao et al., 2017). Similarly, a Montreal study found that non-gentrified areas benefitted more from the expansion of cycling infrastructure than other areas (Kiani et al., 2024). Although it has not yet showed significance in Cardiff, greater prioritization of cycling infrastructure development in the most-deprived LSOAs may help to reduce disparities in active commuting, and subsequently in health. One recent study introduces a framework for prioritization which could be applied to achieve this goal (Zhao and Manaugh, 2023).

This finding is consistent with studies suggesting that levels of active travel among UK adults are changing at different rates by socioeconomic status (Yu and Wang, 2020; Goodman, 2013). Using data from the National Household Travel Survey, Goodman (2013) found that the gap in levels of active travel between those with high and low affluence was decreasing, and Yu and Wang (2020) found decreases in walking to work among low-income adults and those with low education despite increasing levels among the full sample. By examining changes across three deprivation groups, this study identifies an interesting difference between those in middle-deprived LSOAs compared to both the most- and least-deprived, potentially suggesting that the association between active travel and deprivation is not linear.

Although there were no statistically significant differences in cycling across deprivation groups, cycling frequency was highest in the least-deprived LSOAs, and the most-deprived group was the only one to show decreases in cycling. This aligns with previous research that suggests that, in several cities in high income countries, cycling is more common among people with higher income and education (Crossa et al., 2022; Goodman et al., 2013b; Martin et al., 2021), or is increasing among those from less deprived areas (Goodman, 2013). Some studies suggest that there is a distinction between recreational cycling and commuter or transport cycling, with the former being more common among people with higher affluence and the latter more common among those with lower affluence (Beenackers et al., 2012; Pucher et al., 2011) or revealing no clear income pattern (Firth et al., 2021). This distinction could explain why the cycling frequency (which could include recreational purposes) in this study was higher among the least-deprived, while active commuting (which is only to work) was higher among the middle- and most-deprived. The difference could also reflect neighbourhood factors, such as better access to services among the least-deprived (leading to higher transport cycling) and longer distance to work (leading to lower active commuting). The NSW does not ask participants to report the destination of their cycling, so it is not possible to distinguish between recreational and commuter cycling in this sample.

4.3. *Theme 3 – cycle infrastructure, active commuting, and cycling frequency*

When controlling for demographic and environment variables, cycling infrastructure was not a significant predictor of any measure of active travel. Considering the consistently positive association between cycle lanes and cycling in the literature (Aziz et al., 2018; Buehler and Pucher, 2012; Fitzhugh et al., 2010; Fraser and Lock, 2011; Keall et al., 2015; Parker et al., 2011), the lack of associations found in this study may be because infrastructure has not been in place in Cardiff long enough to encourage travel behaviour change (Keall et al., 2015). Active travel was reported in 2018-19 and 2019-20 while cycle lane infrastructure was implemented between 2016-17 when maps were first approved and early 2021 when the cycle lane data was last updated. It could also be due to the low overall prevalence of cycling in Cardiff (only 16% cycled at least monthly) or the disconnectedness of current cycle lanes. Standen et al. (2021) emphasizes the importance of connected cycle networks, especially in ensuring equitable impact of interventions. A study of commuters in Beijing similarly found no association of the distance of cycle lanes with cycling levels (Zhao and Li, 2017). This was explained by the high instance of cars parking in cycle lanes in Beijing, which is also a common problem in the UK. Detecting differences in associations by lane type was difficult because of the limited distance of each.

Although infrastructure was not significant, multivariate regression models indicated that age, car access, proximity to work, and access to services were critical factors when considering how to impact levels of active commuting in Cardiff. This emphasizes the importance of urban design and planning in determining travel behaviour and supports the findings by Christiansen et al. (2016) and Kärmeniemi et al. (2018) who suggested that land use mix (and other built environment factors) was associated with active travel and physical activity, respectively. Findings from a recent study using 2016 Irish Census data echo these results showing that the quality of infrastructure and compactness of development are associated with active travel regardless of sociodemographic composition (O'Driscoll et al., 2023). Findings suggest that efforts to reduce public (and active) travel times to essential services should accompany infrastructure development to create the most optimal environment for active commuting. Further, the lack of association between infrastructure and active commuting could be explained by the high proportion of active commuters who walk or run rather than cycle and that the infrastructure is primarily for cycling.

Age and gender were also a significant predictor of cycling, with male gender and younger age associated with higher odds of cycling. This is supported by numerous studies that find cycling to be more common among men (Aguilar-Farias et al., 2019; Brainard et al., 2019; Martin et al., 2021; Merom et al., 2010). Although active travel interventions cannot be used to change age, gender, or disability, cycle and pedestrian environments can be made more friendly to those groups that are less likely to cycle or walk in the current environment. Research suggests that different demographic groups have different concerns and face different barriers (Hull Grasso et al., 2020; Pearson et al., 2023). For example, a study from Baltimore, Maryland found that being female was associated with concerns about ability to ride comfortably and non-white individuals were concerned with riding with children or cargo (Hull Grasso et al., 2020). Thus, interventions that are tailored towards the barriers of older adults and women, for example, might help to reduce cycling disparities in Cardiff. Interventions may be infrastructure-based or behaviour-based (Savan et al., 2017).

Education was positively associated with cycling. This finding is supported by the literature, which consistently shows higher education to be associated with higher likelihood of cycling (Goodman et al., 2013a,b; Plaut, 2005; Pucher et al., 2011). Compared to having no religion, being Christian was associated with lower odds of cycling. Although few studies examine the association of religion with active travel, these findings support those of Rietveld and Daniel (2004), who found that the proportion of Catholic schools in a neighbourhood was negatively associated with bicycle use. These findings indicate that interventions implemented via religious institutions might lead to increases in active travel by targeting individuals who tend to be less likely to use active travel. Targeted interventions, such as reaching younger individuals through mobile apps and school classes, were recommended by Nikitas et al.

(2021) in a study of cycling-friendly initiatives during the Covid-19 pandemic.

4.4. Strengths and limitations

This study makes use of robust data and thus provides robust evidence on the themes and research questions addressed in this investigation. Utilising different waves of the National Survey for Wales, a representative repeated cross-sectional survey campaign funded by the Welsh Government, the analyses are supported by adequate sample sizes across different years, rigorous study procedures, and standardized question formats in the NSW questionnaire year-on-year, thus ensuring the robustness and consistency of the findings across varying temporal contexts. This is especially important as this study is one of few that examines the change in active travel following the passage of a legal framework encouraging active travel. This study also helps to address the paucity of literature investigating disparities in access to active travel infrastructure in the UK.

The analyses in this study also benefit from linking NSW respondent data with cycling infrastructure geospatial and multiple deprivation data at a fine geographical scale (Local Super Output Area). These high-quality data allowed the development of objective cycling infrastructure and deprivation metrics for each NSW participant, thus adding to the robustness and validity of the findings, while any clustering of respondents within LSOA was accounted for in the mixed regression models.

Limitations and future extensions to this study should also be noted. Firstly, because of the large number of topics covered by the NSW questionnaire, certain questions were not asked of the entire sample every year. This limited the years of available active travel data because questions about cycling frequency were not asked of the entire sample in 2017-18 and 2019-20. Similarly, travel mode was not collected in survey waves prior to 2019-20, and although participants were asked to report their travel mode at the same time the previous year, comparisons to years before 2018 could not be made. Also, reports for 2018-19 are retrospective and may be subject to recall bias. However, the available data has been collected by employing appropriate sampling procedures (Welsh Government, 2022) and in the absence of a National (Wales) Travel Survey currently.

The analysis of the active travel behaviours used the NSW waves for 2018-19 and 2019-20, which slightly lagged the data regarding the length of cycling infrastructure, which was up to date for the year 2021. However, due to COVID-19 restrictions there was practically no new permanent cycling infrastructure constructed between 2020 and 2021. As a result, the 2021 cycling infrastructure data would have minimal (if no) impact upon the credibility of the findings.

Finally, the uneven group sizes for cycling (small proportion of participants who cycled at least monthly) may limit the strength of associations. Although the sample size in this study prevented the examination of predictors of active commuting within demographic subgroups (i.e., by deprivation, age, gender), future research could do so, as some studies, including this one, suggest that demographic factors may moderate the relationship between infrastructure and active travel (e.g., Aguilar-Farias et al., 2019; Guo et al., 2007; Standen et al., 2021). Since Cardiff's ultimate plan is to have five cycle superhighways across the city (Cardiff Council, 2021), it will be important to examine how and for whom the cycle networks are making an impact. A closer analysis of the strongest predictors of active travel within each deprivation group, and as infrastructure expands, could help to inform more effective and tailored interventions. Qualitative research would also help to uncover barriers for subgroups that are hesitant to walk or cycle.

5. Conclusions

This paper sought to: (1) assess the equality of cycling infrastructure distribution across Cardiff, Wales; (2) examine active commuting and cycling frequency by deprivation, and (3) assess the association of cycling infrastructure and active travel, controlling for sociodemographic and environmental variables. The research contributes to wider debates on the equitable deployment cycling infrastructure investment and its association with active travel. This is in line with previous calls to review policies aimed at promoting active travel and conduct research to assess the impacts of policies across different settings and population segments (Winters et al., 2017), and this study contributes towards this research gap, especially in relation to the deployment of cycling infrastructure and equity.

In terms of policy recommendations, findings suggest that active travel interventions that prioritise the needs of older people, women, and those with a limiting illness or disability may help to reduce disparities in levels of active travel. In addition to targeting those with lower levels of active travel currently, the geographical areas identified as having higher and increasing levels of active travel are likely places where new infrastructure will be used immediately and frequently. Applying these findings to active travel interventions in urban areas could help broaden and accelerate the shift from non-active to active modes of travel, reducing dependency on cars and improving the overall health of residents. It would be valuable to combine these elements (population characteristics and active travel trends) with other spatial elements important in predicting active travel (e.g., access to services) to help identify where interventions might be the most effective (e.g., Hayes et al., 2022).

While acknowledging the contributions of this study, there are a few suggested areas for further research that would contribute to the evidence base and support informed policy and decision making. Firstly, the study involved objective measures of cycling infrastructure and thus there is wider scope for spatial analysis of the cycling infrastructure to investigate spatial clustering (spatial autocorrelation) of its deployment. Secondly, although this study only included objective (hard) measures such as physical factors (Krizek et al., 2009) implemented at the route-level (Winters et al., 2017) because cycle lanes were the primary focus of the Active Travel (Wales) Act 2013, future research should examine the impacts of broader society-, city-, and individual-level measures that are a part of the Act and include soft measures such as cycle training programmes. Additionally, although at the time of this study, cycling infrastructure in Cardiff was not associated with levels of active travel, as more infrastructure is built, associations and trends should be re-examined on year-on-year basis.

CRediT authorship contribution statement

Grace Betts: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dimitris Potoglou:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A1
Cycling infrastructure by deprivation group at LSOA level

	Cardiff (214)	Most Deprived (N = 59) (Area = 19.64)	Middle Deprived (N = 90) (Area = 53.44)	Least Deprived (N = 65) (Area = 76.51)	
Type	*Km of cycle lanes* per *km2* per *LSOA*				**ANOVA**[a]
Traffic-free lane	0.46 ± 0.86	0.47 ± 0.89	0.51 ± 0.90	0.38 ± 0.79	F = 0.45, p = 0.64
Shared use path	0.21 ± 0.63	0.23 ± 0.72	0.15 ± 0.47	0.27 ± 0.72	F = 0.70, p = 0.50
Segregated cycle lane	0.07 ± 0.42	0.03 ± 0.12	0.11 ± 0.61	0.06 ± 0.25	F = 0.69, p = 0.50
Non-segregated cycle lane	0.22 ± 0.63	0.23 ± 0.81	0.24 ± 0.60	0.18 ± 0.45	F = 0.16, p = 0.85
All cycle lanes	0.96 ± 1.43	0.96 ± 1.68	1.01 ± 1.34	0.89 ± 1.34	F = 0.15, p = 0.86

[a] ANOVA test compares cycling infrastructure across deprivation groups.

Table A2
Usual mode of transport to work by deprivation group in 2018-19 and 2019-20

	Cardiff			Most deprived			Middle deprived			Least deprived		
	2018–19[a]	2019–20[b]	Δ	2018–19	2019–20	Δ	2018–19	2019–20	Δ	2018–19	2019–20	Δ
Active (%)	117 (24.2)	197 (33.3)	9.1	34 (29.8)	46 (32.8)	3.0	57 (28.2)	118 (43.9)	15.7	26 (15.3)	30 (16.0)	0.7
Public (%)	68 (14.1)	73 (12.3)	−1.8	22 (19.5)	26 (18.7)	−0.8	24 (12.1)	23 (8.5)	−3.6	21 (12.8)	25 (13.5)	0.7
Private (%)	298 (61.7)	323 (54.4)	−7.3	57 (50.6)	67 (48.4)	−2.2	121 (59.7)	128 (47.7)	−12.0	121 (71.9)	130 (70.5)	−1.4
χ^2; p	15.16; p=<0.01			0.39; p = 0.83			18.30; p=<0.01			0.14; p = 0.93		

[a] Chi-Square for Active vs. Not by deprivation group 18–19: Design-based F = 4.31; p = 0.01.
[b] Chi-Square for Active vs. Not by deprivation group 19–20: Design-based F = 13.49; p=<0.01.

Table A3
Cycling frequency by year and deprivation group in 2016-17 and 2018-19

	Cardiff-wide			Most deprived			Middle deprived			Least deprived		
	16–17[a]	18–19[b]	Δ	16–17	18–19	Δ	16–17	18–19	Δ	16–17	18–19	Δ
Monthly N (%)	133 (16.2)	132 (15.8)	−0.3	28 (14.3)	20 (10.2)	−3.1	52 (15.3)	50 (15.1)	0.5	53 (18.8)	62 (20.3)	1.5
χ^2; p	0.05; p = 0.85			1.55; p = 0.32			0.01; 0 = 0.94			0.23; P = 0.71		

[a] Chi-Square for Monthly vs. Less by deprivation group 16–17: Design-based F = 0.62; p = 0.54.
[b] Chi-Square for Monthly vs. Less by deprivation group 18–19: Design-based F = 2.30; p = 0.10.

Table A4
Bivariate associations individual and household characteristics with active travel

	Travel mode to work (active vs not)	Transport cycling 18–19 (≥ monthly vs. never)
Age (M ± SD)	10.08 ± 1.18; p < 0.01	5.68 ± 1.64; p < 0.01
Gender	5.71 (1); p = 0.02	16.25 (1); p < 0.01
Ethnicity	0.09 (2); p = 0.40	2.53 (2); p = 0.08
Econ Status	–	5.49 (1); p = 0.02
Education	4.70 (1); p = 0.03	14.37 (1); p < 0.01
Car Access	39.50 (1); p < 0.01	4.88 (1); p = 0.03
LLTI	0.14 (1); p = 0.71	10.63 (1); p < 0.01
Religion	6.47 (2); p < 0.01	10.45 (2); p < 0.01
Distance to Work	55.99 (2); p < 0.01	–

Table A5
Bivariate associations of environment and infrastructure variables with active travel*

	Travel mode to work 19–20 (not active minus active) (M ± SE)	Transport cycling 18-19 (never - biked)
Greenspace	3.53 ± 3.21 P = 0.27	−1.34 ± 3.29 P = 0.68
Access to services	1.79 ± 0.48 P < 0.01	−0.11 ± 0.50 P = 0.82
Crime incidence	−0.46 ± 0.33 P = 0.16	1.31 ± 0.84 P = 0.12
Total cycle lane length	0.03 ± 0.20 P = 0.88	0.08 ± 0.15 P = 0.62
Shared use lanes	0.09 ± 0.07 P = 0.25	0.01 ± 0.05 P = 0.90
Segregated cycle lanes	0.06 ± 0.05 P = 0.24	0.03 ± 0.02 0.10
Non-segregated lanes	−0.10 ± 0.10 P = 0.30	−0.03 ± 0.09 P = 0.76
Traffic-free lanes	−0.02 ± 0.10 P = 0.86	0.06 ± 0.10 P = 0.53

* Reported mean represents the difference between the non-active group and the active group.

Data availability

The authors do not have permission to share data.

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