# Cycling and socioeconomic disadvantage

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Submitted in accordance with the requirements for the degree of

Doctor of Philosophy

The University of Leeds

School of Geography

October 2021

# Intellectual Property and Publications

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The work in Chapter 2 of this thesis has appeared in publication as follows: Vidal Tortosa, E., Lovelace, R., Heinen, E., Mann, R.P., 2021. *Cycling behaviour and socioeconomic disadvantage: An investigation based on the English National Travel Survey.* Transportation Research Part A: Policy and Practice 152, 173–185. https://doi.org/10.1016/j.tra.2021.08.004. I developed the main idea for this work and wrote the manuscript. Robin Lovelace, Eva Heinen, and Richard Mann provided suggestions and comments.

The work in Chapter 3 of this thesis has appeared in publication as follows: Vidal Tortosa, E., Lovelace, R., Heinen, E., Mann, R.P., 2021. *Infrastructure is not enough: Interactions between the environment, socioeconomic disadvantage, and cycling participation in England.* Journal of Transport and Land Use 14, 693–714. https://doi.org/10.5198/jtlu.2021.1781. I developed the main idea for this work and wrote the manuscript. Robin Lovelace, Eva Heinen, and Richard Mann provided suggestions and comments.

The work in Chapter 4 of this thesis has appeared in publication as follows: Vidal Tortosa, E., Lovelace, R., Heinen, E., Mann, R.P., 2021. *Socioeconomic inequalities in cycling safety: An analysis of cycling injury risk by residential deprivation level in England.* Journal of Transport & Health. 23, p.101291. https://doi.org/10.1016/j.jth.2021.101291. I developed the main idea for this work and wrote the manuscript. Robin Lovelace, Eva Heinen, and Richard Mann provided suggestions and comments.

# Acknowledgements

Doing a PhD is a tough journey full of ups and downs. At times you feel highly motivated, excited about your topic, and convinced that you are making progress. On other occasions, however, you may feel lost, stuck, and even doubt that you can make it.

Now that I have come this far, I realise how much it has been worth it to keep working. I have learned so many new skills and met so many interesting and inspiring people on the way. I also realise that although this is a journey that you make on your own, the motivation, encouragement, and support of others are essential to complete it.

First of all, I would like to express my appreciation and gratitude to my supervisors Robin Lovelace, Eva Heinen, and Richard P Mann, who I believe made a perfect team for me and my research. Thank you so much Robin for counting on me, for being a source of inspiration, for being so good at cheering me up in difficult times, for your enthusiasm, energy, humility, sensitivity, idealism, for all the runs, rides, and coffees together, and ultimately for making it possible. Thank you Eva for your professionalism, for your objective and critical point of view, for your quick responses, for teaching me so well how the 'academic system' works, and for your understanding and support in the most stressful moments. Thank you Richard for your lectures and all your comments and suggestions on the methodological aspects. This really helped me to overcome my initial limitations in statistics and modelling.

I wish also to thank all individuals who gave me feedback in seminars and conferences. I will not be able to name you all but I would particularly like to thank Ian Philips, Roger Beecham, and Claudia Peñaranda Fuentes.

Thanks also to all those who gave me the necessary social support and distractions during the journey. To my colleagues from the Centre for Doctoral Training Keiran, Fran, Vicki, Anabel, Ryan, and Jenny, as well as Caroline, Sedar, and Maria. I really missed seeing you guys face to face during the pandemic! Many thanks also to my friends in Leeds Keiran, Marc, Lamprini, and Elizabeth for their moral support and for helping to make the whole process less isolating.

Finally, I also would like to thank my family and friends from Spain for their generous and warm support in the distance.

Eugeni Vidal Tortosa

Leeds, October 2021

# Abstract

Cycling is an affordable, healthy, and convenient mode of transport and form of leisure. However, not everyone benefits from cycling equally. In some contexts, the socioeconomically disadvantaged, who are most in need of alternatives for transport and an active life, have been found to cycle less, to have less access to cycling facilities, and to be at a higher risk of injury while cycling. Despite the rapid growth of studies on the topic 'socioeconomic inequalities in cycling', several research gaps remain. This thesis, composed of three empirical papers, aims to better understand the relationships between cycling and socioeconomic disadvantage in England from three perspectives: behaviour, environment, and safety. A varied range of datasets (National Travel Survey, Active Lives Adult Survey, STATS19, and population and environmental data from several sources) and quantitative methods (descriptive, regression, and multilevel regression analyses) were used. Despite finding that deprived areas have a higher density of cycling facilities, the socioeconomically disadvantaged were found to cycle less overall than the non-disadvantaged. This suggests that infrastructure is not enough to increase cycling levels among these populations. Socioeconomically disadvantaged populations were also found to have much less ownership and access to bicycles. Finally, the results also show that the socioeconomically disadvantaged are at a higher risk of being slightly, seriously, and fatally injured while cycling, that disadvantaged children are most at risk, and that inequalities in cycling safety may have increased over the last years. These findings have policy implications, which put into practice may enable socioeconomically disadvantaged populations to cycle more and safer. The project also raises new pressing questions for researchers and policy-makers.

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# List of abbreviations

ALS — Active Lives Adult Survey
Bkm — Billion kilometres
BSS — Bicycle share schemes
CI — Confidence interval
DfT — Department for Transport
GIS — Geographic information systems
GVIF — Generalized variance inflation factors
HES — Hospital Episode Statistics
IMD — Index Multiple of Deprivation
KSI — Killed and seriously injured
LA — Local authority
LSOA — Lower Layer Super Output Areas
LTN — Low traffic neighbourhood schemes
MET — Metabolic equivalents of tasks
NS-SEC — National Statistics Socio-economic Classification
NTS — National Travel Survey
OSM — Open Street Map
ONS — Office for National Statistics
OR — Odds ratio
RQ — Research question
SES — Socioeconomic status
STATS19 — Database of road traffic casualties in Britain
VIF — Variance inflation factor

# Chapter 1

# Introduction

## 1.1 Background

Cycling provides individual and social benefits. For individuals, it is a healthy, affordable, and convenient mode of transport and form of leisure. For society, cycling for transport improves environmental quality, reduces traffic congestion, and tackles climate change (Heinen et al., 2010; Oja et al., 2011; Garrard et al., 2012). Consequently, in the last decade, policy interest in promoting cycling has increased substantially at all administrative levels.

One group that has much to gain from cycling uptake is the socioeconomically disadvantaged populations (Day, 2006; Lee et al., 2012).[1] First, because socioeconomically disadvantaged populations tend to suffer greater transport disadvantage (Lucas, 2012), and cycling could help them to access jobs, education, and other services that with other modes of transport they may not. Second, because these populations also tend to be less physically active and have a higher incidence of obesity and chronic diseases (Lindström et al., 2001; Droomers, 2001; Giles-Corti, 2002; Day, 2006), and regular cycling could contribute to increasing their levels of physical activity and improving their health and well-being (Oja et al., 2011; Garrard et al., 2012).

However, a growing literature suggests that in some contexts, such as the UK, the most socioeconomically disadvantaged have relatively low levels of cycling (e.g. Parkin et al., 2008; Green et al., 2010; Whyte and Waugh, 2015). Recent studies also show that, in some areas, cycling facilities are not evenly distributed (e.g. Teunissen et al., 2015; Tucker and Manaugh, 2018; Winters et al., 2018; Braun, 2019). Moreover, research indicates that people living in the most deprived areas are at a higher risk of injury while cycling (and also while travelling by other modes) (e.g. Edwards et al., 2008; Feleke et al., 2018; O'Toole and Christie, 2018).

This section provides a review on these three areas related to the topic 'socioeconomic inequalities in cycling': i) variations in cycling levels among socioeconomic groups, ii) spatial inequalities in the distribution of cycling facilities, and iii) socioeconomic inequalities in cycling safety.

The review is organised as follows. First, it reports the results of the literature on the research into variations in cycling levels among socioeconomic groups. In this subsection, the variations in cycling levels by income, education, and occupation groups are analysed separately. Second, it outlines the results of the literature on the research into socio-spatial inequalities in the distribution of cycling facilities. This subsection

[1] In this thesis, the term *socioeconomically disadvantaged populations* is used to mean "all populations who experience disadvantage in terms of income, education, or occupation".

distinguishes between studies that assessed equity to access cycling networks and studies that assessed equity to access bike share schemes (BSS). Finally, it provides an overview of papers that explore socioeconomic inequalities in cycling safety.

### 1.1.1 Variations in cycling levels among socioeconomic groups

Cycling levels have been found to vary substantially by socio-demographic variables. In car-oriented countries, females and old people cycle considerably less than males and young/middle-aged (e.g. Heinen et al., 2010; Heesch et al., 2012; Goodman and Aldred, 2018). These disparities are less present or non-existent in places where cycling is more common and cycling infrastructure safer (Aldred et al., 2016; Goodman and Aldred, 2018). Cycling levels have been also found to vary by physical condition and ethnicity. In England, people with disabilities were found to cycle half as much as people without disabilities (Goodman and Aldred, 2018). In the Netherlands, Denmark, and England, ethnic minorities were found to cycle less than the average (Harms, 2007; Heinen et al., 2010; Goodman and Aldred, 2018).

Since cycling is a cheap mode of transport and source of leisure, one would expect socioeconomically disadvantaged populations to cycle more than non-disadvantaged populations. However, in many contexts, this is not the case. This subsection reviews the literature on the associations between cycling levels and the socioeconomic factors income, education, and occupation.

#### Income

Most authors agree that leisure cycling is more common among higher-income populations (e.g. Kamphuis et al., 2008; Heesch et al., 2015). However, for utility cycling, there is no simple and universal pattern. In European countries where cycling for transport is common such as the Netherlands, Germany, and Belgium, all socioeconomic populations seem to cycle, although there seem to be some variations. In the Netherlands, Ton et al. (2018) found no significant association between household income and cycling. However, Fishman et al. (2015) reported that higher income was associated with more minutes cycling. In Germany, a positive association was found between income and cycling for transport (Finger et al., 2019). In Ghent (Belgium), by contrast, the highest income populations were found to cycle less (Witlox and Tindemans, 2004).

In the UK, where cycling for transport is less common, most studies found a positive association between income and utility cycling. In England and Wales, at an aggregate level, Parkin et al. (2008) found that higher-income populations cycled more to work than lower-income populations. Similarly, in Scotland, and also at an aggregate level, non-deprived populations were found to cycle to work or study substantially more than deprived populations (Whyte and Waugh, 2015). In the same direction, but at an individual level, Green et al. (2010) concluded that in London not only the highest-income group made more cycling trips, but also that these trips were generally longer and further. However, Goodman (2013), using aggregate census data, found that commuting cycling in England and Wales was more common among low-income populations. Goodman (2013) pointed out, nevertheless, that in the period 2001-2011 the differences between income groups had reduced and in the highest cycling locations reversed, predicting that future cycling to work in England and Wales may become increasingly more common among affluent populations.

In North America, mixed results were reported. The US 2009 National Household Travel Survey indicated a higher bike mode share in the lowest income quartile (Pucher et al., 2011). This was supported by Plaut (2005). However, Dill and Carr (2003), in a study in US cities >250.000 inhabitants, and Handy and Xing (2011), in a study in six small US cities, found that income had no significant effect on commuting cycling. Dill and Voros (2007) found that people with higher incomes ($100,000 and above) in Portland were more likely to be regular cyclists but not to ride for utilitarian purposes. In Canada, income was found to have a positive effect on utility cycling (Winters et al., 2007) and on commuting cycling at an aggregate level (Fuller and Winters, 2017).

In South American countries, the existing literature agrees: cycling is used mainly by low-income populations. This is the conclusion of studies in Brazil (Bandeira et al., 2017), Colombia (Guzman and Bocarejo, 2017), and Chile (Ortúzar et al., 2000; Arellano Yévenes and Saavedra Peláez, 2017). Finally, in Oceania, two studies reported a positive relationship between cycling and income in Australia (Merom et al., 2010; Heesch et al., 2015), and the only one in New Zealand found no significant association (Tin Tin et al., 2009).

#### Education

In terms of education, most research from Europe, North America, and Oceania found that higher educated people tend to cycle more. In the Netherlands, higher education was associated with more cycling (Fishman et al., 2015; Ton et al., 2018). Similarly, in Germany education was also positively associated with cycling for transport (Finger et al., 2019) and in Flanders (Belgium) with cycling to work (Geus et al., 2007). In England, education was found progressively associated with leisure cycling, but not with utility cycling within most English local authorities (Aldred et al., 2018). In the US, Plaut (2005) found an association between college education and active travel, but Handy and Xing (2011) did not find any association. Also in Canada and Brisbane (Australia), a positive relationship between education and cycling was found (Winters et al., 2007; Heesch et al., 2015).

By contrast, in South America, the three papers reviewed showed that people with lower education levels tend to cycle more. In Brasil, workers with lower education levels were more likely to cycle than those with higher education (Bandeira et al., 2017). In Santiago de Chile, people with lower education level were found more willing to cycle (Ortúzar et al., 2000; Arellano Yévenes and Saavedra Peláez, 2017). Arellano Yévenes and Saavedra Peláez (2017) reported, however, that the number of cyclists with higher education levels in Santiago de Chile is increasing, suggesting the emergence of a new type of cyclist no longer associated with low-income and working-class populations.

**Occupation**

The relationship between occupation and cycling has been less investigated. In Germany, a progressive positive association was found between occupation status and cycling for transport (Finger et al., 2019). In England and Wales, at an aggregate level, 'Higher professionals' were found positively associated with cycling to work; although the rest of the higher and middle socioeconomic classes ('Higher managerial & professional in larger organisation', 'Lower managerial and professional', 'Intermediate occupations', 'Small employers & own account workers') were negatively associated (Parkin et al., 2008).

In the Netherlands, Fishman et al. (2015) found that part-time workers, students, unemployed, and retired people had a greater likelihood of cycling than full-time workers. However, Ton et al. (2018) found no association between working hours and cycling but a positive association between being a student and cycling. In Australia, cycling levels have been found to be higher among full-time workers (Merom et al., 2010; Heesch et al., 2015).

Table 1.1 summarises the literature on the relationship between income, education, and occupation and cycling levels reviewed in this subsection. It shows the country, area, or city of study; the cycling measure or dependent variable explored; the trip purpose; the level of analysis; the socioeconomic factor analysed; and the sign of association of each of the papers.

Table 1.1: Studies on the relationship between income, education, and occupation and cycling levels.

| Country, area, or city | Cycling measure[a] | Trip purpose[b] | Level of analysis[c] | Socioeconomic factor | Sign of association[d] | Reference |
|---|---|---|---|---|---|---|
| Netherlands | Binary variable | All | Ind. | Income, Education, Occupation | o/+/o | Ton et al., 2018 |
| Netherlands | MET hours cycling | All | Ind. | Income, Education, Occupation | +/+/- | Fishman et al., 2015 |
| Germany | Cycling >600 MET min/week | All | Ind. | Income, Education, Occupation | -/+/+ | Finger et al., 2019 |
| Ghent (BE) | Bicycle share | All | Ind. | Income | - | Witlox and Tindemans, 2004 |
| Flanders (BE) | % cyclists | Com. | Ind. | Education | + | De Geus et al., 2007 |
| England and Wales (GB) | Bicycle share | Com. | Aggr. | Income, Occupation | +/hp+ | Parkin et al., 2008 |
| Scotland (GB) | Bicycle share | Util. | Aggr. | Deprivation | + | Whyte et al., 2015. |
| London (GB) | % cyclists and time | All | Ind. | Income | + | Green et al., 2010 |
| England and Wales (GB) | Bicycle share | Com. | Aggr. | Income | -+ | Goodman, 2013 |
| England (GB) | Categorical variable/% of cycling | All | Ind. | Education | l+ | Goodman and Aldred, 2018 |
| United States | Bicycle share | All | Ind. | Income | - | Pucher et al., 2011 |
| United States | Bicycle share | Com. | Ind. | Income, Education | -/+ | Plaut, 2005 |
| Cities > 250,000 (US) | Bicycle share | Com. | Aggr. | Income | o | Dill and Carr, 2003 |
| 6 small US cities (US) | Binary variable | Com. | Ind. | Income, Education | o/o | Handy and Xing, 2011 |
| Portland (US) | % cyclists | All | Ind. | Income | + | Dill and Voros, 2007 |
| Canada | Binary variable | Util. | Ind. | Income, Education | +/+ | Winters, 2007 |
| 8 middle Canadian cities (CA) | Bicycle share | Com. | Aggr. | Income | + | Fuller and Winters, 2017 |
| Brazil | Categorical variable | All | Ind. | Income, Education | -/- | Bandeira et al., 2016 |
| Bogotá (CO) | Bicycle share | All | Ind. | Income | - | Guzman and Bocarejo, 2016 |
| Santiago (CL) | % cyclists | All | Ind. | Income, Education | -+/-+ | Arellano and Saavedra, 2017 |
| Santiago (CL) | Binary variable | All | Ind. | Income, Education | -/- | Ortuzar et al., 2000 |
| Sydney Greater Metropolitan Area (AU) | Binary variable | All | Ind. | Income, Occupation | +/+ | Merom et al., 2010 |
| Brisbane (AU) | Categorical variable | All | Ind. | Income, Education, Occupation | +/+/+ | Heesch et al., 2014 |
| New Zealand | Bicycle share | Com. | Aggr. | Income | o | Tin Tin et al., 2009 |

[a] MET = metabolic equivalents of tasks.
[b] Com. = commuting, Util. = utility.
[c] Aggr. = aggregated, Ind. = individual.
[d] '+' = positive, '-' = negative, 'o' = no association, 'hp+' = positive higher professionals, '-+' negative with positive trend, 'l+' positive leisure.

### 1.1.2 Spatial inequalities in the distribution of cycling facilities

There is evidence that investment in cycling infrastructure results in increases in cycling levels (Buehler and Pucher, 2012; Buehler and Dill, 2016; Winters et al., 2016; Lee et al., 2017). Therefore, and given that socioeconomic populations tend to live clustered in geographic areas, spatial inequalities in the distribution of cycling facilities could lead to socioeconomic variations in cycling levels.

Scholars and practitioners, mainly from North America, have investigated the extent to which cycling facilities (mostly cycling networks and bike-share stations) have been equitably distributed geographically among different social groups. Most of these investigations use quantitative methods involving Geographic information systems (GIS).

#### Access to cycling networks

The criteria on where to build cycling infrastructure have traditionally been based on centrality, population density, estimated demand, or focused on recreational purposes. As a consequence, cycling networks often serve communities unevenly (Lee et al., 2017; Winters et al., 2018).

In Europe and the UK, to the best of my knowledge, no research has examined the distribution of cycling networks by socioeconomic group. However, a few studies have investigated the extent to which traffic-calming measures are equitably distributed. For example, Rodgers et al. (2010) found that deprived areas in England and Wales had on average more traffic-calming measures. Steinbach, Grundy, et al. (2011) found that the implementation of 20 mph zones in London targeted mostly deprived areas and that this helped to mitigate socioeconomic inequalities in road injury. Most recently, Aldred et al. (2021) found that the Low traffic neighbourhood (LTN) schemes, set up in London during Covid-19, were overall equitably distributed.

In North America, most studies found important deficiencies among disadvantaged groups in accessing cycling networks. Based on data from 22 large US cities, Braun et al. (2019) found that people with lower socioeconomic status (SES) and minority residents had significantly lower access to bicycle lanes. Similarly, Wang and Lindsey (2017) revealed that the cycling infrastructure in Minnesota disproportionately benefited wealthier populations. Dill and Haggerty (2009) found in Portland that minority communities, youth, and the elder had some limitation in access to cycling lanes; however, low-income populations had greater access. Kent and Karner (2019) found slightly better access by bicycle to specific services in Baltimore for black and low-income communities, but worse for Hispanics. In Canada, Fuller and Winters (2017) reported that low-income populations had less access in most large cities. However, Winters et al. (2018) found the opposite in medium-sized cities (Victoria and Kelowna). In Montreal, Longueuil, and Laval, Houde et al. (2018) found good accessibility for low-income individuals, but inaccessibility for recent immigrants, older populations, and children.

Findings from South America generally coincide: the poor areas tend to be under-served. In Bogotá (Colombia), the low-income areas were the least accessible to the *cicloruta* bicycle network and the *ciclovía* recreational programme, even though most of their users came from these areas (Teunissen et al., 2015). In Rio de Janeiro and Curitiba (Brazil), the wealthiest areas were found to have more than twice the supply of cycling infrastructure than the poorest areas (Tucker and Manaugh, 2018). Likewise, in Santiago de Chile, cycling lanes were also found concentrated in high-income neighbourhoods (Arellano Yévenes and Saavedra Peláez, 2017).

In Melbourne (Australia), the cycling infrastructure was found generally equitably distributed, although the off-road infrastructure was slightly higher in more affluent areas (Pistoll and Goodman, 2014).

#### Access to bike share schemes

One of the main barriers to cycle among disadvantaged populations is not having access to a bicycle, either due to the cost of ownership or lack of secure storage space (McNeil et al., 2017). Bike share schemes (BSS) could provide a solution for these constraints. However, as with cycling networks, the location of BSS is generally based on criteria of centrality and estimated demand, rather than equity or inclusion.

In Europe, all the studies reviewed that assessed the distribution of BSS reported that disadvantaged areas were on average under-served. Goodman and Cheshire (2014) found a higher provision of stations of the London BSS in non-deprived areas, although they argued that over time this scheme had become more inclusive. This was later supported by Lovelace et al. (2020). Clark and Curl (2016) suggested that people with higher qualifications and in employment had higher rates of access to bike share in Glasgow.

In North America, most studies also suggest that BSS benefit affluent populations. In the US, Ursaki and Aultman-Hall (2015) found significant differences in access based on race, income, and education level in Chicago, Denver, Seattle, and New York City. Conrow et al. (2018) found that low-income populations in Phoenix were under-represented. Barajas (2017) examined the distribution of bike-share stations in terms of jobs location in 29 different cities of the US. Their finding was that almost all of the systems served significantly more higher-income and higher-skilled jobs. In Canada, Hosford and Winters (2018) found that in Vancouver, Toronto, Ottawa-Gatineau, and Montréal the disadvantaged had lower access to BSS, but in Hamilton, they had greater access. Fuller et al. (2013) found, however, that in the Island of Montréal individuals with lower incomes lived significantly closer to the BSS. Differences in methods may explain the conflicting results in Montréal.

The two studies found in South America agree: wealthier areas have greater access to BSS. In Porto Alegre, Recife, Rio, Salvador and Sao Paulo (Brazil) the coverage of BSS favoured wealthier and centrally located neighbourhoods with a higher proportion of white population (Duran et al., 2018). In Manizales (Colombia), the upper-class groups had higher access than the middle and lower (Cardona et al., 2017).

Table 1.2 outlines the studies on spatial access to cycling facilities reviewed in this subsection. It shows the country, area, or city of study; the facility assessed (cycling network/BSS); and the result of the accessibility assessment regarding disadvantaged populations of each of the papers.

Table 1.2: Studies on spatial access to cycling facilities.

| Country, area, or city | Facility assessed | Accessibility assessment result | Reference |
|---|---|---|---|
| 22 large US cities (US) | Cycling network | Lower (low SES and minority residents) | Braun et al., 2019. |
| Minnesota (US) | Cycling network | Lower | Wang and Lindsey, 2017 |
| Portland (US) | Cycling network | Greater (low-income people), Lower (black, youth, and old people) | Dill and Haggerty, 2009 |
| Baltimore (US) | Cycling network | Greater (black and low-income people), Lower (Hispanic people) | Kent and Karner, 2019 |
| 8 Canadian cities (CA) | Cycling network | Lower | Fuller and Winters, 2017 |
| Victoria, Kelowna, and Halifax (CA) | Cycling network | Greater (in 2 out of 3 cities) | Winters et al., 2018 |
| Montreal, Longueuil and Laval (CA) | Cycling network | Lower (immigrants, children, and old people), Greater (low-income people). | Houde et al., 2018 |
| Bogotá (CO) | Cycling network | Lower | Teunissen et al., 2015 |
| Rio de Janeiro and Curitiba (BR) | Cycling network | Lower | Tucker and Manaugh, 2017 |
| Santiago (CL) | Cycling network | Lower | Arellano and Saavedra, 2017 |
| Melbourne (AU) | Cycling network | Evenly distributed (although more off-road infrastructure in affluent areas) | Pistoll and Goodman, 2014 |
| London (GB) | BSS | Lower | Lovelace et al, 2020 |
| London (GB) | BSS | Lower | Goodman and Cheshire, 2014 |
| Glasgow (GB) | BSS | Lower | Clark and Curl, 2016 |
| 7 large US Cities (US) | BSS | Lower (non-white, low-educated, low-income people) | Ursaki and Aultman-Hall, 2015 |
| Phoenix (US) | BSS | Lower | Conrow et al., 2018 |
| 29 large cities (US) | BSS | Lower | Barajas, 2017 |
| Island of Montreal (CA) | BSS | Greater | Fuller et al., 2013 |
| 5 Canadian cities (CA) | BSS | Lower (in 4 out of 5 cities) | Hosford and Winters, 2017 |
| 5 Brazilian cities (BR) | BSS | Lower | Duran et al., 2018 |
| Manizales (CO) | BSS | Lower | Cardona et al., 2017 |

### 1.1.3 Socioeconomic inequalities in cycling safety

Previous research has found a positive association between deprivation and road injury risk (Hayes et al., 2008; Christie et al., 2010). This is clearly stated for child pedestrians by extensive literature (e.g. Grayling, 2002; Graham et al., 2005; Cottrill and Thakuriah, 2010; Green et al., 2011). Some studies, most of them more recent, have also investigated the association between deprivation and the risk of cycling injuries.

Most of the studies that have explored the association between deprivation and the risk of cycling injuries focused on the level of deprivation of the *crash location*, i.e., on the level of deprivation of the area where the crash occurred. For example, Aldred et al. (2018) found a slightly higher cycling injury risk in more deprived areas in England. Marshall and Ferenchak (2017) found that the highest income areas in the US had the highest pedestrian and cyclist fatality rate (pedestrian + cyclist casualties/population). They also found, however, that the poorest areas had a relatively high pedestrian and cyclist fatality rate. Rebentisch et al. (2019) found an overrepresentation of cyclist injuries in lower-income blocks of the New York boroughs of Bronx, Queens, and Staten Island, though not in Brooklyn and Manhattan. Morency et al. (2012) and Silverman et al. (2013) examined socio-spatial inequalities in road traffic injuries at intersections in Canada. Morency et al. (2012) reported nearly four times more cycling injuries at intersections in the poorest areas than in the wealthiest areas in the Island of Montreal. Silverman et al. (2013) found that collisions in intersections involving cyclists were more common in areas of increased residential instability and ethnic concentration in Toronto. Carvajal (2020) found that of the seven areas in Bogotá (Colombia) with the highest rate of fatal collisions per square three were in low-income areas, three in middle-income areas, and one in a high-income area.

These studies help to assess how safe areas are, but they provide limited insight into the relative risk of living in a particular place. This is because, although there is evidence that a large proportion of cycling injuries occur close to home (e.g. Steinbach et al., 2013), the location of the crash does not necessarily equate to the place of residence. The focus on the level of deprivation of the *casualty postcode* (or residential level of deprivation), instead of on the crash location, allows a better understanding of how living in a particular place affects the risk of road traffic injury.

Most studies that explored the association between residential level of deprivation and cycling injury risk focused on serious and/or fatal injuries, children, and a specific point in time. For example, Edwards et al. (2008) analysed serious road traffic injuries in children (aged 0 to 15) using Hospital Episode Statistics (HES) data. They found a higher likelihood of serious cycling injuries in children from deprived areas in England (child cyclists seriously injured/100.000 children). O'Toole and Christie (2018) compared the risk of being killed or seriously injured (KSI) between children aged 4 to 10 and 11 to 15 years using the STATS19 database. This study found that young children from the most deprived areas in England were particularly at higher risk of being KSI while cycling (child cyclists KSI/100.000 children). It also found that this risk was much higher in male than in female children, especially in the most deprived areas.

Feleke et al. (2018) analysed inequalities in road traffic fatality risk for all age groups (children and adults) using data from the Office for National Statistics (ONS). They found that child cyclists from the most deprived areas in England had higher fatality rates (child cyclist fatalities/billion km cycled and child cyclist fatalities/million hours cycling) than child cyclists from non-deprived areas; they did not find, however, significant differences for any adult cyclists age group.

Table 1.3 outlines the studies on inequalities in cycling safety reviewed in this subsection. It shows the country, area, or city of study; the mode of transport analysed (cycling, walking and cycling, or all modes); the age groups analysed; the focus of the study (crash location or casualty postcode); the severity of casualties analysed; and the unit of exposure used to estimate the risk in each of the papers.

Table 1.3: Studies on socioeconomic inequalities in cycling safety.

| Country, area, or city | Mode of transport | Age groups | Focus | Severity | Unit of Exposure | Reference |
|---|---|---|---|---|---|---|
| London (GB) | Cycling | All | Crash location | Slight and KSI | Trips | Aldred et al., 2018 |
| England (GB) | All modes | All | Casualty postcode | Fatal | Distance and time | Feleke et al., 2018 |
| England (GB) | Walking and cycling | Children | Casualty postcode | Serious | Population | Edwards et al., 2008 |
| England (GB) | All modes | Children | Casualty postcode | KSI | Population | O'Toole and Christie, 2018 |
| United States | All modes | All | Crash location | Fatality | Population | Marshall et al., 2017 |
| New York (US) | Walking and cycling | All | Crash location | Non-fatal and fatal | Area, population, street network length | Rebentisch et al., 2019 |
| Toronto (CA) | Walking and cycling | All | Crash location | Slight, serious, and fatal | Trips | Silverman et al., 2013 |
| Island of Montreal (CA) | All modes | Over 5 | Crash location | Serious | Trips | Morency et al., 2012 |
| Bogotá (CO) | Cycling | All | Crash location | Non-fatal and fatal | Area | Carvajal et al., 2020 |

## 1.2 Research gaps

Despite the rapid growth of studies in each of the areas reviewed in this section (variations in cycling levels among socioeconomic groups, spatial inequalities in the distribution of cycling facilities, and socioeconomic inequalities in cycling safety), several research gaps remain.

First, many studies have explored cycling levels in relation to age and gender and to a lesser extent disability and ethnicity; however, less have investigated the relationships between income and other socioeconomic factors associated with disadvantage and cycling. Moreover, most of the research in socioeconomic inequalities in cycling levels measured cycling based on bicycle share or a binary dependent variable on whether people cycled or do not cycle for a period of time. Few studies considered other measurements of cycling behaviour such as frequency, distance, and time cycled. There are also very few studies that distinguished between cycling purposes or types of cycling (e.g. Heesch et al., 2015; Aldred et al., 2018).

Second, more research in spatial inequalities in the distribution of cycling facilities in Europe is needed. There are a few studies on traffic calming measures and BSS in the UK but, to the best of my knowledge, no study in Europe has explored equity in the distribution of cycling networks or cycle-friendly environments.

Third, the existing methods to assess spatial equity to cycle have significant limitations. Most of these methods focus on the distribution of cycling facilities (cycling networks or BSS stations), but not on how cyclable an area is. There is evidence that cycling facilities are associated with higher cycling levels (Buehler and Pucher, 2012; Buehler and Dill, 2016; Winters et al., 2016; Lee et al., 2017), but also with other spatial factors such as urban form, connectivity, hilliness, road safety, and aesthetics (Fraser and Lock, 2011; Wang et al., 2016). Some sophisticated studies, however, have used a cyclability indicator that incorporates some of these additional spatial factors (e.g. McNeil, 2011; Winters et al., 2013; Fuller and Winters, 2017).

Fourth, there is a lack of studies that explore the possible link between the different areas reviewed in this section (inequalities in cycling levels, inequalities in the distribution of cycling facilities, and inequalities in cycling safety). Understanding the extent to which these three areas are interconnected is important to make cycling more inclusive and safer.

Fifth, although some studies have analysed the association between residential deprivation and cycling injury risk (e.g. Edwards et al., 2008; Feleke et al., 2018; O'Toole and Christie, 2018), several questions in this area remain unanswered. First, whether there are socioeconomic inequalities in minor cycling injuries. Previous studies focused on serious and/or fatal casualties. This is mostly because these studies compared the injury risk among different modes of transport and given that minor cycling injuries are exceptionally under-reported (Mindell et al., 2012; DfT, 2018b), they were not directly comparable. Second, whether there are socioeconomic inequalities in serious cycling injuries in adults. Feleke et al. (2018) found no significant differences in the risk of dying while cycling in adults, however, the number of cycling fatalities might be too small to show whether cycling is overall more dangerous for a specific socioeconomic group of adults. Third, whether potential socioeconomic inequalities in cycling injury risk in adults vary by sex and age, as it does in children (O'Toole and Christie, 2018). Finally, how socioeconomic inequalities in cycling injury risk have evolved over time.

Sixth, there is very little research on non-spatial barriers to cycling among socioeconomically disadvantaged populations. Previous research found not having a bicycle or associated equipment, lack of secure storage at work and home (McNeil et al., 2017), and cultural aspects such as self-image and social norms (Bird, 2010; Steinbach, Green, et al., 2011) as some of the main barriers to cycle among these groups. However, more qualitative research in this regard is needed.

Seventh, most research in each of the areas reviewed in this section is done in Western countries. More research is needed in low- and middle-income countries. This is especially important in countries such as China or India, which together represent 37% of the entire world population and, where cycling has traditionally been one of the most important modes of transport. Investigation of cycling inequalities in these countries is essential to help reduce transport disadvantage issues, which are generally higher than in Western countries.

## 1.3 Research aim and questions

This thesis aims to better understand the relationships between cycling and socioeconomic disadvantage in England from three perspectives: behaviour, environment, and safety. This will provide an evidence base that could feed into future policies that are effective at enabling socioeconomically disadvantaged populations to cycle more and safer. In addition, making cycling for transport more inclusive and safer for all will contribute to reducing motorised transport, which will help to tackle other issues of fundamental importance for society, such as climate change, complex mobility problems, and environmental pollution.

This aim leads to three research questions (RQ1, RQ2, and RQ3) successively addressed by three empirical papers presented in Chapters 2 to 4. RQ1 aims to fill the first research gap described in the previous section; RQ2 aims to fill the second, third, and fourth gaps; and RQ3 aims to fill the fifth gap. The sixth and seventh gaps are not addressed in this research.

*RQ1: To what extent do income and other factors of socioeconomic disadvantage influence cycling behaviour?*

The paper in Chapter 2 addresses this first question by analysing the relationship between income and other factors of socioeconomic disadvantage (i.e. education, economic status, parenting, single-parenting, driving licence holding, and car availability) and three cycling behaviours (cycling participation, cycling frequency, and cycling distance), distinguishing between utility and leisure cycling.

*RQ2: To what extent do the environments in which socioeconomically disadvantaged populations live explain socioeconomic inequalities in cycling participation?*

The paper in Chapter 3 addresses this second question by examining i) the distribution of cycling levels and five environmental variables (cycle paths, cycle lanes, levels of traffic stress, population density, and hilliness) by area deprivation level, and ii) the associations between cycling levels, these five environmental variables, and deprivation level (controlling for other individual variables).

*RQ3: To what degree have socioeconomically disadvantaged populations a greater risk of being injured or killed while cycling than non-socioeconomically disadvantaged populations?*

The paper in Chapter 4 addresses this final question by exploring i) inequalities in cycling injury risk by residential deprivation for all recorded casualties (slight, serious, and fatal), ii) whether these inequalities vary by sex and age, and iii) how they have changed over time.

## 1.4 Research design

Quantitative research methods were used in all the empirical papers. All the datasets used were secondary, anonymised, and open or safeguarded data. No ethical approval was required.

The paper in Chapter 2 used data from the 2017 National Travel Survey (NTS) (DfT, 2017b). Descriptive statistics and three different regression models (a binomial, a zero-truncated negative binomial, and a gamma regression) were estimated to predict cycling participation, cycling frequency, and cycling distance.

The paper in Chapter 3 used data at the individual level from the 2017 Active Lives Adult Survey (ALS) (Sport England, 2019) and at the area level from several sources and years. 'Level of deprivation' was obtained from the English Indices of Deprivation 2015 (DfCLG, 2015); 'cycle tracks' and 'cycle lanes' from the Cycling Infrastructure Prioritisation Toolkit (extracted from the Open Street Map [OSM] mid-2017) (University of Leeds, 2019); 'quietness' (% score per level of stress of routes in each area) from the Cycle Streets website (Cycle Streets, 2020); 'population density' from the Office for National Statistics (ONS, 2019b); and 'hilliness' from the Propensity for Cycle Tool (Lovelace et al., 2017). Descriptive statistics and two multilevel regression models (a logistic and a gamma regression) were estimated to predict cycling participation and cycling duration.

Finally, the paper in Chapter 4 used the STATS19 database of road traffic casualties in Britain (DfT, 2020c), the NTS (DfT, 2020a), and population estimates for England (ONS, 2020) over the six-year period 2014-2019. Cycling injury rates were estimated as the ratio of slight, serious, and fatal cycling casualties per billion kilometres (Bkm) cycled by i) residential IMD quintile, ii) residential IMD quintile and sex and age group, and iii) residential IMD quintile and year.

Figure 1.1 illustrates the connection between datasets, chapters/papers, and analysis techniques used.

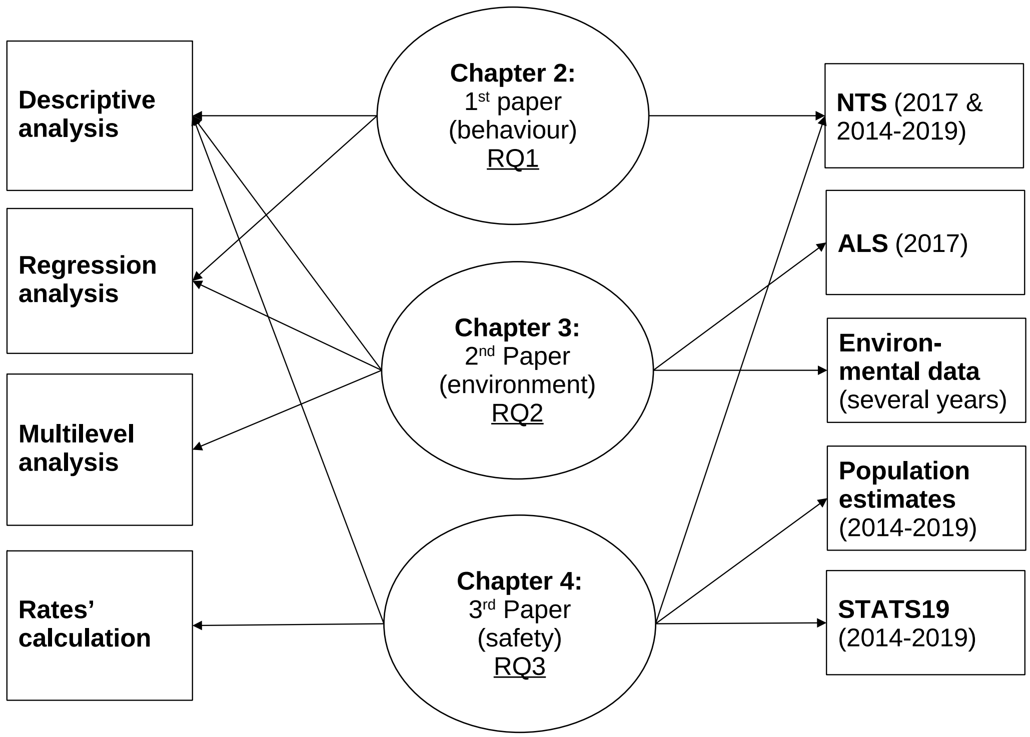


Figure 1.1: Connection between datasets, chapters/papers, and analysis techniques.

## 1.5 Thesis outline

This thesis is composed of five chapters. Chapters 2 to 4 are three empirical studies based on three papers published in international peer-reviewed journals. Each of these works focuses on a different area of disadvantage: behaviour (Chapter 2), environment (Chapter 3), and safety (Chapter 4). The content of the papers in the thesis have been reformatted and in some cases rewritten to ensure integration with the central arguments of the thesis. Finally, Chapter 5 summarises the main findings to answer the research questions, discusses limitations and other issues to consider when interpreting the results of the thesis as a whole, indicates policy implications of the findings, recommends directions for further research, and concludes with a summary of the entire work of the thesis.

Figure 1.2 illustrates the connection between the chapters and the research questions of the thesis.

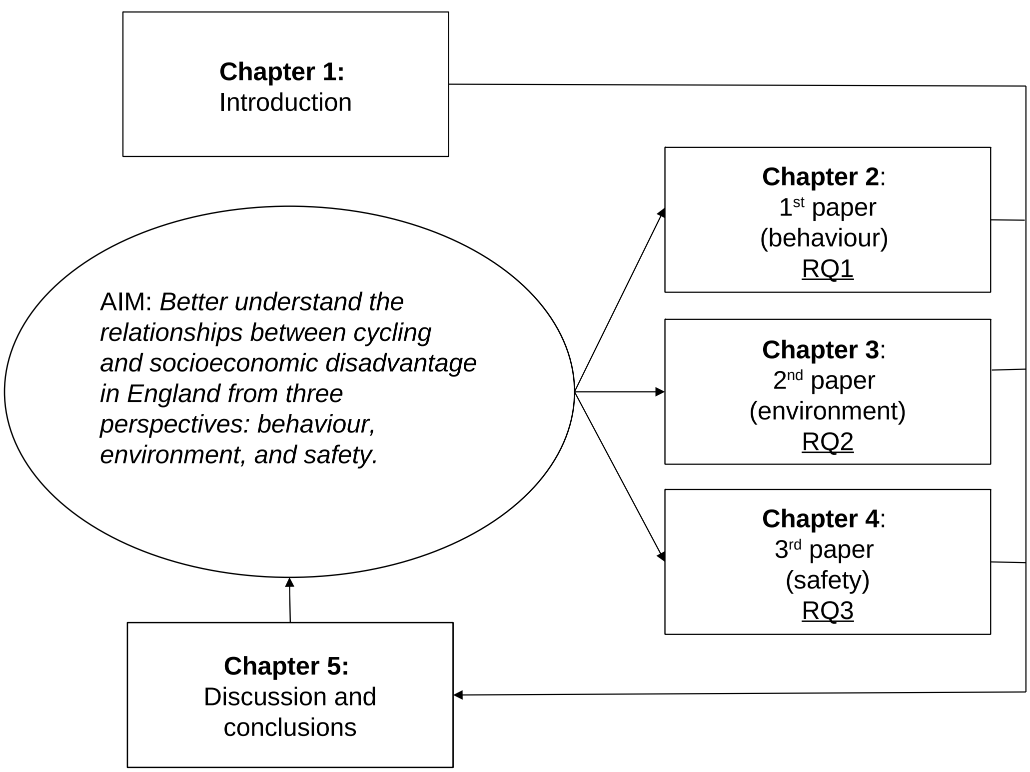


Figure 1.2: Connection between chapters/papers, research questions, and aim.

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# Chapter 2

# Cycling behaviour and socioeconomic disadvantage: An investigation based on the English National Travel Survey

This chapter is based on the paper: Vidal Tortosa, E., Lovelace, R., Heinen, E., Mann, R.P., 2021. *Cycling behaviour and socioeconomic disadvantage: An investigation based on the English National Travel Survey.* Transportation Research Part A: Policy and Practice 152, 173–185. https://doi.org/10.1016/j.tra.2021.08.004

# Abstract

One of the main challenges for policymakers aiming to promote cycling in car-oriented transport systems is how to increase social diversity among its users. The under-representation of certain groups makes it difficult to normalise cycling and distribute its benefits throughout society. Many studies have explored cycling levels in relation to age and gender, and to a lesser extent disability and ethnicity. Less attention has been paid to bicycle use related to income and other socioeconomic factors associated with disadvantage. This study aims to better understand the relationship between income and other factors of socioeconomic disadvantage and cycling behaviour. We analysed data from the English National Travel Survey to estimate the likelihood of cycling participation (if individuals cycle at all), cycling frequency ('how often' they cycle), and cycling distance ('how far' they cycle) using regression models. We found that people in lower-income households cycle less for transport, particularly for commuting, than people in higher-income households. However, no income inequalities were found for leisure cycling. In addition, low-income leisure cyclists were found to cycle more often, but higher-income leisure cyclists further. Our findings may have important policy implications. Favouring a broader focus on non-commuting cycling and subsidising cycle access and maintenance could help to diversify cycling.

**keywords**: Cycling; Cycling frequency; Cycling distance; Cycling inequalities; Social disadvantage; Health inequalities.

## 2.1 Introduction

The benefits of cycling are increasingly recognised. Cycling is healthy for body and mind, and as a mode of transport (utility cycling) is convenient, affordable, and environmentally friendly (Heinen et al., 2010; Pucher et al., 2010; Oja et al., 2011; Garrard et al., 2012). Consequently, cycling promotion has been gradually more prominent in high-income car-oriented countries during the last two decades (Pucher and Buehler, 2012).

One of the main challenges for policymakers aiming to promote cycling in car-oriented transport systems is how to increase social diversity among its users. The under-representation of certain groups makes it difficult to normalise cycling and distribute its benefits throughout society. Cycling diversity is important to increase overall cycling levels, with health and environmental benefits for the whole of society, but it can also help to reduce inequalities of certain social groups in terms of transport and health (Iacono et al., 2010; Lee et al., 2017). Cycling can improve mobility and increase access to jobs, education, recreation, and social interaction for social groups with difficulties to afford other modes of transport (particularly cars, but also public transport) (Golub, 2016). Moreover, cycling can increase the physical activity of less active groups and, consequently, improve their health and well-being (Oja et al., 2011; Garrard et al., 2012).

Cycling inequalities in age and gender have been extensively studied. In car-oriented countries, female and elderly populations seem to cycle considerably less (particularly for transport) than male and young/middle-aged populations (Heinen et al., 2010; e.g. Heesch et al., 2012). These disparities are less present or non-existent in places where cycling is more common (Aldred et al., 2016; Goodman and Aldred, 2018).

The relationship between disability and ethnicity have also received some scientific attention. In England, people with disabilities were found half as likely to have cycled in the past four weeks as people without disabilities (Goodman and Aldred, 2018). Enacting more policies focused on inclusive infrastructure seems key to increase cycling uptake among these populations (Clayton et al., 2017; Andrews et al., 2018). Cycling levels also vary by ethnic group (Harms, 2007; Goodman and Aldred, 2018). Unlike age, gender, and disability, these differences are observed in countries with low as well as high cycling levels. In the Netherlands and Denmark, where overall cycling levels are high, ethnic minorities tend to cycle less frequently (Harms, 2007; Heinen et al., 2010). Similarly, in England, where cycling is marginal, non-white individuals were found around half as likely as white people to have cycled in the past four weeks (Goodman and Aldred, 2018). Cultural differences may explain these differences (Harms, 2007).

More complex and less well understood are cycling inequalities related to income and other socioeconomic factors associated with disadvantage. Most studies agree that leisure cycling is more common among higher-income groups (Kamphuis et al., 2008; Heesch et al., 2014; e.g. Heesch et al., 2015). However, the relationship between income and utility cycling does not seem simple or universal. In Canada, a study in cities with a population greater than 50,000 (Winters et al., 2007) and another in the Metro Vancouver Region (Winters et al., 2010) found a negative association between income and utility cycling. Similarly, in the US, the 2009 National Household Travel Survey reported a higher bike share among the lowest income quartile (Pucher et al., 2011); however, another study using data from 42 US large cities (Dill and Carr, 2003) found no association between income and commuting cycling. In the UK, most studies found that low-income groups cycle less for transport (e.g. Parkin et al., 2008 in England and Wales; Green et al., 2010 in London; and Whyte and Waugh, 2015 in Scotland); although one study found commuting cycling more common among socioeconomically disadvantaged groups in England and Wales (Goodman, 2013). In Australia, specifically in the Sydney Greater Metropolitan Area (Merom et al., 2010), Brisbane (Heesch et al., 2014; Heesch et al., 2015), and Queensland state (Sahlqvist and Heesch, 2012) low-income populations were found to cycle less.

Since cycling has been connected to the presence of cycling infrastructure (Dill and Carr, 2003; Mölenberg et al., 2019), one hypothesis to explain, at least in part, the inequalities in cycling levels by socioeconomic groups is that these may depend on the socio-spatial distribution of cycling infrastructure. However, there does not seem to be a clear relationship between socioeconomic inequalities in access to cycling infrastructure and socioeconomic inequalities in cycling levels. For example, in the US where disadvantaged groups have significantly lower access to bike lanes (Braun et al., 2019), lower-income populations have been found to cycle more (Pucher et al., 2011) or no less than higher-income populations (Dill and Carr, 2003); while in the UK and Australia where access to cycling infrastructure is more equitable (Pistoll and Goodman, 2014), low-income populations seem to cycle less (Parkin et al., 2008; Green et al., 2010; Merom et al., 2010; Sahlqvist and Heesch, 2012; Heesch et al., 2014; Heesch et al., 2015). Beyond infrastructural factors, other barriers to cycling found particularly important for socioeconomically disadvantaged populations include not having a bicycle or associated equipment, lack of secure storage at work and home (McNeil et al., 2017), and cultural aspects such as self-image and social norms (Bird, 2010; Steinbach, Green, et al., 2011).

The few studies that have investigated the association between income and cycling have tended to measure cycling based on bike mode share or on a binary variable on whether people cycled or did not cycle over a period of time. By contrast, other measures of cycling behaviour such as how often or how far population cycle have been rarely explored. Moreover, among the studies that have studied this association, only a few have distinguished between utility cycling and leisure (Heesch et al., 2014; e.g. Heesch et al., 2015).

This paper analyses the relationship between income and other factors of socioeconomic disadvantage (i.e. education, economic status, parenting, single parenting, driving licence holding, and car availability) and three cycling behaviours (cycling participation, cycling frequency, and cycling distance), distinguishing between utility cycling and leisure cycling. Better understanding socioeconomic inequalities in cycling behaviour and to what extent these inequalities occur per type of cycling can help in identifying policies best suited to meet the needs of disadvantaged populations to cycling, and in turn, diversify and make more equitable cycling uptake.

## 2.2 Data and methods

### 2.2.1 National Travel Survey

We used data from the National Travel Survey (NTS), the primary source of data on individual travel among residents of England. Individuals in sampled households were interviewed face-to-face to collect personal information, such as age, gender, economic status, driving licence holding, and car access. They were also asked to complete a seven-day travel diary and provide details of trips undertaken, including mode of travel, purpose, and trip length. The dataset used for this study is the End User Licence version from 2017 (DfT, 2018a). In 2017, the number of households included in the diary sample (i.e. fully co-operating with completed individual interviews and travel diaries) was 6,135 and the number of individuals covered 14,541.

The NTS is organised in several files for households, vehicles, individuals, days, journeys and stages. For this study, we used the Journeys, Households, and Individuals files and carried out the following steps to prepare the data for analysis.

1) Using the Journeys file, we calculated for each individual a binary variable expressing whether they cycled or did not cycle at least once a week (cycling participation), a count variable specifying their number of weekly trips (cycling frequency), and a continuous variable specifying the weekly miles they travelled by bicycle (cycling distance). For the calculation of these variables, we applied weights provided by the NTS to adjust for the drop-off in the number of trips recorded by respondents during the course of the travel week. Each of

these variables was calculated for utility cycling and for leisure cycling[1]. This information was added to the Individuals file.

2) From the Households file, we selected a range of variables by individual: area type, household income quintile, children in the household, and single parent family. This information was also added to the Individuals file.

3) Finally, from the Individuals file, we considered the variables age, sex, ethnicity, mobility difficulties, educational qualifications, economic status, driving licence holding, car access, and own or use a bicycle.

Our analyses were restricted to adults (population 16 and over). Sixty-seven participants were excluded with missing data (in the variables educational qualifications, driving licence holding, car access, area type, and ethnicity) and after adjusting for non-response bias (applying the non-response weights provided by the NTS), the total final diary sample was of 11,897.

### 2.2.2 Measurements

#### Dependent variables

As dependent variables, we used three measurements of cycling behaviour 1) cycling participation (a binary variable expressing whether individuals cycled or did not cycle at least once a week), 2) cycling frequency (a count variable specifying the number of weekly cycling trips of those who cycled at least once a week), and 3) cycling distance (a continuous variable specifying the weekly miles that those who cycled at least once a week travelled by bicycle), separately calculated for utility and leisure cycling.

#### Independent variables

The selection of the independent variables was based on the literature on transport disadvantage (Social Exclusion Unit, 2003; Lucas et al., 2016). As explanatory variables, we used seven socioeconomic disadvantage factors. Household income quintile (1st (lowest

[1] Leisure cycling refers to all cycling for the trip purpose category 'leisure' pre-defined in the variable TripPurpose B04ID, which is an aggregation of the trip purpose categories of the variable TripPurpose B02ID: visiting friends at private home, visiting friends elsewhere, entertainment / public activity, sport, holiday, and day trip. Utility cycling refers to all cycling for the rest of trip purpose categories of the variable TripPurpose B04ID, i.e., commuting, business, education/escort education, shopping, other escort, and personal business. We used these two aggregated categories of cycling (utility and leisure) for simplicity and to obtain a sufficient sample size to provide reliable models of cycling frequency and cycling distance.

20%), 2nd, 3rd, 4th, 5th), which we used as a proxy for socioeconomic disadvantage, and six other specific variables associated with socioeconomic disadvantage: educational qualifications (any certificated educational qualifications: yes, no)[2], economic status (full-time, part-time, unemployed, student, economically inactive), children in the household (yes, no), single parent family (yes, no), driving licence (yes, no), and car access (yes, no). As control variables, we included socio-demographic characteristics previously associated with cycling levels (Heinen et al., 2010; Winters et al., 2010; Fraser and Lock, 2011; Wang et al., 2016). These were area type (inner London, other urban area - over 250k population, other urban area - 25k to 250k population, other urban area - 10k to 25k population, other urban area - 3k to 10k population, built-up areas, rural), age (16-29, 30-64, >64), sex (male, female), ethnicity (white, non-white), and mobility difficulties (yes, no).

### 2.2.3 Statistical analyses

To examine the extent to which income and other socioeconomic disadvantage factors are associated with cycling behaviour, we first evaluated descriptive statistics using bar graphs and contingency tables broken down by household income quintile. Next, we estimated Odds Ratios (ORs) based on the set of independent variables using three regression models that followed a hierarchical structure. The first was a binomial regression model to predict the binary dependent variable 'cycling participation', which expresses whether individuals cycled or did not cycle at least once a week; and for those who cycled at least once a week, we used two other regression models: a zero-truncated negative binomial regression to predict the count dependent variable 'cycling frequency' (i.e. the number of weekly cycling trips of those who cycled at least once a week), and a gamma regression to predict the continuous dependent variable 'cycling distance' (i.e. the weekly miles that those who cycled at least once a week travelled by bicycle). We conducted these analyses for utility and leisure cycling separately. Figure 3.1 illustrates the conceptual models.

[2] This is the only variable regarding education levels provided in the reduced version (EUL) of the NTS 2017 used in this study. Another categorical variable on educational qualifications (EdAttn4 B01ID) with seven levels (from Higher degree or postgraduate qualifications to no qualifications) is only available in the Secure and Special License dataset versions of the NTS.

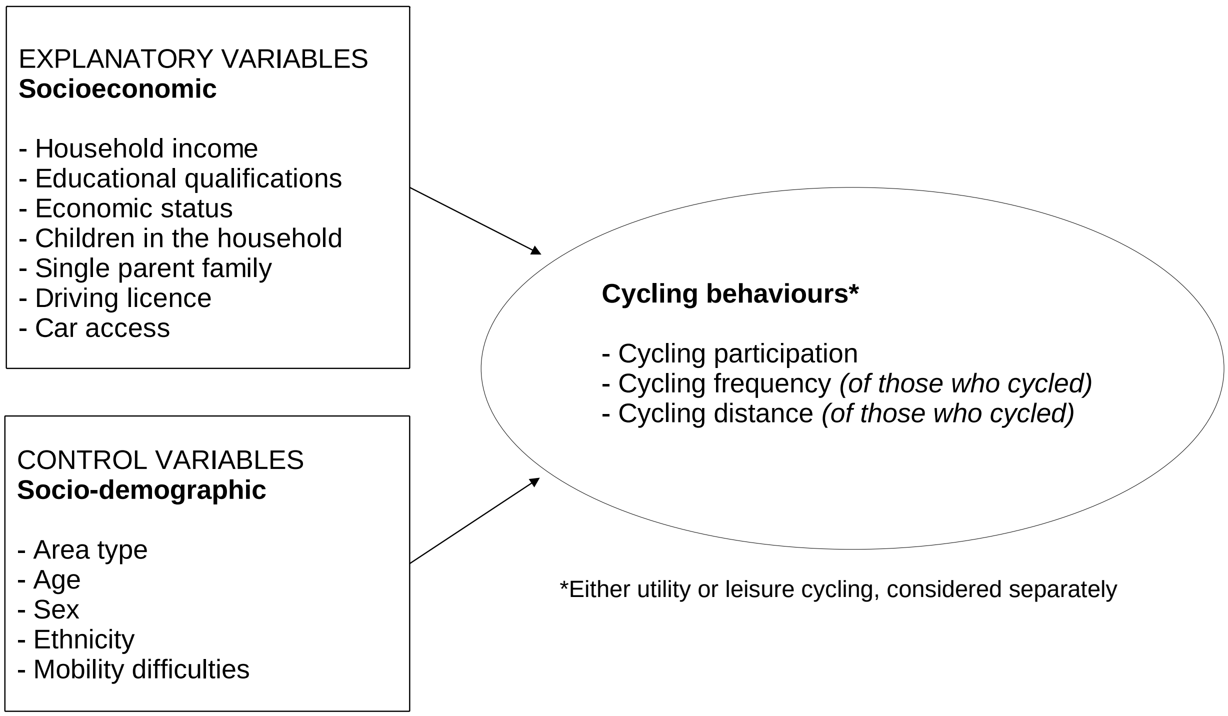


Figure 2.1: Conceptual models.

Several independent variables were initially considered in the models but later discarded. 'Own or use a bicycle', which collects whether individuals own or have use of a household or a non-household bicycle, was discarded because we understood that owning or having use of a bicycle implies an intention to want to cycle. Therefore, its inclusion in the models would have been to some extent like considering the variable we were predicting and may have hindered potential associations between other independent variables and cycling participation. Even so, this variable was considered in the descriptive statistics analysis. The variables 'type of household', 'walk time from household to the nearest bus stop', and 'health condition' were discarded because were found not significantly associated ($p<0.05$) with cycling participation.

A multicollinearity test was conducted to avoid multiple factors correlated to each other using the generalised variance inflation factors (GVIF) (Fox and Monette, 1992). All values were lower than 2, except for a pair between 2 and 3, indicating no substantial multicollinearity among the independent variables (James et al., 2013).

To test for any geographical variation between London and the rest of England and to what extent this variation might affect the results for all England, we fitted the cycling participation model separately for London, the rest of England, and all England. This analysis was not performed, however, for the frequency and distance models because the London sample size of those who participated in cycling was too small (less than 100) to get meaningful results.

## 2.3 Results

### 2.3.1 Descriptive statistics

Individuals of the 2017 NTS sample made 1.7% of their trips by bicycle: 1.2% for utility purposes (i.e., commuting, shopping, education, escort education, personal business, business, and other escort) and 0.6% for leisure (i.e., visiting friends at private home, visiting friends elsewhere, entertainment / public activity, sport, holiday, and day trip).

Commuting was the main purpose for cycling for individuals from all household income quintiles. However, people in the lower household income quintile made a quarter as many commuting cycling trips as people in the highest household income quintile. The differences concerning other cycling trip purposes were less pronounced being in some cases, such as visiting friends at private home and education, greater among people in lower household income quintiles than among people in higher household income quintiles (Figure 2.2).

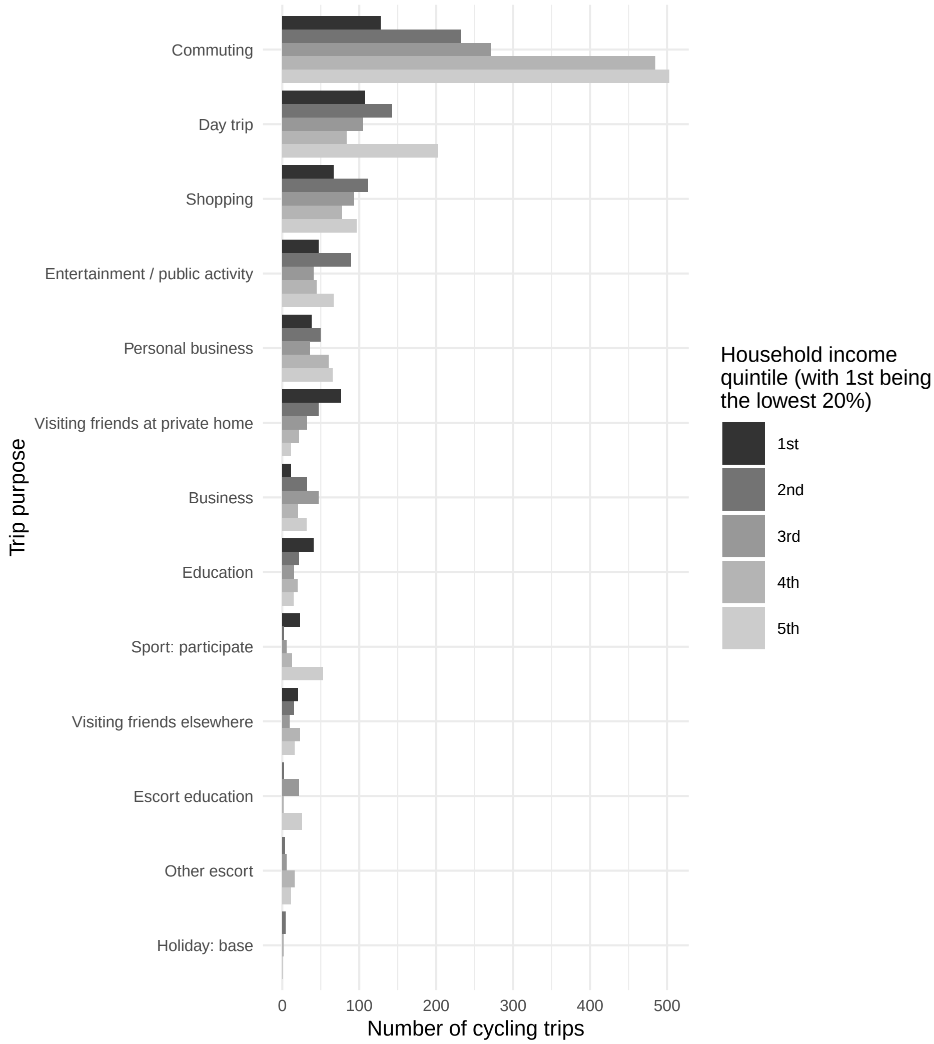


Figure 2.2: Cycling trips by purpose and household income quintile.

Five per cent of individuals participated in a cycling activity at least once a week: 3.3% for utility cycling and 3.0% for leisure cycling. There was a gradual positive association between household income quintile and utility cycling participation, i.e., the higher the income, the greater the number of individuals who cycled at least once a week for utility purposes. The relationship between household income quintile and leisure cycling was not gradual, although individuals in the highest quintile (5th) cycled more for leisure than the rest (Figure 2.3).

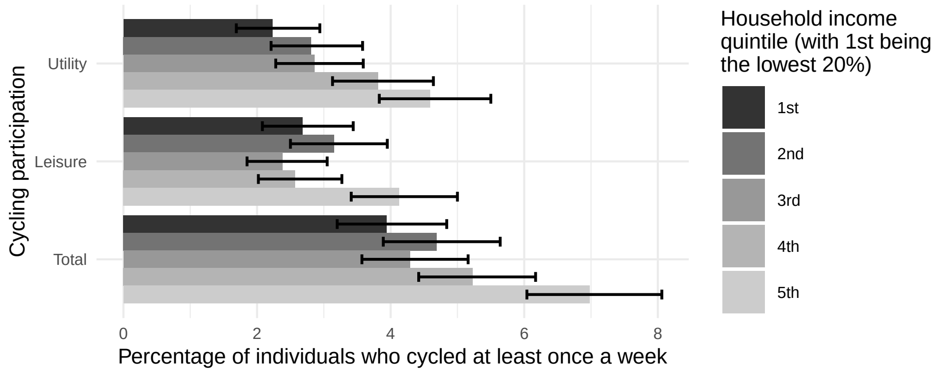


Figure 2.3: Cycling participation by type of cycling and household income quintile. The error bars show 95% confidence intervals of the observed proportions.

The mean weekly cycling trips of those who cycled at least once a week was 6.6: 6.8 for utility cyclists and 3.7 for leisure cyclists. Utility cyclists from the lowest income quintile (1st) cycled moderately less frequently than utility cyclists from the rest of the quintiles. By contrast, leisure cyclists with lower incomes cycled progressively more frequently than leisure cyclists with higher incomes (Figure 2.4).

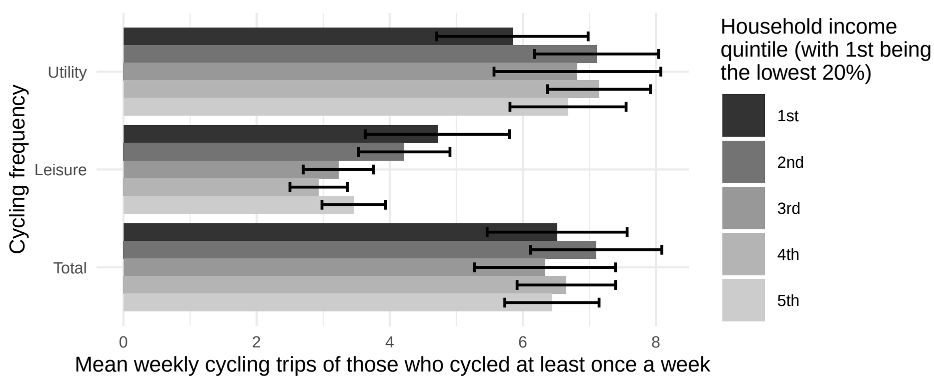


Figure 2.4: Cycling frequency by type of cycling and household income quintile. The error bars show 95% confidence intervals of the observed means.

The distance cycled represented 0.9% of the total distance travelled by all modes of transport. The mean weekly miles cycled for those who cycled at least once a week was 24.5: 19.9 for utility cyclists and 19.6 for leisure cyclists. Although there was no gradual association between household income quintile and the mean of weekly miles cycled, both the utility and leisure distance means were higher for cyclists in the higher household income quintiles, and lower for cyclists in the lowest household income quintile (1st). (Figure 2.5).

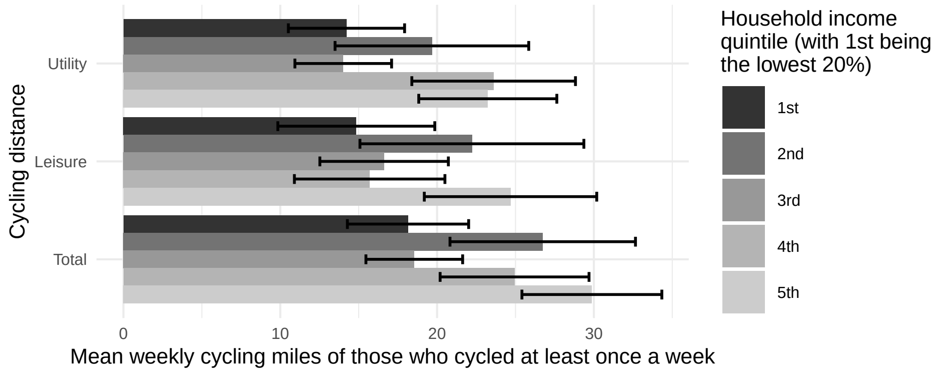


Figure 2.5: Cycling distance by type of cycling and household income quintile. The error bars show 95% confidence intervals of the observed means.

All the explanatory variables (educational qualifications, economic status, children in the household, single parent family, driving licence, car access, and own or use a bicycle) were aligned with 'household income quintile', with lower income quintiles linked to disadvantages of each of these factors (Table 2.1). This observation supports our use of 'household income quintile' as the main explanatory variable and proxy for socioeconomic disadvantage. The disparity of owning or having use of a bicycle should be noted, due to the great influence that this might have on cycling use. While some people might not have a bicycle simply because they are not keen on cycling, others might not cycle because they do not have access to a bicycle. Only two in ten in the 1st quintile owned or had use of a bicycle, compared to almost five in ten in the 5th quintile.

Table 2.1: Independent variables by household income quintile.

| | 1st (lowest) (n=2185) | 2nd (n=2264) | 3rd (n=2516) | 4th (n=2496) | 5th (highest) (n=2436) | Overall (n=11897) |
|---|---|---|---|---|---|---|
| Educational qualifications: Yes (n, perc.)[a b] | 1401 (64) | 1612 (71) | 2113 (84) | 2204 (88) | 2184 (90) | 9513 (80) |
| Educational qualifications: No | 785 (36) | 652 (29) | 403 (16) | 292 (12) | 252 (10) | 2384 (20) |
| Economic status: Full Time | 453 (21) | 662 (29) | 1216 (48) | 1557 (62) | 1737 (71) | 5625 (47) |
| Economic status: Part Time | 303 (14) | 347 (15) | 417 (17) | 320 (13) | 260 (11) | 1648 (14) |
| Economic status: Unemployed | 92 (4) | 29 (1) | 32 (1) | 15 (1) | 14 (1) | 183 (3) |
| Economic status: Student | 213 (10) | 137 (6) | 116 (5) | 79 (3) | 74 (3) | 619 (5) |
| Economic status: Economically inactive | 1124 (51) | 1088 (48) | 734 (29) | 524 (21) | 352 (14) | 3822 (32) |
| Children in the household: Yes | 750 (34) | 624 (28) | 834 (33) | 652 (26) | 716 (29) | 3575 (30) |
| Children in the household: No | 1436 (66) | 1640 (72) | 1681 (67) | 1844 (74) | 1721 (71) | 8322 (70) |
| Single parent family: Yes | 116 (5) | 55 (2) | 33 (1) | 10 (0) | 10 (0) | 224 (2) |
| Single parent family: No | 2069 (95) | 2209 (98) | 2483 (99) | 2486 (100) | 2426 (100) | 11673 (98) |
| Driving licence: Yes | 1449 (66) | 1656 (73) | 2066 (82) | 2167 (87) | 2213 (91) | 9550 (80) |
| Driving licence: No | 736 (34) | 608 (27) | 450 (18) | 329 (13) | 223 (9) | 2347 (20) |
| Car access: Yes | 1408 (64) | 1737 (77) | 2196 (87) | 2220 (89) | 2124 (87) | 9685 (81) |
| Car access: No | 778 (36) | 526 (23) | 320 (13) | 276 (11) | 312 (13) | 2212 (19) |
| Own or use a bicycle: Yes | 510 (23) | 682 (30) | 960 (38) | 1006 (40) | 1180 (48) | 4338 (36) |
| Own or use a bicycle: No | 1675 (77) | 1582 (70) | 1555 (62) | 1490 (60) | 1257 (52) | 7559 (64) |
| Area type: Inner London | 135 (6) | 146 (6) | 90 (4) | 142 (6) | 192 (8) | 705 (6) |
| Area type: Built-up areas | 277 (13) | 322 (14) | 339 (13) | 325 (13) | 233 (10) | 1496 (13) |
| Area type: > 250k | 571 (26) | 587 (26) | 716 (28) | 655 (26) | 548 (22) | 3077 (26) |
| Area type: 25k to 250k | 138 (6) | 163 (7) | 249 (10) | 204 (8) | 171 (7) | 926 (8) |
| Area type: 10k to 25k | 86 (4) | 153 (7) | 149 (6) | 158 (6) | 152 (6) | 698 (6) |
| Area type: 3k to 10k | 775 (35) | 582 (26) | 604 (24) | 657 (26) | 691 (28) | 3308 (28) |
| Area type: Rural | 203 (9) | 311 (14) | 368 (15) | 355 (14) | 449 (18) | 1686 (14) |
| Age: 16-29 | 568 (26) | 417 (18) | 606 (24) | 559 (22) | 437 (18) | 2587 (22) |
| Age: 30-64 | 1051 (48) | 1056 (47) | 1349 (54) | 1517 (61) | 1745 (72) | 6719 (56) |
| Age: >64 | 566 (26) | 790 (35) | 560 (22) | 420 (17) | 254 (10) | 2590 (22) |
| Sex: Male | 1011 (46) | 1033 (46) | 1210 (48) | 1282 (51) | 1278 (52) | 5813 (49) |
| Sex: Female | 1175 (54) | 1231 (54) | 1306 (52) | 1214 (49) | 1158 (48) | 6084 (51) |
| Ethnicity: White | 1775 (81) | 1992 (88) | 2217 (88) | 2245 (90) | 2142 (88) | 10371 (87) |
| Ethnicity: Non-white | 410 (19) | 271 (12) | 298 (12) | 251 (10) | 294 (12) | 1526 (13) |
| Mobility difficulties: Yes | 309 (14) | 296 (13) | 196 (8) | 123 (5) | 95 (4) | 1019 (9) |
| Mobility difficulties: No | 1876 (86) | 1968 (87) | 2320 (92) | 2373 (95) | 2342 (96) | 10878 (91) |

[a] Number and percentage of individuals.

[b] For educational qualifications 'Yes' indicates any certificated educational qualifications.

### 2.3.2 Multivariate analyses

#### Utility cycling

We found that being in the highest household income quintile (5th) is significantly positively associated with the likelihood of utility cycling participation (Table 2.2, binomial model). Specifically, individuals in the 5th income quintile were 62% more likely to cycle for transport than people in the 1st quintile. Other socioeconomic factors significantly positively associated with engaging in utility cycling were being a part-time worker (Odds ratio 1.43, 95% CI 1.05-1.96) and lacking car access (OR 1.98, 95% CI 1.47-2.68). Among the control variables, utility cycling participation was significantly negatively associated with the area types urban from 10k to 25k population, built-up and rural, and with being a female, and non-white; and significantly positively associated with having no mobility difficulties.

No significant association was found between cyclists' household income quintile and the odds of cycling for transport more frequently (Table 2.2, zero-truncated negative binomial model). However, cycling for transport more frequently was significantly negatively associated with being a student (OR 0.68, 95% CI 0.48-0.97) and economically inactive (OR 0.57, 95% CI 0.43-0.76); and positively associated with lacking car access (OR 1.21, 95% CI 1.01-1.45). Regarding the control variables, a lower likelihood of utility cycling frequency in rural areas was found.

We also found no association between utility cyclists income and utility cycling distance (Table 2.2, gamma model). A significant negative association was found, however, between being a part-time worker (OR 0.71, 95% CI 0.51-0.98), unemployed (OR 0.33, 95% CI 0.12-0.91), a student (OR 0.58, 95% CI 0.34-0.99), economically inactive (OR 0.39, 95% CI 0.26-0.58), having no children (OR 0.74, 95% CI 0.59-0.98), and cycling further away for transport. Lacking car access was also positively associated with utility cycling distance (OR 1.38, 95% CI 1.04-1.84). Among the control variables, a significant negative association was found between being a female utilitarian cyclist and cycling distance.

Table 2.2: Multivariate associations with utility cycling participation, frequency, and distance.

| | Cycling participation | Cycling frequency | Cycling distance |
|---|---|---|---|
| | Binomial model [a] OR (95% CI)[d] | Zero-truncated model [b] OR (95% CI) | Gamma model [c] OR (95% CI) |
| Household income quintile: 1st (lowest) | 1 | 1 | 1 |
| Household income quintile: 2nd | 1.22 (0.82, 1.80) | 1.19 (0.91, 1.56) | 1.25 (0.83, 1.88) |
| Household income quintile: 3rd | 1.12 (0.75, 1.66) | 1.10 (0.84, 1.44) | 0.92 (0.61, 1.38) |
| Household income quintile: 4th | 1.35 (0.92, 1.99) | 1.14 (0.87, 1.50) | 1.47 (0.98, 2.22) |
| Household income quintile: 5th (highest) | 1.62 (1.10, 2.38) * | 1.11 (0.85, 1.45) | 1.35 (0.90, 2.02) |
| Educational qualifications: Yes | 1 | 1 | 1 |
| Educational qualifications: No | 0.72 (0.52, 1.01) | 1.16 (0.91, 1.49) | 1.36 (0.93, 1.99) |
| Economic status: Full Time | 1 | 1 | 1 |
| Economic status: Part Time | 1.43 (1.05, 1.96) * | 0.95 (0.77, 1.17) | 0.71 (0.51, 0.98) * |
| Economic status: Unemployed | 0.63 (0.24, 1.63) | 0.51 (0.24, 1.07) | 0.33 (0.12, 0.91) * |
| Economic status: Student | 1.06 (0.64, 1.75) | 0.68 (0.48, 0.97) * | 0.58 (0.34, 0.99) * |
| Economic status: Economically inactive | 0.72 (0.48, 1.06) | 0.57 (0.43, 0.76) *** | 0.39 (0.26, 0.58) *** |
| Children in the household: Yes | 1 | 1 | 1 |
| Children in the household: No | 1.05 (0.83, 1.33) | 0.92 (0.78, 1.08) | 0.74 (0.59, 0.98) * |
| Single parent family: Yes | 1 | 1 | 1 |
| Single parent family: No | 2.26 (0.64, 7.99) | 2.08 (0.78, 5.56) | 2.51 (0.66, 9.54) |
| Driving licence: Yes | 1 | 1 | 1 |
| Driving licence: No | 1.06 (0.77, 1.45) | 0.87 (0.71, 1.07) | 0.82 (0.60, 1.13) |
| Car access: Yes | 1 | 1 | 1 |
| Car access: No | 1.98 (1.47, 2.68) *** | 1.21 (1.01, 1.45) * | 1.38 (1.04, 1.84) * |
| Area type: Inner London | 1 | 1 | 1 |
| Area type: > 250k | 1.02 (0.67, 1.55) | 0.95 (0.72, 1.25) | 1.01 (0.66, 1.55) |
| Area type: 25k to 250k | 0.85 (0.57, 1.26) | 1.17 (0.92, 1.50) | 0.84 (0.57, 1.24) |
| Area type: 10k to 25k | 0.58 (0.34, 0.97) * | 0.92 (0.65, 1.31) | 0.97 (0.57, 1.67) |
| Area type: 3k to 10k | 0.57 (0.32, 1.02) | 0.81 (0.55, 1.20) | 0.88 (0.48, 1.59) |
| Area type: Built-up areas | 0.41 (0.27, 0.62) *** | 0.99 (0.75, 1.29) | 0.96 (0.63, 1.46) |
| Area type: Rural | 0.44 (0.27, 0.71) *** | 0.66 (0.48, 0.93) * | 0.65 (0.40, 1.06) |
| Age: 16-29 | 1 | 1 | 1 |
| Age: 30-64 | 1.17 (0.90, 1.54) | 0.95 (0.79, 1.14) | 1.01 (0.75, 1.34) |
| Age: >64 | 0.67 (0.41, 1.10) | 1.29 (0.90, 1.84) | 0.86 (0.50, 1.48) |
| Sex: Male | 1 | 1 | 1 |
| Sex: Female | 0.37 (0.29, 0.47) *** | 1.04 (0.89, 1.22) | 0.77 (0.60, 0.99) * |
| Ethnicity: White | 1 | 1 | 1 |
| Ethnicity: Non-white | 0.34 (0.21, 0.53) *** | 1.17 (0.86, 1.59) | 0.82 (0.50, 1.35) |
| Mobility difficulties: Yes | 1 | 1 | 1 |
| Mobility difficulties: No | 3.06 (1.47, 6.38) ** | 0.74 (0.46, 1.18) | 0.72 (0.33, 1.56) |
| n | 11581 | 363 | 363 |
| Pseudo R-squared (Nagelkerke) | 0.09 | 0.15 | 0.29 |

[a] The binomial model estimates the association between the independent variables and utility cycling participation (yes/no weekly utility cycling).
[b] The zero-truncated negative binomial model estimates the association between the independent variables and cycling frequency of those who participated in weekly utility cycling.
[c] The gamma model estimates the association between the independent variables and miles travelled by bicycle for those who participated in weekly utility cycling.
[d] OR (95%) = Odds ratio and 95% confidence intervals.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

**Leisure cycling**

No significant association was found between household income and the likelihood of engaging in leisure cycling (Table 2.3, binomial model). However, people with lower education levels were significantly less likely to participate in leisure cycling (OR 0.54, 95% CI 0.37-0.78). Other explanatory variables found positively associated with leisure cycling participation were being a part-time worker (OR 1.82, 95% CI 1.31-2.52), a student (OR 2.99, 95% CI 1.86-4.80), and lacking car access (OR 1.90, 95% CI 1.39-2.59). Among the control variables, people between 30 and 64 years and having no mobility difficulties were found to be more likely to cycle for leisure; by contrast, females and particularly non-white populations were less likely.

A significant negative association was found between leisure cyclists from the 3rd (OR 0.70, 95% CI 0.52-0.95) and 4th (OR 0.63, 95% CI 0.45-0.86) household income quintile and leisure cycling frequency (Table 2.3, zero-truncated negative binomial model). Also being a student (OR 0.49, 95% CI 0.30-0.79) was significantly negatively associated with leisure cycling frequency. However, significant positive associations were found between being a part-time worker (OR 1.48, 95% CI 1.15-1.89), unemployed (OR 1.79, 95% CI 1.09-2.92), lacking car access (OR 1.39, 95% CI 1.10-1.77), and leisure cycling.

Finally, we found a positive association between cyclists from the 5th income quintile (OR 1.55, 95% CI 1.03-2.35), unemployed (OR 2.65, 95% CI 1.19-5.89), and leisure cycling distance (Table 2.3, gamma model). By contrast, cyclists with no 'educational qualifications' were found to be significantly associated with less leisure cycling distance (OR 0.60, 95% CI 0.39-0.91). Among the control variables, female and non-white cyclists were significantly negatively associated with leisure cycling distance.

Table 2.3: Multivariate associations with leisure cycling participation, frequency, and distance.

| | Cycling participation | Cycling frequency | Cycling distance |
|---|---|---|---|
| | Binomial model [a] OR (95% CI)[d] | Zero-truncated model [b] OR (95% CI) | Gamma model [c] OR (95% CI) |
| Household income quintile: 1st (lowest) | 1 | 1 | 1 |
| Household income quintile: 2nd | 1.21 (0.84, 1.74) | 0.90 (0.69, 1.18) | 1.35 (0.91, 2.00) |
| Household income quintile: 3rd | 0.87 (0.59, 1.29) | 0.70 (0.52, 0.95) * | 1.09 (0.71, 1.66) |
| Household income quintile: 4th | 0.86 (0.58, 1.27) | 0.63 (0.45, 0.86) ** | 0.95 (0.62, 1.47) |
| Household income quintile: 5th (highest) | 1.39 (0.95, 2.02) | 0.81 (0.60, 1.08) | 1.55 (1.03, 2.35) * |
| Educational qualifications: Yes | 1 | 1 | 1 |
| Educational qualifications: No | 0.54 (0.37, 0.78) ** | 1.00 (0.75, 1.34) | 0.60 (0.39, 0.91) * |
| Economic status: Full Time | 1 | 1 | 1 |
| Economic status: Part Time | 1.82 (1.31, 2.52) *** | 1.48 (1.15, 1.89) ** | 0.93 (0.65, 1.33) |
| Economic status: Unemployed | 2.02 (0.99, 4.13) | 1.79 (1.09, 2.92) * | 2.65 (1.19, 5.89) * |
| Economic status: Student | 2.99 (1.86, 4.80) *** | 0.49 (0.30, 0.79) ** | 1.29 (0.74, 2.25) |
| Economic status: Economically inactive | 1.24 (0.86, 1.80) | 1.20 (0.92, 1.58) | 1.25 (0.85, 1.85) |
| Children in the household: Yes | 1 | 1 | 1 |
| Children in the household: No | 1.20 (0.93, 1.55) | 0.89 (0.72, 1.10) | 0.89 (0.66, 1.19) |
| Single parent family: Yes | 1 | 1 | 1 |
| Single parent family: No | 2.06 (0.60, 7.07) | 1.48 (0.53, 4.12) | 0.64 (0.16, 2.53) |
| Driving licence: Yes | 1 | 1 | 1 |
| Driving licence: No | 0.72 (0.51, 1.01) | 0.95 (0.72, 1.26) | 0.93 (0.64, 1.37) |
| Car access: Yes | 1 | 1 | 1 |
| Car access: No | 1.90 (1.39, 2.59) *** | 1.39 (1.10, 1.77) ** | 1.07 (0.76, 1.50) |
| Area type: Inner London | 1 | 1 | 1 |
| Area type: > 250k | 1.42 (0.88, 2.31) | 1.08 (0.74, 1.58) | 1.18 (0.71, 1.97) |
| Area type: 25k to 250k | 0.97 (0.61, 1.54) | 1.09 (0.75, 1.58) | 0.81 (0.50, 1.33) |
| Area type: 10k to 25k | 0.58 (0.31, 1.10) | 1.18 (0.71, 1.97) | 1.37 (0.69, 2.72) |
| Area type: 3k to 10k | 1.27 (0.72, 2.26) | 1.05 (0.66, 1.67) | 1.36 (0.73, 2.53) |
| Area type: Built-up areas | 0.82 (0.51, 1.30) | 1.13 (0.78, 1.64) | 1.35 (0.82, 2.22) |
| Area type: Rural | 0.65 (0.38, 1.12) | 1.25 (0.81, 1.91) | 1.20 (0.67, 2.16) |
| Age: 16-29 | 1 | 1 | 1 |
| Age: 30-64 | 1.53 (1.12, 2.09) ** | 1.06 (0.80, 1.39) | 1.39 (0.94, 2.05) |
| Age: >64 | 0.72 (0.43, 1.18) | 1.10 (0.74, 1.63) | 1.08 (0.61, 1.92) |
| Sex: Male | 1 | 1 | 1 |
| Sex: Female | 0.40 (0.31, 0.50) *** | 0.85 (0.70, 1.03) | 0.61 (0.47, 0.79) *** |
| Ethnicity: White | 1 | 1 | 1 |
| Ethnicity: Non-white | 0.26 (0.16, 0.44) *** | 1.19 (0.76, 1.87) | 0.35 (0.19, 0.66) ** |
| Mobility difficulties: Yes | 1 | 1 | 1 |
| Mobility difficulties: No | 1.92 (1.07, 3.43) * | 0.72 (0.47, 1.09) | 0.86 (0.45, 1.66) |
| n | 11581 | 332 | 332 |
| Pseudo R-squared (Nagelkerke) | 0.08 | 0.2 | 0.22 |

[a] The binomial model estimates the association between the independent variables and leisure cycling participation (yes/no weekly leisure cycling).
[b] The zero-truncated negative binomial model estimates the association between the independent variables and cycling frequency of those who participated in weekly leisure cycling.
[c] The gamma model estimates the association between the independent variables and miles travelled by bicycle for those who participated in weekly leisure cycling.
[d] OR (95%) = Odds ratio and 95% confidence intervals.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

### Geographical variation

Some variations were found between the ORs of utility and leisure cycling participation by household income quintile in London and the rest of England. However, the impact that London had on all of England seems quite small. As we can see in Figure 2.6, the differences between the results of the rest of England and all England are almost unnoticeable.

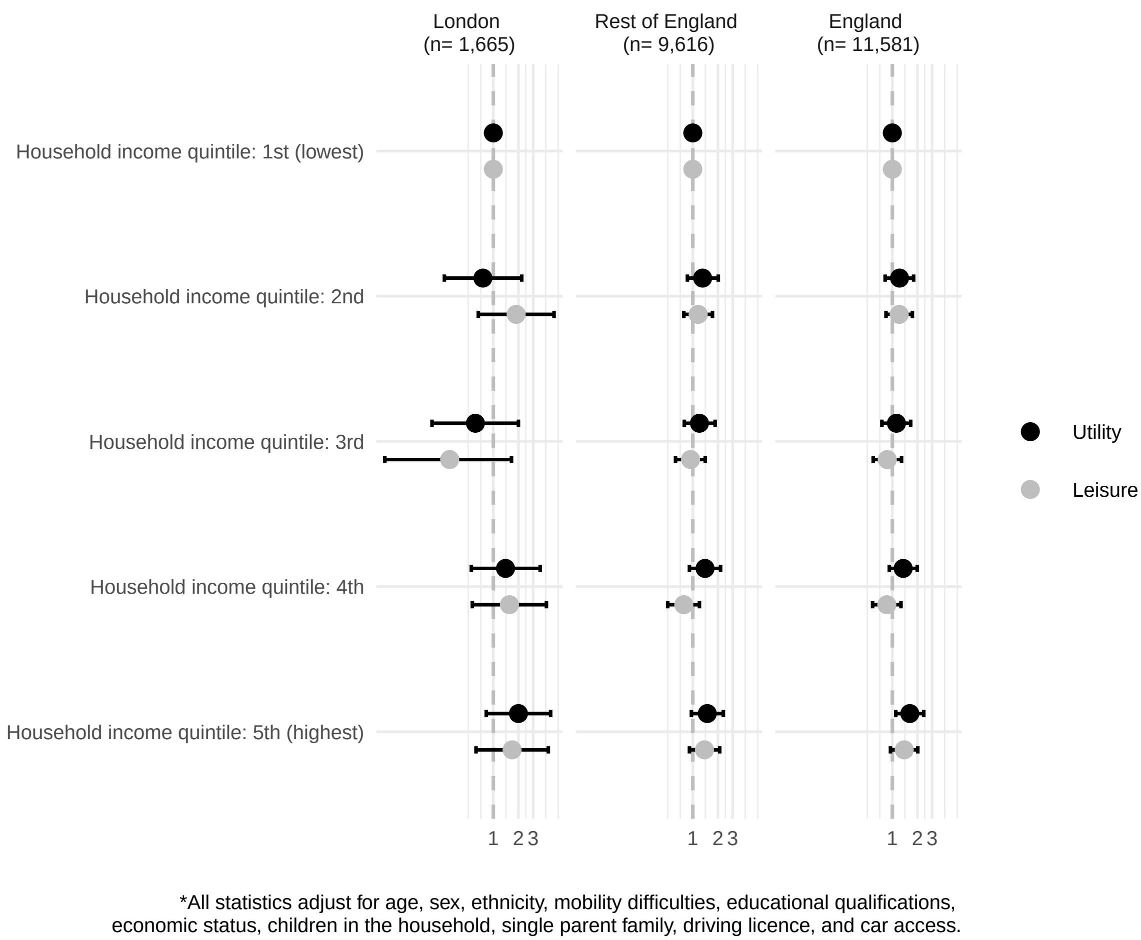


Figure 2.6: Forest plot displaying exponentiated ORs (95% CI) of utility and leisure cycling participation by household income quintile and geographical area (London, rest of England, and England).

## 2.4 Discussion

This paper examined the extent to which income and other factors of socioeconomic disadvantage are related to cycling behaviour based on a large household travel survey in a wealthy country with a car-dominated transport system (England). Descriptive statistics and regression models enabled explorations of the associations between socioeconomic variables and three dependent variables (cycling participation, cycling frequency, and cycling distance) for both utility and leisure cycling.

### 2.4.1 Findings from the descriptive statistics

An interesting and unexpected finding from the descriptive statistics is that people in the lowest household income quintile made a quarter as many commuting cycling trips as people in the highest household income quintile. This may be, in part, because low-income populations tend to be proportionally less economically active (see the gradient in the economic status rows by income quintile in Table 2.1). This finding may have important policy implications, since it could be indicating that urban cycling planning overly focused on commuting cycling benefits more higher-income cyclists than lower-income cyclists, which may be reinforcing socioeconomic inequalities in cycling levels.

The descriptive analysis also shows substantial inequalities in bicycle ownership and access, with only two in ten individuals in the 1st income quintile owning or having use of a bicycle, compared to five in ten in the 5th quintile. This corresponds with findings from the US (National Highway Traffic Safety Administration, 2008). In this sense, qualitative research on barriers to cycling among disadvantaged populations found that not having a bicycle or finding it too expensive is one of the main barriers to cycling among disadvantaged groups (McNeil et al., 2017). These findings suggest that measures to provide access to working bicycles such as via the implementation of bicycle share schemes (BSS) and funding for bicycle repair (e.g. Big Bike Revival) may contribute to reducing barriers to cycling, especially for low-income groups.

### 2.4.2 Findings from the multivariate analyses

#### Cycling and household income

Our model predicting utility cycling participation show that individuals from the highest household income quintile were significantly more likely to engage in utility cycling. This corresponds with most previous findings in the UK (Green et al., 2010 in London; Parkin et al., 2008 in England and Wales; and Whyte and Waugh, 2015 in Scotland), although not with Goodman (2013), who using aggregate census data found that commuting cycling was more common among people from deprived areas in England and Wales. Goodman (2013) shows, however, that between 2001 and 2011 this association had weakened and in the highest cycling locations reversed.

Contrary to our expectations, no significant association between income and leisure cycling participation was found.

Finally, we also found that low-income leisure cyclists cycle more frequently than higher-income leisure cyclists, but higher-income leisure cyclists cycle further. This is consistent with previous research in London that found that higher-income cyclists cycle longer distances (Green et al., 2010) and with the growth of long-distance sport cycling among the higher classes (e.g. D.G., 2013; Dirs, 2014).

#### Cycling and other socioeconomic factors associated with disadvantage

Having no educational qualifications was not associated with utility cycling participation, but negatively associated with leisure cycling participation. A similar conclusion was drawn in a study conducted in England using the Active Travel Survey (Goodman and Aldred, 2018). According to that study, individuals with a lower level of education were progressively associated with lower probabilities of utility and leisure cycling, but within most English local authorities this association was absent for utility cycling. We also found a negative association between lower levels of education and cycling distance for leisure. Xing et al. (2010) found this association for utility, but not for leisure.

Several categories of economic status were found associated with cycling behaviour for both utility and leisure cycling. It is worth highlighting the higher likelihood of utility cycling participation and frequency, and leisure cycling participation among part-time workers. This may be because these populations might tend to live closer to their work and have more spare time for recreational activities (ONS, 2017). However, previous studies found part-time employment associated with utility cycling, but not with recreational cycling (Heesch et al., 2014). More spare time could also explain the higher likelihood of the unemployed population to participate and cycle more frequently for leisure. Surprisingly, students were found significantly positively associated with leisure cycling participation, but not with utility cycling. In addition, students cyclists were found to cycle less frequently for both utility and leisure cycling, and shorter distances for utility. This supports previous research indicating that worker cyclists cycle longer distances than student cyclists (Larsen et al., 2010). Economically inactive cyclists were found to cycle less frequently and shorter distances for utility than working full-time cyclists. This might be because the former make no commuting trips.

Lacking car access was strongly positively associated with utility cycling participation, frequency, and distance. Contrary to previous research (e.g. Heesch et al., 2014; Goodman and Aldred, 2018), this variable was also positively associated with leisure cycling participation and frequency.

#### Cycling and other socio-demographic variables

The associations found regarding the control variables broadly supports prior findings. Built-up areas and urban areas between 10k to 25k inhabitants were associated with less utility cycling participation, and rural areas with less utility cycling participation and utility cycling frequency. This corresponds with Harms et al. (2014), who found that people living in rural areas in the Netherlands cycled less often, although not for leisure cycling. Similarly, Pucher et al. (2011) found lower levels of cycling to work in rural areas in the US, but not of leisure cycling. Age was only associated with cycling leisure participation, although previous studies found it also associated with utility and commuting cycling (Heinen et al., 2010; Green et al., 2010; Winters et al., 2010; Pucher et al., 2011; e.g. Goodman and Aldred, 2018). A strong negative association was found between females and both utility and leisure cycling participation. Associations of similar magnitude were found in previous studies (Handy and Xing, 2011; Heesch et al., 2012; e.g. Goodman and Aldred, 2018). Females were also significantly associated with cycling shorter distances, which supports Heesch et al. (2012) and Larsen et al. (2010). The negative association between non-white population and utility and leisure cycling participation was even stronger. This agrees with Goodman and Aldred (2018). Finally, people with no mobility difficulties were significantly positively associated with both utility and leisure cycling participation, which also corroborates previous research (Clayton et al., 2017; Andrews et al., 2018; Goodman and Aldred, 2018).

### 2.4.3 Strengths and limitations

The strengths of this paper include the use of well-established national data set with a large representative sample and an in-depth focus on the impact of income and other factors of socioeconomic disadvantage on cycling, distinguishing between cycling participation, cycling frequency, and cycling distance, as well as between leisure and utility cycling. Nevertheless, this paper has several limitations. First, despite the advantages of using the NTS, the sample size for the cycling frequency and distance models (only cyclists) was relatively small. This may result in less reliable estimation and less likely identification of significant relationships. Second, the measurement of leisure cycling in the NTS is poor.

The NTS only collects data on the public highway, excluding cycling leisure travel across the open countryside and unsurfaced paths. Consequently, the findings regarding leisure cycling should be interpreted cautiously. Third, since the dependent variable cycling participation refers to individuals who did or did not cycle in a specific week, the binary model might have not considered as cyclists a few regular cyclists that for any reason (e.g. illness, bad weather, bicycle in repair, etc.) did not cycle during that specific week. In the same way, the model could have considered as regular cyclists, occasional cyclists who for whatever reason cycled during that week. Fourth, the models presented may be omitting powerful explanatory variables not available in the NTS that might affect cycling behaviour and perhaps some of our explanatory variables, for example, cultural background or attitudes and social norms. Fifth, the variable 'Educational qualifications' divides the sample size of the NTS 2017 (n = 11,897) into two quite unequal groups: those with some certified educational qualification (80%) and those without certified educational qualifications (20%). This may have made us overlook associations between different levels of education as well as affected the reliability of the results of the cycling frequency and distance models (based only on the sample of cyclists).

### 2.4.4 Further research

The results presented in this paper clearly show that there is no simple, universal, relationship between cycling and socioeconomic disadvantage. Our findings raise further questions and suggest directions for future research. The finding that people in low-income households cycle substantially more for non-commuting than for commuting purposes raises the question: why? The paper provides a motivation for qualitative research into the extent to which the perceptions of decision-makers about cycling and disadvantage reflect the evidence: we hypothesise that decision-makers under-estimate the importance of non-commuting cycling for people from low-income households. Further modelling work could explore interaction effects: do the impacts of explanatory variables depend on the state of a second variable? In particular, the interactions between income and car ownership, having children and gender, income and education, education and ethnicity and cycling could offer interesting additional insights. Two other interesting unanswered questions are how have the relationships between cycling and socioeconomic disadvantage changed over time and why.

## 2.5 Conclusions

The research reported in this paper reveals that people in lower-income households participate less in utility cycling, particularly in commuting cycling, than people in higher-income households. Contrary to prior expectations, no income inequalities were found for leisure cycling participation. In addition, low-income leisure cyclists were found to cycle relatively more frequently, but higher-income leisure cyclists further. Other remarkable findings are that people with lower levels of education participate less in leisure cycling and cycle shorter distances for leisure; part-time workers participate more in utility and leisure cycling and cycle more frequently for utility; students participate more in leisure cycling but cycle less frequently and shorter distances for utility; and people with no car participate and cycle more often for utility and leisure cycling, and cycle further for utility. The study also shows a substantial disparity in bicycle ownership and access by income household quintile.

These findings may have important policy implications, given that much investment in cycling seems to be based on the premise that building infrastructure for cycling commuting is the best way to get people cycling. Data from the NTS shows that commuter cycling participation rise continuously with household income, meaning that alternative interventions such as greenways and a dense, connected and permeable network created by Low Traffic Neighbourhoods (LTN) may be more beneficial to low-income groups than major arterial routes (cycle-superhighways) aimed to commuter cyclists. Our findings also suggest that bicycle ownership and maintenance support could be key for cycling inclusion.

## Acknowledgements

We would like to thank UK Data Service (Sharon Bolton) for providing access to the SN 5340 version of the 2017 NTS. EVT completed this work as part of a Doctorate funded by the Economics and Social Research Council (ES/R501062/1). RPM was supported by a UK Research and Innovation Future Leaders Fellowship (MR/S032525/1).

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# Chapter 3

# Infrastructure is not enough: Interactions between the environment, socioeconomic disadvantage, and cycling participation in England

This chapter is based on the paper: Vidal Tortosa, E., Lovelace, R., Heinen, E., Mann, R.P., 2021. *Infrastructure is not enough: Interactions between the environment, socioeconomic disadvantage, and cycling participation in England.* Journal of Transport and Land Use 14, 693–714. https://doi.org/10.5198/jtlu.2021.1781

# Abstract

Cycling can be particularly beneficial for socioeconomically disadvantaged populations for two main reasons. First, cycling enables access to opportunities that may be unaffordable by other modes. Second, cycling increases physical activity levels and, consequently, improves health. In this context, we analyse the extent to which socioeconomic disadvantage impacts cycling participation and cycling duration for both leisure and utility cycling. Then, we examine whether socioeconomic inequalities in cycling participation can be explained by the environment in which disadvantaged populations live. The study population includes 167,178 individuals, residing in 2,931 areas, and 326 Local Authorities. Data on individual factors were drawn from the Active Lives Survey and data on environmental factors from several sources. Descriptive statistics and multilevel regression models were estimated. We found that the likelihood of cycling is lower among people living in deprived areas than among people living in non-deprived areas. This difference is significant for leisure, but also for utility cycling when controlling for individual and environmental factors. However, cyclists living in deprived areas are more likely to cycle longer per week than cyclists living in non-deprived areas, particularly for utility cycling. We also found that deprived areas have a higher density of cycling infrastructure, lower levels of traffic stress, higher population density, and fewer hills than non-deprived areas. This suggests that infrastructure is not enough to increase cycling levels among disadvantaged populations. Further research on other barriers to cycling among disadvantaged populations is required.

**Keywords**: Utility cycling; Leisure cycling; Transport equity; Physical activity; Environmental justice.

## 3.1 Introduction

The benefits of cycling are widely recognised. Cycling is healthy, affordable, efficient, improves environmental quality, traffic congestion, and avoids climate change (Heinen et al., 2010; Pucher et al., 2010; Oja et al., 2011; Garrard et al., 2012). For this reason, governments at different administrative levels are increasingly implementing policies to encourage people of all ages and backgrounds to cycle.

One group that has much to gain from cycling uptake is the socioeconomically disadvantaged populations (Lee et al., 2012). First, because cycling can allow them to access opportunities such as better work, training or leisure, that by other modes of transport they may not afford. Second, because it can help them to increase their physical activity levels and, consequently, improve their health and well-being. Disadvantaged populations tend to be less physically active than non-disadvantaged populations (Lindström et al., 2001; Droomers, 2001; Giles-Corti, 2002), which has been suggested to explain, at least in part, their poorer health condition and life expectancy (Lynch et al., 1996).

The relationship between socioeconomic disadvantage and cycling is ambiguous. Most authors agree that cycling for recreation and sport (leisure cycling) is more common among middle- and high-income groups (e.g. Kamphuis et al., 2008; Heesch et al., 2014; Heesch et al., 2015). However, the extent to which different socioeconomic groups use cycling for transport (utility cycling) seems to be context-dependent. Whereas in developing countries utility cycling is mainly used by low-income groups (Vasconcellos, 2001; Brussel and Zuidgeest, 2012), in developed countries this is not always the case. In Northern Europe, cycling levels are relatively constant between different socioeconomic groups (Pucher and Buehler, 2008). However, in developed countries where cycling is rare findings are mixed. In the US and Canada, there is evidence that cycling for transport is more common among low-income populations (e.g. Schwanen and Mokhtarian, 2005; Plaut, 2005; Winters et al., 2010; Pucher et al., 2011). Also in the US, some authors found no association between socioeconomic status and utility cycling (e.g. Dill and Carr, 2003; Handy and Xing, 2011). In the UK and Australia, by contrast, research has found higher levels of utility cycling among middle- and high-income groups (e.g. Parkin et al., 2008; Green et al., 2010; Steinbach, Green, et al., 2011; Sahlqvist and Heesch, 2012).

Research shows that environmental factors such as cycle-friendly infrastructure, traffic volume, density, and hilliness influence cycling levels (Heinen et al., 2010; Winters et al., 2010; Fraser and Lock, 2011; Wang et al., 2016). Therefore, the environment in which specific groups live could explain, at least in part, inequalities in cycling participation. It is in this context in which the research area 'cycling equity' has recently emerged. In the

US, for example, a recent study based on data from 22 large cities found that access to cycling infrastructure was lower in groups with particular types of disadvantage (lower education, higher Hispanic populations, lower composite SES), but not in groups with other types of disadvantage (higher black populations, lower-income, higher poverty) (Braun et al., 2019). In most Canadian cities, low-income populations were found to have better access to cycling facilities than wealthier populations (Fuller and Winters, 2017; Winters et al., 2018). By contrast, in South America, the result of two studies found that the poor areas were under-served (Teunissen et al., 2015; Tucker and Manaugh, 2018). Finally, in Melbourne (Australia), the cycling network was found generally equitably distributed, although more off-road infrastructure, i.e., safer cycling routes, was found in wealthier areas (Pistoll and Goodman, 2014).

In recent years, there has been a rise in walking and cycling investment in the UK (DfT, 2017a). Some of these projects aim to enable disadvantaged groups to cycle. For example, the Bradford Leeds Cycle Superhighway (WYCA, 2019) was designed to offer one of the most disadvantaged communities in West Yorkshire (UK) a cheap and healthy means of transportation between the cities of Bradford and Leeds. However, no study in England has explored to date the influence that the level of deprivation in which population lives might have on cycling. The level of cycle-friendliness of deprived areas, or to what extent the environmental improvement of these areas could help increase cycling participation among the most disadvantaged groups have also not been considered.

This paper fills these gaps by addressing two aims. First, it analyses the extent to which socioeconomic disadvantage in England impacts cycling participation and cycling duration for both leisure and utility cycling. Second, it examines whether socioeconomic inequalities in cycling participation could be explained by the environment in which disadvantaged populations live. The findings of the study are intended to inform policies to facilitate cycling among socioeconomically disadvantaged populations. This will allow vulnerable groups to gain accessibility and health, and get more people cycling, which in the long run will benefit us all.

## 3.2 Data and methods

### 3.2.1 Data

To understand the relationships between the environment, socioeconomic disadvantage and cycling participation a combination of 'individual' and 'area' level sources was needed. The individual-level data were extracted from the Active Lives Adult Survey (ALS). The ALS is a biannual survey that contains frequencies and duration of physical activity of adults aged 16+ in England, including walking and cycling for travel. For this study, the ALS November 17/18 was used (Ipsos MORI, 2019). Its sample was selected from the Postcode Address File using random probability sampling and one letter was sent to each address inviting up to two adults from the household to take part. The sampling was clustered at the Local Authority (LA) level with a minimum of 500 interviews in most LAs (303 of 326), which allows performing analysis up to this geographical level. Responses were collected between 16th November 2017 and 15th November 2018 using an online questionnaire (59.6%) and a paper self-completion questionnaire (40.4%), the latter sent on the second reminder. Completed questionnaires were rewarded with a £5 shopping voucher. Valid responses were received from 179,747 people in total, with an overall response rate of 18.9%.

The area-level data were obtained from the English Indices of Deprivation 2015 (DfCLG, 2015), Cycling Infrastructure Prioritisation Toolkit (University of Leeds, 2019), the CycleStreets website (Cycle Streets, 2020), the Office for National Statistics (ONS, 2019b), and the open-source online system for sustainable transport planning Propensity for Cycle Tool (Lovelace et al., 2017).

### 3.2.2 Variables

#### Response variables

Respondents of the ALS were asked for the frequency (number of times in the last 4 weeks) and the duration (minutes per week) of their cycling activity. Based on this, we used two response variables: 1) a binary variable 'cycling participation' expressing whether individuals cycled or did not cycle in the last 4 weeks, and 2) a continuous variable 'cycling duration' specifying the weekly minutes they travelled by bicycle. Each of these variables was calculated separately for total cycling, leisure cycling, and utility cycling. The categories leisure and utility cycling were pre-defined by the ALS.[1]

[1] Leisure cycling includes mountain biking, BMX, road cycling and racing, track cycling, cycle cross, cycle class, exercise bike, and other types of leisure cycling; utility cycling all cycling for travel.

### Explanatory variables

A range of individual and area-level factors previously found to be associated with cycling (Heinen et al., 2010; Winters et al., 2010; Fraser and Lock, 2011; Wang et al., 2016) were selected as explanatory variables (see Table 3.1). Seven individual-level factors were extracted from the ALS: ‘Gender’ (male/female), ‘Age’ (16–34, 35–54, 55-74, 75+), ‘Ethnicity’ (white/non-white), ‘Education’ (low, medium, high)[2], ‘Occupation’ (NS-SEC 1-2 Higher social groups, NS-SEC 3-5 Middle social groups, NS-SEC 6-8 Lower social groups, and NS-SEC 9 Students and other)[3], ‘Type of area’ (urban/rural), and ‘Level of deprivation’ (Q1 most, Q2, Q3, Q4, Q5 least). ‘Level of deprivation’ is used as a proxy for socioeconomic disadvantage and is based on a decile-to-quintile transformation of the Multiple Deprivation Index (IMD) of the small areas in England (Lower Layer Super Output Areas (LSOA)) where the respondents resided.

Five area-level factors were used from several sources. ‘Cycle tracks (off-road)’ and ‘Cycle lanes (on-road)’ were collected from the Cycling Infrastructure Prioritisation Toolkit (University of Leeds, 2019)[4], and ‘Quietness’ (% score per level of stress of routes in each area) from the CycleStreets website (Cycle Streets, 2020). For these three variables, a 1 km buffer per area was created to avoid over or under-representation in the smallest areas. ‘Density’ (Population/km2) was provided from the Office for National Statistics (ONS, 2019b). Finally, ‘Hilliness’ (average fast route gradient (%) of commute trips in zone with fast route distance <10km at the English Middle-layer Super Output Areas (MSOA) level) was taken from the Propensity for Cycle Tool (Lovelace et al., 2017).

[2]Education was categorised as ‘low’ (levels 1 or 2 and equivalents (UK qualification levels) or below, or ‘No qualifications’, or ‘Another type of qualification’), ‘medium’ (level 3 and equivalents), or ‘high’ (level 4 or above).

[3]Occupation was categorised as ‘NS-SEC 1-2 Higher social groups’ (Managerial, administrative and professional occupations), ‘NS-SEC 3-5 Middle social groups’ (Intermediate occupations, small employers and own account workers, and Lower supervisory and tech occupations), ‘NS-SEC 6-8 Lower social groups’ (Semi-routine, routine occupations, and Long term unemployed or never worked), or ‘NS-SEC 9 Students and other’ (Full-time student and unclassified).

[4]The data used in the Cycling Infrastructure Prioritisation Toolkit was extracted from the Open Street Map (OSM) mid 2017.

Table 3.1: Descriptive statistics.

| Variables | Statistics |
|---|---|
| Individual factors | |
| No. of individuals (n) | 167178 |
| Gender | |
| Male | 73904 (44.2%) |
| Female | 93274 (55.8%) |
| Age | |
| 16-34 | 31785 (19.0%) |
| 35-54 | 55293 (33.1%) |
| 55-74 | 64352 (38.5%) |
| 75+ | 15748 (9.4%) |
| Ethnicity | |
| White | 154399 (92.4%) |
| Non-white | 12779 (7.6%) |
| Education | |
| High | 85098 (50.9%) |
| Medium | 25258 (15.1%) |
| Low | 56822 (34.0%) |
| Occupation | |
| NS SEC 1-2: Higher social groups | 84636 (50.6%) |
| NS SEC 3-5: Middle social groups | 39353 (23.5%) |
| NS SEC 6-8: Lower social groups | 18500 (11.1%) |
| NS SEC 9: Students and others | 8941 (5.3%) |
| Missing | 15748 (9.4%) |
| Type of area | |
| Urban | 128530 (76.9%) |
| Rural | 38648 (23.1%) |
| Level of deprivation | |
| Q1 (most) | 32163 (19.2%) |
| Q2 | 33189 (19.9%) |
| Q3 | 33786 (20.2%) |
| Q4 | 33748 (20.2%) |
| Q5 (least) | 34292 (20.5%) |
| Environmental factors | |
| No. of areas (n) | 2931 |
| Cycle tracks (off-road) (km/km^2), mean (SD) | 3.7 (6.5) |
| Cycle lanes (on-road) (km/km^2), mean (SD) | 1.4 (6.6) |
| Quietness (%), mean (SD) | 71.9 (1.7) |
| Density (population/km^2), mean (SD) | 2583.7 (3141.7) |
| Hilliness (%), mean (SD) | 1.9 (0.9) |

### 3.2.3 Data preparation

Respondents with missing data for 'Ethnicity', 'Education', 'Gender', and 'Age' were excluded (n = 12,569), which reduced the sample size to n = 167,178 (Table 3.1). To avoid the presence of extreme high values in the response variable 'cycling duration', a cut-off of 3,000 minutes/week (50 hours/week) was used. For those individuals who exceed this value (n = 42), the mean duration of those who cycled at least once in the last 4 weeks per type of cycling was imputed. Since we did not have access to the residential LSOA of individuals in the ALS (the area-level at which the IMD decile is collected), to merge the individual and the area datasets at a level that could take into account deprivation, we proceeded as follows. First, we aggregated the area dataset (initially at the LSOA level) by 'IMD decile' and 'Local Authority (LA)'. Then, we joined the individual and area dataset by the common fields 'IMD decile' and 'LA'. The result was a single dataset with two levels: i) the individual-level with 167,178 individuals and 13 variables (3 outcomes for cycling participation, 3 outcomes for cycling duration, and 7 individual explanatory variables), and ii) the IMD decile LA-level with 2,931 areas and 5 environmental explanatory variables.

### 3.2.4 Statistical methods

First, we carried out descriptive statistics. For this, two response variables at the IMD decile LA-level per type of cycling were calculated: the 'proportion cycling participation', and the 'average cycling duration'. With these variables, we mapped the proportions of cycling per type of cycling and created several boxplots. A boxplot of proportions of cycling participation by quintile level of deprivation, a boxplot of average cycling duration by quintile level of deprivation, and a boxplot of the density of cycling infrastructure (cycle tracks and cycle lanes) by quintile level of deprivation. We also draw a bar graph with the area-level response variable proportion of cycling participation per type of cycling and the explanatory environmental variables standardised by quintile level of deprivation. To do this, for each observed value of each variable, we subtracted the mean and divided by the standard deviation.

Second, considering the hierarchical structure of the data (individuals, IMD decile LA areas, and LAs) and the distribution of the two response variables, we estimated odds ratios (ORs) to explain cycling participation and cycling duration for the explanatory variables using two multilevel regression models: 1) a multilevel logistic regression to predict cycling participation (binary variable), where 'participating' individuals were those who cycled at least once in the last 4 weeks, and for those who cycled at least once in the last 4 weeks 2) a multilevel gamma regression to predict weekly cycling duration (continuous variable). We conducted this analysis per each type of cycling: total, leisure, and utility cycling. Figure 3.1 illustrates the conceptual models.

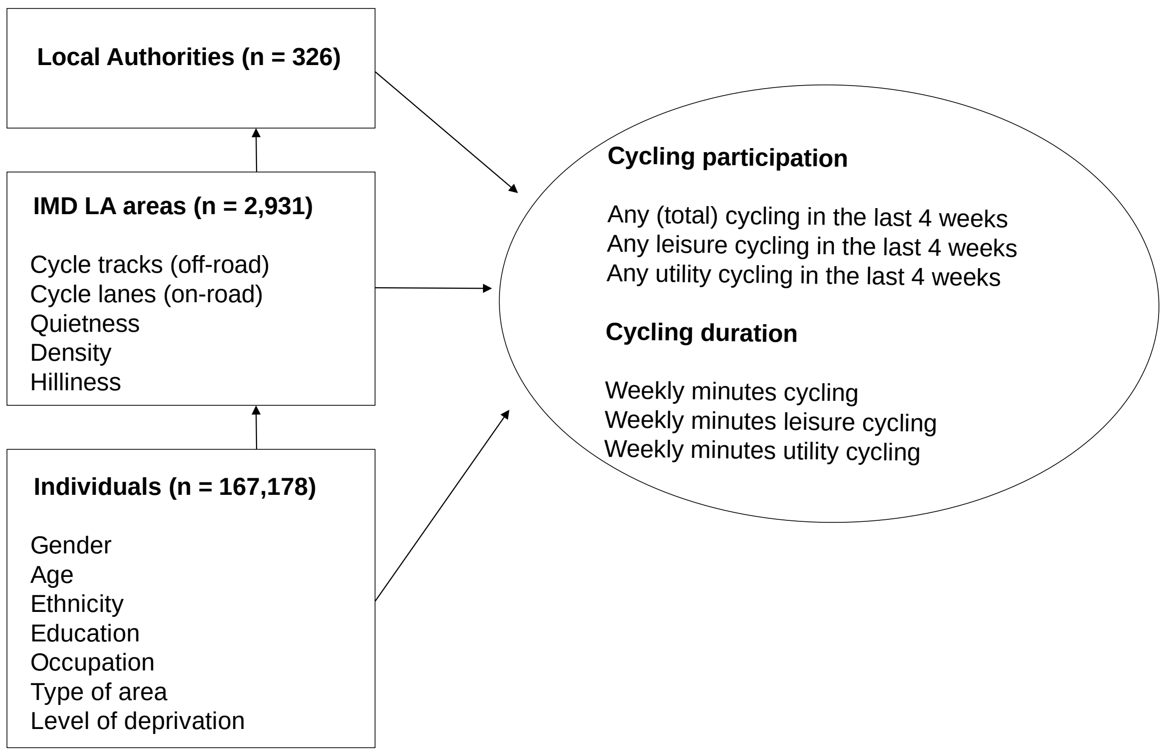


Figure 3.1: Conceptual models.

Multicollinearity was tested to avoid multiple factors correlated to each other. For this, multiple logistic regression models were fitted and the Variance Inflation Factor (VIF) among factors measured. All values were lower than 5, indicating no substantial multicollinearity among factors (James et al., 2013). We adjusted the models for the 'individual' fixed effects; and then, for both the 'individual' and 'environmental' fixed effects. To simplify and focus on the aims of the study, the models were presented in a table stratified by quintile level of deprivation without showing the rest of the explanatory variables (Table 3.2). The full results of the models can be seen in Table 3.3, Table 3.4, and Table 3.5 in Appendix A. Final weights (wt_final) provided for the ALS were applied to reduce the bias in survey estimates.

## 3.3 Results

### 3.3.1 Descriptive results

Overall, in England, 20% of the population cycled in the last 4 weeks, 17% for leisure and 8% for utility. The average weekly time of those who cycled in the last 4 weeks was 181 minutes, 140 minutes for those who cycled for leisure, and 199 minutes for those who cycled for utility.

Whereas leisure cycling is rather evenly geographically distributed (Figure 3.2 Centre), utility cycling appears more concentrated in specific urban areas such as Cambridge, Oxford, or Hackney (Figure 3.2 Right). A higher proportion of leisure cycling does not necessarily correspond with a higher proportion of utility cycling. For example, Local Authorities such as Rushcliffe or Hart, with more than 25% of leisure cycling, have less than 10% of utility cycling. In contrast, most of the areas with high utility cycling have also a significant presence of leisure cycling.

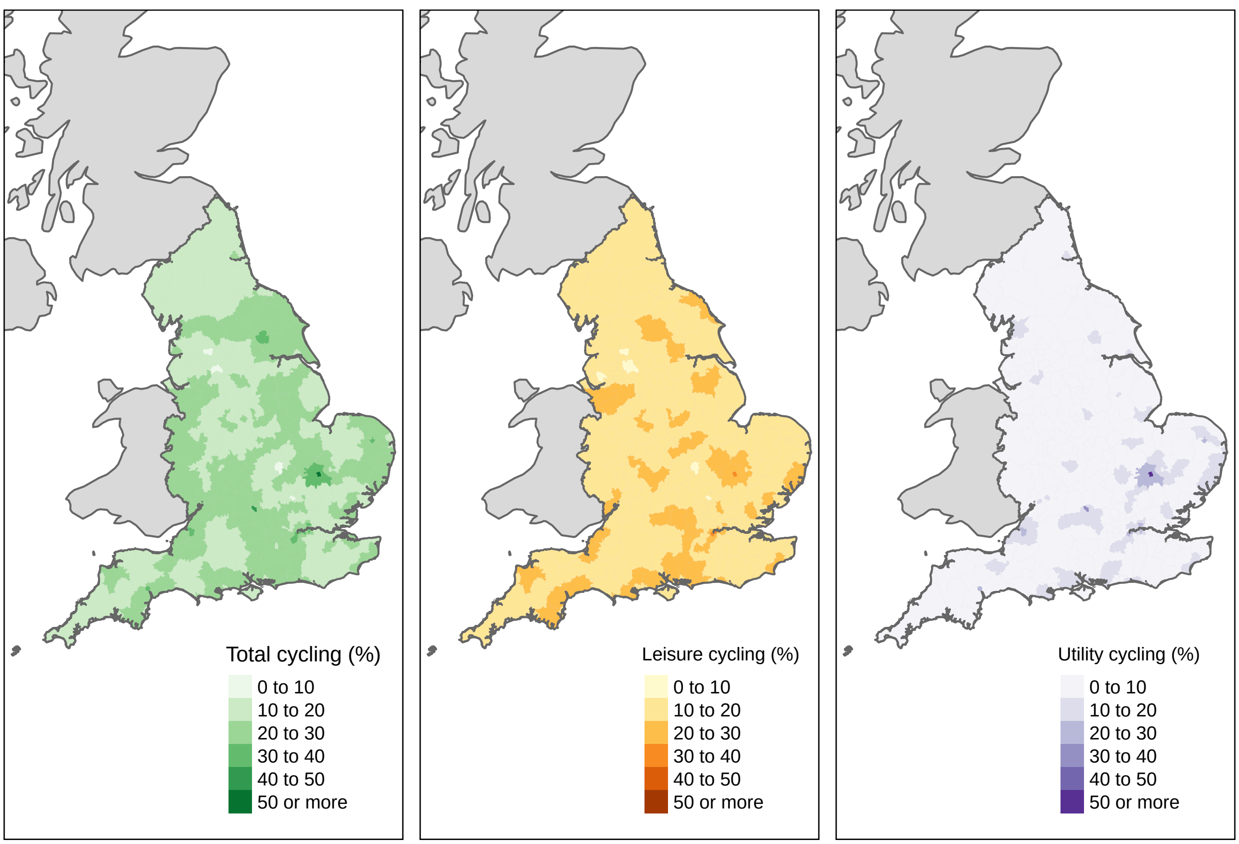


Figure 3.2: Proportion of people who did any (total) cycling (left), leisure cycling (centre), and utility cycling (right) in the last 4 weeks.

Overall, the lower the level of deprivation, the higher the proportion of cycling participation (Figure 3.3 Left). This trend is clearly observed for leisure cycling (Figure 3.3 Centre). However, utility cycling remains flat across all levels of deprivation (Figure 3.3 Right).

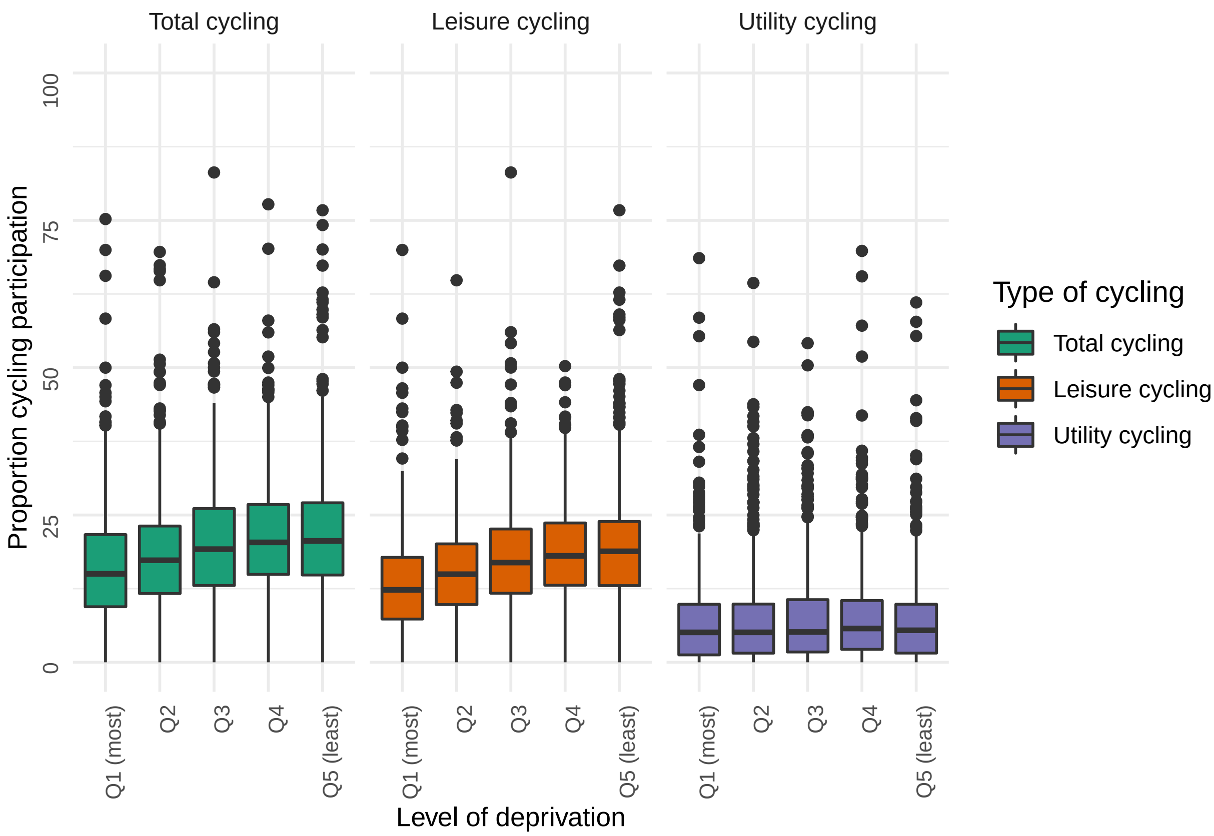


Figure 3.3: Proportion of people who did any (total) cycling (left), leisure cycling (centre), and utility cycling (right) in the last 4 weeks by quintile level of deprivation.

By contrast, the average cycling duration is slightly higher in more deprived areas than in less deprived areas (Figure 3.4 Left). This difference is more remarkable for utility cycling, particularly in the most deprived areas (Figure 3.4 Right).

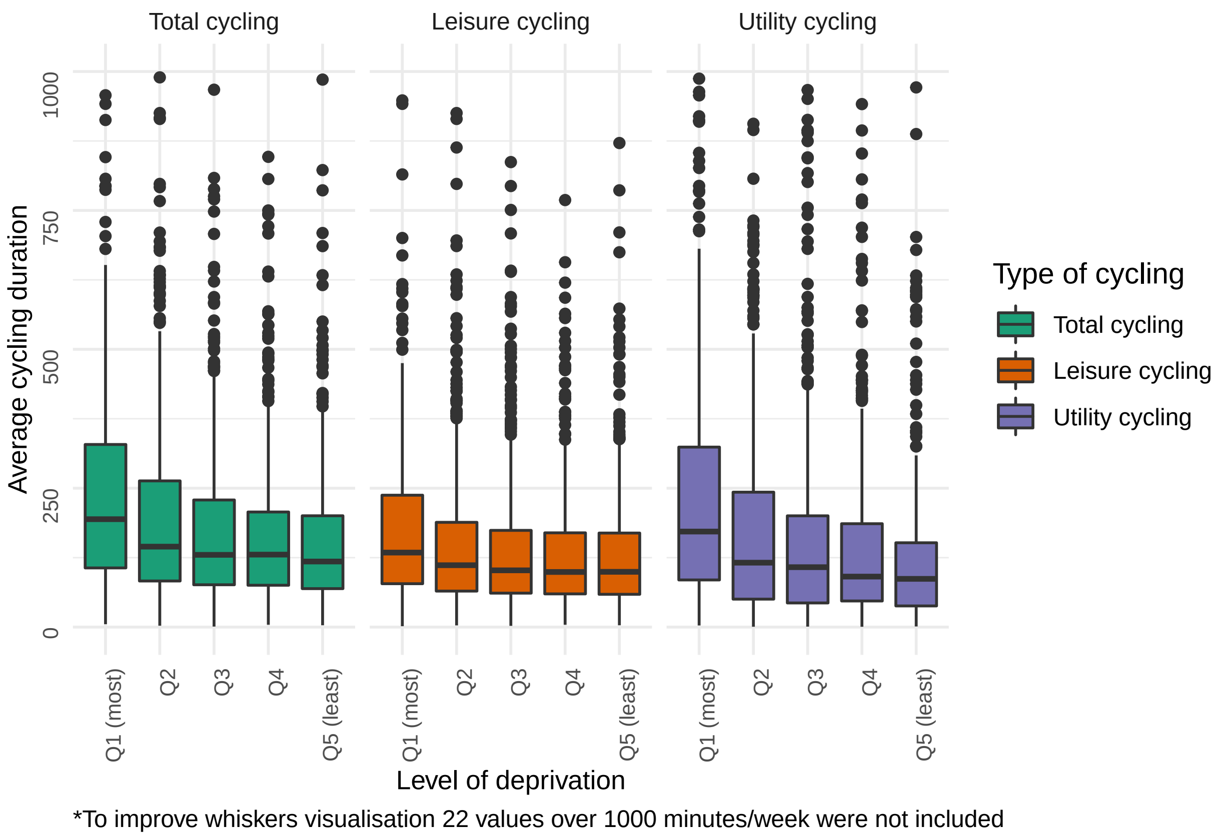


Figure 3.4: Average cycling duration (in minutes per week) for those who did any (total) cycling (left), leisure cycling (centre), and utility cycling (right) in the last 4 weeks by quintile level of deprivation.

Contrary to our expectations, on average, the more deprived the areas the higher is the density of cycling infrastructure. This is the case for both considered types of cycling infrastructure: cycle tracks (off-road) and cycle lanes (on-road) (Figure 3.5).

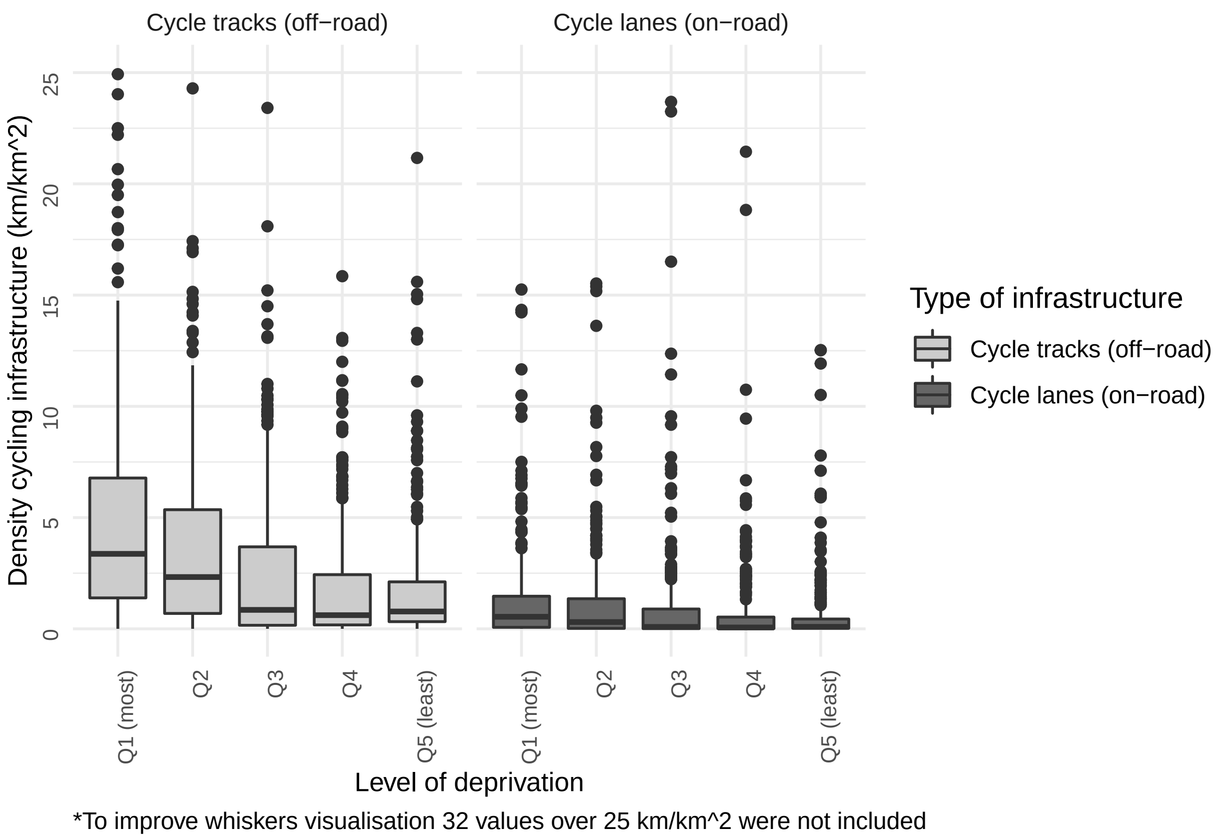


Figure 3.5: Density of cycle tracks (left) and cycle lanes (right) by quintile level of deprivation.

Figure 3.6 shows the area-level variables proportion cycling participation (for total, utility, and leisure cycling), cycle tracks, cycle lanes, quietness, density, and hilliness standardised by quintile level of deprivation. The result is paradoxical: while the proportions of total and leisure cycling, as well as hilliness, follow a positive trend from more to less deprived quintile, the environmental variables referring to the built environment (cycle tracks, cycle lanes, quietness, and density) generally follow the opposite tendency. That is, in areas where the environment is supposedly more suitable for cycling, cycling proportions are lower; whereas in areas where the environment is less cycle-friendly, cycling proportions are higher.

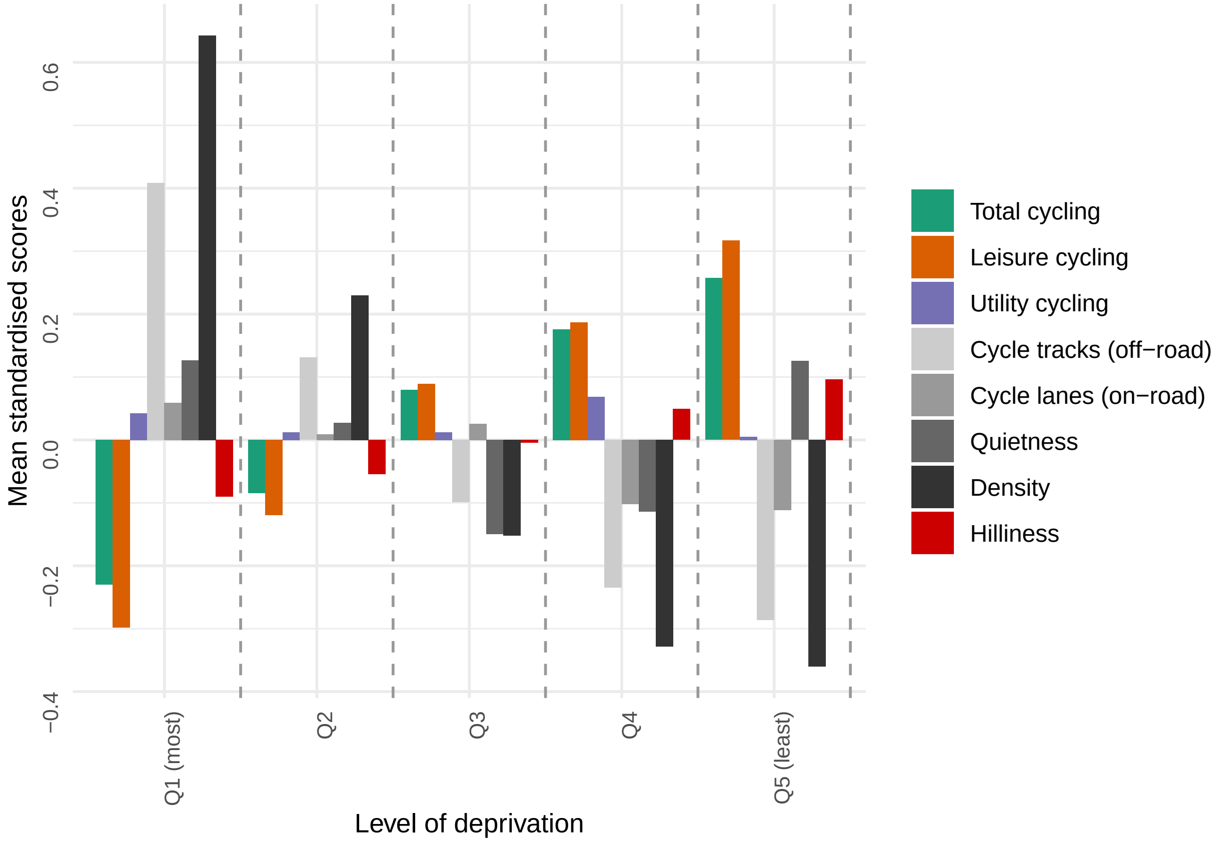


Figure 3.6: Mean standardised scores of the area-level variables proportion cycling participation (total, utility, and leisure), cycle tracks, cycle lanes, quietness, density, and hilliness by quintile level of deprivation.

### 3.3.2 Multilevel analyses

#### Associations between level of deprivation and cycling participation

The multilevel logistic models adjusting for the 'individual' fixed effects (Table 3.2) show a clear negative association between level of deprivation and total cycling participation: the higher the level of deprivation the lower the likelihood of any cycling participation. This trend is slightly stronger for leisure cycling than for total cycling. For utility cycling, no significant association was found.

When we adjust the models for the 'individual' and 'area' fixed effects (Table 3.2), the disparities increase. All else being equal, someone in Q5 is 52% more likely to have cycled in the last 4 weeks than a similar individual in a comparable environment in Q1. This increase of inequalities in total cycling is mostly caused by the increment of disparities in the Q3, Q4, and Q5 quintiles for utility cycling. This suggests that if the areas in these quintiles (Q3, Q4, and Q5) had the same environmental attributes (in terms of cycle tracks, density, and hilliness) as the areas in Q1, more people that live in them would cycle for transport. Therefore, we can conclude that the environmental variables found significantly associated with utility cycling participation (i.e. cycle tracks density, population density, and hilliness – see Table 3.5) contribute to reducing socioeconomic inequalities in cycling levels.

**Associations between level of deprivation and cycling duration**

The multilevel gamma models adjusting for 'individual' fixed effects (Table 3.2) show a positive association between level of deprivation and cycling duration. That is, those who did any cycling in the last 4 weeks living in deprived areas were more likely to cycle more time on average per week than those who did any cycling in the last 4 weeks living in non-deprived areas. The effect of this association is slightly higher for utility than for leisure cycling.

Adjusting the gamma models for the 'individual' and 'area' fixed effects (Table 3.2) hardly alter the ORs and significance results. This suggests that the environmental attributes (considered in our models) do not substantially influence the time that people cycle per week.

Table 3.2: Associations between level of deprivation and total cycling participation and duration, leisure cycling participation and duration, and utility cycling participation and duration.

| | Multilevel logistic models (cycling participation) | | Multilevel gamma models (cycling duration) | |
|---|---|---|---|---|
| | adjusting 'individual' fixed effects OR (95% CI) [a] | adjusting 'individual' and 'area' fixed effects OR (95% CI) [b] | adjusting 'individual' fixed effects OR (95% CI) [c] | adjusting 'individual' and 'area' fixed effects OR (95% CI) [d] |
| **Total cycling** | | | | |
| Q1 (most) | 1 | 1 | 1 | 1 |
| Q2 | 1.11 (1.03, 1.18) ** | 1.12 (1.04, 1.20) ** | 0.89 (0.81, 0.98) * | 0.89 (0.89, 0.89) *** |
| Q3 | 1.28 (1.20, 1.35) *** | 1.32 (1.24, 1.40) *** | 0.83 (0.74, 0.92) *** | 0.83 (0.83, 0.83) *** |
| Q4 | 1.36 (1.28, 1.44) *** | 1.44 (1.36, 1.52) *** | 0.84 (0.76, 0.93) *** | 0.85 (0.85, 0.85) *** |
| Q5 (least) | 1.42 (1.34, 1.50) *** | 1.52 (1.44, 1.60) *** | 0.81 (0.73, 0.90) *** | 0.82 (0.82, 0.82) *** |
| **Leisure cycling** | | | | |
| Q1 (most) | 1 | 1 | 1 | 1 |
| Q2 | 1.11 (1.03, 1.18) ** | 1.12 (1.04, 1.19) ** | 0.90 (0.83, 0.98) * | 0.87 (0.79, 0.95) *** |
| Q3 | 1.28 (1.21, 1.35) *** | 1.30 (1.22, 1.37) *** | 0.85 (0.78, 0.93) *** | 0.80 (0.72, 0.88) *** |
| Q4 | 1.38 (1.31, 1.46) *** | 1.41 (1.33, 1.49) *** | 0.87 (0.79, 0.95) *** | 0.81 (0.72, 0.89) *** |
| Q5 (least) | 1.45 (1.38, 1.53) *** | 1.49 (1.41, 1.57) *** | 0.88 (0.80, 0.96) ** | 0.82 (0.73, 0.90) *** |
| **Utility cycling** | | | | |
| Q1 (most) | 1 | 1 | 1 | 1 |
| Q2 | 0.99 (0.86, 1.12) | 1.05 (0.92, 1.18) | 0.88 (0.78, 0.98) * | 0.91 (0.80, 1.01) |
| Q3 | 1.05 (0.92, 1.18) | 1.23 (1.10, 1.37) ** | 0.85 (0.74, 0.95) ** | 0.89 (0.78, 1.00) * |
| Q4 | 1.12 (0.99, 1.25) | 1.39 (1.26, 1.53) *** | 0.82 (0.72, 0.92) *** | 0.87 (0.76, 0.98) * |
| Q5 (least) | 1.07 (0.93, 1.20) | 1.39 (1.25, 1.53) *** | 0.76 (0.65, 0.86) *** | 0.81 (0.69, 0.92) *** |

[a] This multilevel logistic model estimates the association between level of deprivation (IMD quintiles) and cycling participation adjusting for the 'individual' fixed effects.
[b] This multilevel logistic model estimates the association between IMD quintiles and cycling participation adjusting for the 'individual' and 'area' fixed effects.
[c] This multilevel gamma model estimates the association between IMD quintiles and cycling duration adjusting for the 'individual' fixed effects.
[d] This multilevel gamma model estimates the association between IMD quintiles and cycling duration adjusting for the 'individual' and 'area' fixed effects.
Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; OR (95% CI) = Odds ratio and 95% confidence intervals.

## 3.4 Discussion

The first aim of this study was to analyse the extent to which socioeconomic disadvantage in England impacts cycling participation and cycling duration for both leisure cycling and utility cycling. A significant negative relationship between level of deprivation and cycling participation was found for leisure cycling. However, for utility cycling, no significant association was found. Although to the best of our knowledge, no study in the UK has explored the relationship between the level of deprivation and leisure cycling, most research from other countries support our finding concluding that leisure cycling is more common among non-deprived populations than among deprived populations (Kamphuis et al., 2008; Heesch et al., 2014; Heesch et al., 2015). Previous studies that looked at the relationship between deprivation and utility cycling in England have focused on commuting cycling. Parkin et al. (2008) found a positive link between low-income areas and commuting cycling. However, Goodman (2013) found that low-income groups commuted by bicycle slightly more than higher affluent groups. Nevertheless, she pointed out that in the period 2001-2011 the differences had been reduced, and reversed in the highest cycling locations, predicting that future cycling in England and Wales might become increasingly concentrated among affluent groups.

On the contrary, a significant positive relationship between level of deprivation and cycling duration was found, i.e. cyclists living in deprived areas were more likely to cycle longer per week than cyclists living in non-deprived areas. This association was slightly stronger for utility than for leisure cycling. Less accessibility to other modes of transport, such as cars or public transport, by socioeconomically disadvantaged cyclists may explain this disparity in utility cycling.

The second aim of the study was to examine whether the socioeconomic inequalities in cycling participation could be explained by inequality in the distribution of environments more prone to cycling. Contrary to our expectations, both the descriptive and the multilevel model analyses indicate that more deprived areas in England are, in general terms, more suitable for cycling and better provided of cycle-friendly infrastructure than less deprived areas. This rejects the hypothesis that the difference in cycling participation per socioeconomic level, demonstrated when addressing the first aim, might be partly explained by inequality in the distribution of cycle-friendly environments (at least in terms of the factors that we analysed in this study, i.e., cycling infrastructure, quietness, density, and hilliness).

We attribute higher density of cycling infrastructure in deprived areas to the fact that these areas in England (and in most industrialized countries) tend to be located in or close to the centre of the cities (Margo, 1992; Mieszkowski and Mills, 1993; Mills and Sende Lubuele, 1997); and traditionally city centres have been equipped with more transport infrastructure. However, not in all cities of most industrialized countries, deprived areas are more cycle-friendly. For example, in 22 large US cities was found that access to bike lanes was lower in areas with lower education, higher Hispanic populations, and lower composite SES (Braun et al., 2019). Also in Chicago (Prelog, 2015) and Minnesota (Wang and Lindsey, 2017), a clear inequity in the distribution of cycling infrastructure was found. Neither in all countries and cities, most deprived populations live in central and dense areas. In Latin American countries, for instance, low-income populations live primarily in distant peripheral areas (Sabatini, 2006). This might explain, at least in part, that studies conducted in Latin American countries (Teunissen et al., 2015; Tucker and Manaugh, 2018) found disadvantaged areas significantly worse provided of cycling infrastructure than middle and upper-class areas.

The fact that population living in deprived areas despite having better infrastructure and cycle-friendly environment cycle less leads to the conclusion that although spatial determinants are important for cycling promotion (particularly for utility cycling), social and economical factors must be essential to engage disadvantaged people in cycling.

As full models showed (see Appendix A), non-whites, low-educated, and people with occupations of lower social groups, which are social groups generally linked with socioeconomic disadvantage, were also negatively correlated with cycling. Non-white and low-educated individuals were particularly less likely to cycle for utility (OR 0.43 and OR 0.60, respectively); whereas, people with occupations of the lower social groups were particularly less likely to cycle for leisure (OR 0.69). According to research, other individual barriers to cycle among disadvantaged populations are: not having a bicycle or gear related, lack of secure storage at home and where they go (McNeil, 2011), and cultural aspects such as the social stigma of using a bicycle as a mode of transport (Steinbach, Green, et al., 2011; Bratman and Jul, 2014).

Strengths of this study include the use of the nationally representative ALS. The ALS is one of the largest surveys of its kind, with 179,747 valid responses for the period mid-November 2017 to mid- November 2018 (Ipsos MORI, 2019). The inclusion of both leisure cycling and utility cycling in the analyses is another strength. Most of the studies that previously looked at the relationship between socioeconomic disadvantage and cycling in the UK were focused only on cycling commuting.

Several limitations associated with the input data and our focus on IMD scores as a proxy for disadvantage should be considered when interpreting the results and drawing conclusions. First, the data used from the ALS is self-reported which implies a potential risk of bias assessment. A systematic review (Prince et al., 2008) comparing direct versus self-report measures for assessing physical activity in adults found out that, self-report measures of physical activity were both higher and lower than directly measured levels of physical activity.

Second, we did not have access to the residential LSOA of individuals, which is the level at which the IMD is collected. To overcome this limitation, we had to aggregate the LSOAs dataset by IMD decile and Local Authority (LA). This allowed exploring associations between environmental factors and cycling participation per level of deprivation at a sub-local authority level (see section 2.3).

Third, although most of our data were at the individual-level, the key variable of the analysis, 'level of deprivation', referred to the level of deprivation of the area where respondents lived, but not the level of deprivation of individuals or households. Therefore, among the cycling participation considered of disadvantaged populations, there could be included, for example, cycling participation of affluent young professionals, who tend to live in gentrified areas and cycle more often than average. This suggests that bicycle use of disadvantaged populations could be even lower than we reported. In the same way, though, cycling participation considered of non-deprived populations could be of disadvantaged populations living in wealthier areas.

Fourth, the research did not account for potential confounding variables such as attractiveness/aesthetics, crime, road safety, and air quality previously linked with cycling levels (Mitchell and Dorling, 2003; Edwards, Green, et al., 2006; Timms and Tight, 2010; Kremers et al., 2012). These could plausibly affect the likelihood of cycling in ways that are not accounted for in our research.

Fifth, although the study distinguishes between 'cycle track (off-road)' and 'cycle lane (on-road)', no information was available regarding the quality and maintenance of the infrastructure, which may be particularly important in deprived areas. Nor on whether the infrastructure met the needs and preferences of disadvantaged groups, for example, whether it led to the main destinations of these groups.

Sixth, full-term unemployed or never worked (NS-SEC 8) and full-time students and other/unclassified represent (NS-SEC 9) were under-represented in the 2017/18 ALS (Ipsos MORI, 2019), with 2.1% and 7.7% of respondents compared to 5.6% and 9.0% in the general population (ONS, 2021). This may have slightly affected the reliability of the models' estimates.

Finally, the variables 'cycle track (off-road)' and 'cycle lane (on-road)' were sourced from the OpenStreetMap (OSM) which is built through crowdsourced volunteered geographic information. This implies the risk that in areas where people contribute more the information may be more detailed and vice-versa, suggesting further avenues for research that use more accurate and systematically collected data on cycling infrastructure.

## 3.5 Conclusions

This research found that the likelihood of cycling in England is lower among people living in deprived areas than among people living in non-deprived areas. This difference is statistically significant for leisure cycling, but also for utility cycling when controlling for individual and environmental factors. However, cyclists living in deprived areas were found to cycle longer per week than cyclists living in non-deprived areas, particularly for utility cycling. The study also found, contrary to our expectations, that deprived areas in England have a higher density of cycling infrastructure, lower levels of traffic stress, higher population density, and fewer hills than non-deprived areas. The paradox of a lower likelihood of cycling in deprived areas where the environment may be more cycle-friendly suggests that the provision of infrastructure alone is not enough to engage more disadvantaged populations in cycling.

Interventions to increase access to bicycles (either for ownership and secure storage space) and against the social stigma of cycling among socioeconomically disadvantaged populations should be taken into consideration, as some studies suggest. Even so, further research on barriers to cycling among socioeconomically disadvantaged populations, and how these barriers intersect with other types of disadvantage is required to provide the evidence needed for effective interventions to enabling the benefits of cycling to be available for all.

## Appendix A: Models full results

This appendix shows the full results of the multilevel regression models for total cycling (Table 3.3), for leisure cycling (Table 3.4), and for utility cycling (Table 3.5).

Table 3.3: Associations with total cycling participation and duration.

| | | Multilevel logistic models (cycling participation) | | Multilevel gamma models (cycling duration) | |
|---|---|---|---|---|---|
| | | adjusting 'individual' fixed effects OR (95% CI) | adjusting 'individual' and 'area' fixed effects OR (95% CI) | adjusting 'individual' fixed effects OR (95% CI) | adjusting 'individual' and 'area' fixed effects OR (95% CI) |
| Gender | Male | 1 | 1 | 1 | 1 |
| | Female | 0.53 (0.50, 0.56) *** | 0.53 (0.50, 0.56) *** | 0.60 (0.57, 0.63) *** | 0.60 (0.60, 0.60) *** |
| Age | Age 16-34 | 1 | 1 | 1 | 1 |
| | Age 35-54 | 1.13 (1.10, 1.17) *** | 1.14 (1.11, 1.18) *** | 1.06 (1.02, 1.09) ** | 1.06 (1.06, 1.06) *** |
| | Age 55-74 | 0.65 (0.61, 0.69) *** | 0.65 (0.61, 0.70) *** | 0.99 (0.94, 1.03) | 0.99 (0.99, 0.99) *** |
| Ethnicity | White | 1 | 1 | 1 | 1 |
| | Non-white | 0.60 (0.55, 0.64) *** | 0.59 (0.54, 0.63) *** | 0.82 (0.77, 0.87) *** | 0.82 (0.81, 0.82) *** |
| Education | High | 1 | 1 | 1 | 1 |
| | Medium | 0.76 (0.72, 0.80) *** | 0.77 (0.73, 0.80) *** | 0.98 (0.94, 1.02) | 0.98 (0.98, 0.98) *** |
| | Low | 0.69 (0.65, 0.72) *** | 0.69 (0.65, 0.72) *** | 1.03 (0.99, 1.06) | 1.03 (1.03, 1.03) *** |
| Occupation | nssec 1-2: Higher social groups | 1 | 1 | 1 | 1 |
| | nssec 3-5: Middle social groups | 0.86 (0.83, 0.90) *** | 0.87 (0.83, 0.90) *** | 0.92 (0.88, 0.96) *** | 0.92 (0.92, 0.92) *** |
| | nssec 6-8: Lower social groups | 0.75 (0.70, 0.79) *** | 0.75 (0.71, 0.80) *** | 1.03 (0.98, 1.08) | 1.03 (1.03, 1.03) *** |
| | nssec 9: Students and other | 1.24 (1.19, 1.28) *** | 1.24 (1.19, 1.28) *** | 1.00 (0.95, 1.05) | 1.00 (1.00, 1.01) *** |
| Type of area | Urban | 1 | 1 | 1 | 1 |
| | Rural | 1.00 (0.96, 1.04) | 1.03 (0.99, 1.08) | 0.95 (0.91, 0.99) * | 0.95 (0.95, 0.95) *** |
| Level of deprivation | Q1 (most) | 1 | 1 | 1 | 1 |
| | Q2 | 1.11 (1.03, 1.18) ** | 1.12 (1.04, 1.20) ** | 0.89 (0.81, 0.98) * | 0.89 (0.89, 0.89) *** |
| | Q3 | 1.28 (1.20, 1.35) *** | 1.32 (1.24, 1.40) *** | 0.83 (0.74, 0.92) *** | 0.83 (0.83, 0.83) *** |
| | Q4 | 1.34 (1.28, 1.44) *** | 1.44 (1.36, 1.52) *** | 0.84 (0.76, 0.93) *** | 0.85 (0.85, 0.85) *** |
| | Q5 (least) | 1.42 (1.34, 1.50) *** | 1.52 (1.44, 1.60) *** | 0.81 (0.73, 0.90) *** | 0.82 (0.82, 0.82) *** |
| | Cycle tracks (off-road) | | 1.01 (1.00, 1.02) ** | | 1.00 (1.00, 1.00) |
| | Cycle lanes (on-road) | | 1.02 (1.00, 1.03) ** | | 1.00 (1.00, 1.01) *** |
| | Quietness | | 1.00 (0.98, 1.01) | | 1.00 (1.00, 1.00) *** |
| | Density | | 1.00 (1.00, 1.00) | | 1.00 (1.00, 1.00) |
| | Hilliness | | 0.89 (0.86, 0.92) *** | | 1.02 (1.02, 1.02) *** |
| Observations | | 151430 | 149501 | 31240 | 30822 |
| Log Likelihood | | -64649 | -64155 | -196829 | -195341 |
| AIC | | 129332 | 128354 | 393695 | 390727 |
| BIC | | 129501 | 128572 | 393845 | 390919 |

Significance: * p < 0.05, ** p < 0.01, *** p < 0.001; OR (95% CI) = Odds ratio and 95% confidence intervals; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 3.4: Associations with leisure cycling participation and duration.

| | | Multilevel logistic models (cycling participation) | | Multilevel gamma models (cycling duration) | |
|---|---|---|---|---|---|
| | | adjusting 'individual' fixed effects OR (95% CI) | adjusting 'individual' and 'area' fixed effects OR (95% CI) | adjusting 'individual' fixed effects OR (95% CI) | adjusting 'individual' and 'area' fixed effects OR (95% CI) |
| Gender | Male | 1 | 1 | 1 | 1 |
| | Female | 0.59 (0.56, 0.62) *** | 0.59 (0.56, 0.62) *** | 0.60 (0.58, 0.63) *** | 0.61 (0.58, 0.63) *** |
| Age | Age 16-34 | 1 | 1 | 1 | 1 |
| | Age 35-54 | 1.18 (1.14, 1.21) *** | 1.19 (1.15, 1.22) *** | 1.10 (1.07, 1.14) *** | 1.10 (1.07, 1.14) *** |
| | Age 55-74 | 0.72 (0.67, 0.76) *** | 0.72 (0.68, 0.76) *** | 1.08 (1.04, 1.12) *** | 1.08 (1.04, 1.12) *** |
| Ethnicity | White | 1 | 1 | 1 | 1 |
| | Non-white | 0.65 (0.60, 0.70) *** | 0.64 (0.59, 0.69) *** | 0.85 (0.80, 0.90) *** | 0.86 (0.81, 0.91) *** |
| Education | High | 1 | 1 | 1 | 1 |
| | Medium | 0.79 (0.75, 0.83) *** | 0.79 (0.75, 0.83) *** | 1.00 (0.97, 1.04) | 1.00 (0.97, 1.04) |
| | Low | 0.71 (0.68, 0.75) *** | 0.72 (0.68, 0.75) *** | 1.10 (1.06, 1.13) *** | 1.09 (1.06, 1.13) *** |
| Occupation | nssec 1-2: Higher social groups | 1 | 1 | 1 | 1 |
| | nssec 3-5: Middle social groups | 0.87 (0.84, 0.91) *** | 0.87 (0.84, 0.91) *** | 0.91 (0.87, 0.94) *** | 0.90 (0.87, 0.94) *** |
| | nssec 6-8: Lower social groups | 0.69 (0.65, 0.74) *** | 0.69 (0.65, 0.74) *** | 0.98 (0.93, 1.03) | 0.98 (0.93, 1.02) |
| | nssec 9: Students and other | 1.11 (1.03, 1.12) *** | 1.11 (1.06, 1.16) *** | 1.01 (0.96, 1.06) | 1.01 (0.96, 1.06) |
| Type of area | Urban | 1 | 1 | 1 | 1 |
| | Rural | 1.07 (1.03, 1.12) ** | 1.09 (1.04, 1.13) *** | 1.02 (0.98, 1.06) | 0.99 (0.95, 1.03) |
| Level of deprivation | Q1 (most) | 1 | 1 | 1 | 1 |
| | Q2 | 1.11 (1.03, 1.18) ** | 1.12 (1.04, 1.19) ** | 0.90 (0.83, 0.98) * | 0.87 (0.79, 0.95) *** |
| | Q3 | 1.28 (1.21, 1.35) *** | 1.30 (1.22, 1.37) *** | 0.85 (0.78, 0.93) *** | 0.80 (0.72, 0.88) *** |
| | Q4 | 1.38 (1.31, 1.46) *** | 1.41 (1.33, 1.49) *** | 0.87 (0.79, 0.95) *** | 0.81 (0.72, 0.89) *** |
| | Q5 (least) | 1.45 (1.38, 1.53) *** | 1.49 (1.41, 1.57) *** | 0.88 (0.80, 0.96) ** | 0.82 (0.73, 0.90) *** |
| | Cycle tracks (off-road) | | 1.00 (1.00, 1.01) | | 1.00 (0.99, 1.01) |
| | Cycle lanes (on-road) | | 1.01 (1.00, 1.02) | | 1.01 (1.00, 1.01) |
| | Quietness | | 1.00 (0.98, 1.01) | | 1.00 (0.99, 1.00) |
| | Density | | 1.00 (1.00, 1.00) | | 1.00 (1.00, 1.00) *** |
| | Hilliness | | 0.93 (0.90, 0.96) *** | | 1.05 (1.02, 1.07) ** |
| Observations | | 151430 | 149501 | 26993 | 26634 |
| Log Likelihood | | -59449 | -59030 | -160102 | -158823 |
| AIC | | 118932 | 118104 | 320239 | 317692 |
| BIC | | 119101 | 118322 | 320387 | 317880 |

Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; OR (95% CI) = Odds ratio and 95% confidence intervals; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 3.5: Associations with utility cycling participation and duration.

| | | Multilevel logistic models (cycling participation) | | Multilevel gamma models (cycling duration) | |
|---|---|---|---|---|---|
| | | adjusting 'individual' fixed effects OR (95% CI) | adjusting 'individual' and 'area' fixed effects OR (95% CI) | adjusting 'individual' fixed effects OR (95% CI) | adjusting 'individual' and 'area' fixed effects OR (95% CI) |
| Gender | Male | 1 | 1 | 1 | 1 |
| | Female | 0.35 (0.31, 0.40) *** | 0.35 (0.31, 0.40) *** | 0.83 (0.80, 0.87) *** | 0.83 (0.79, 0.87) *** |
| Age | Age 16-34 | 1 | 1 | 1 | 1 |
| | Age 35-54 | 1.01 (0.96, 1.06) | 1.02 (0.97, 1.07) | 0.99 (0.94, 1.03) | 0.99 (0.95, 1.04) |
| | Age 55-74 | 0.50 (0.43, 0.56) *** | 0.50 (0.44, 0.57) *** | 0.95 (0.89, 1.00) * | 0.95 (0.89, 1.00) |
| Ethnicity | White | 1 | 1 | 1 | 1 |
| | Non-white | 0.44 (0.38, 0.51) *** | 0.43 (0.37, 0.50) *** | 1.00 (0.94, 1.06) | 0.99 (0.92, 1.05) |
| Education | High | 1 | 1 | 1 | 1 |
| | Medium | 0.71 (0.65, 0.76) *** | 0.72 (0.66, 0.77) *** | 1.03 (0.98, 1.09) | 1.03 (0.98, 1.09) |
| | Low | 0.59 (0.53, 0.64) *** | 0.60 (0.55, 0.66) *** | 1.10 (1.05, 1.16) *** | 1.11 (1.06, 1.16) *** |
| Occupation | nssec 1-2: Higher social groups | 1 | 1 | 1 | 1 |
| | nssec 3-5: Middle social groups | 0.78 (0.72, 0.84) *** | 0.78 (0.72, 0.84) *** | 1.02 (0.97, 1.07) | 1.03 (0.98, 1.08) |
| | nssec 6-8: Lower social groups | 0.95 (0.89, 1.01) | 0.96 (0.89, 1.02) | 1.08 (1.02, 1.14) * | 1.09 (1.03, 1.15) ** |
| | nssec 9: Students and other | 1.60 (1.53, 1.66) *** | 1.59 (1.52, 1.65) *** | 0.86 (0.80, 0.92) *** | 0.87 (0.81, 0.93) *** |
| Type of area | Urban | 1 | 1 | 1 | 1 |
| | Rural | 0.68 (0.61, 0.75) *** | 0.74 (0.66, 0.81) *** | 0.93 (0.87, 0.99) * | 0.96 (0.89, 1.02) |
| Level of deprivation | Q1 (most) | 1 | 1 | 1 | 1 |
| | Q2 | 0.99 (0.86, 1.12) | 1.05 (0.92, 1.18) | 0.88 (0.78, 0.98) * | 0.91 (0.80, 1.01) |
| | Q3 | 1.05 (0.92, 1.18) | 1.23 (1.10, 1.37) ** | 0.85 (0.74, 0.95) ** | 0.89 (0.78, 1.00) * |
| | Q4 | 1.12 (0.99, 1.25) | 1.39 (1.26, 1.53) *** | 0.82 (0.72, 0.92) *** | 0.87 (0.76, 0.98) * |
| | Q5 (least) | 1.07 (0.93, 1.20) | 1.39 (1.25, 1.53) *** | 0.76 (0.65, 0.86) *** | 0.81 (0.69, 0.92) *** |
| | Cycle tracks (off-road) | | 1.02 (1.01, 1.03) *** | | 1.00 (0.99, 1.00) |
| | Cycle lanes (on-road) | | 1.02 (0.99, 1.04) | | 1.00 (0.98, 1.01) |
| | Quietness | | 1.00 (0.98, 1.03) | | 1.01 (1.01, 1.01) *** |
| | Density | | 1.00 (1.00, 1.00) *** | | 1.00 (1.00, 1.00) *** |
| | Hilliness | | 0.79 (0.74, 0.84) *** | | 1.00 (0.96, 1.03) |
| Observations | | 151430 | 149501 | 11603 | 11433 |
| Log Likelihood | | -35140 | -34793 | -77626 | -77093 |
| AIC | | 70315 | 69631 | 155287 | 154232 |
| BIC | | 70483 | 69849 | 155420 | 154401 |

Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; OR (95% CI) = Odds ratio and 95% confidence intervals; AIC = Akaike information criterion; BIC = Bayesian information criterion.

## Acknowledgements

We would like to thank Sport England (Nathan Cheetham and Helen Price) for providing the ALS dataset used for this study. Thanks also to Professor Kelvyn Jones (University of Bristol) and Andrea Gilardi (University of Milan) for the useful discussions on multilevel modelling. EVT completed this work as part of a Doctorate funded by the Economics and Social Research Council [ES/R501062/1]. RPM was supported by a UK Research and Innovation Future Leaders Fellowship [MR/S032525/1].

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# Chapter 4

# Socioeconomic inequalities in cycling safety: An analysis of cycling injury risk by residential deprivation level in England

This chapter is based on the paper: Vidal Tortosa, E., Lovelace, R., Heinen, E., Mann, R.P., 2021. *Socioeconomic inequalities in cycling safety: An analysis of cycling injury risk by residential deprivation level in England.* Journal of Transport & Health. 23, p.101291. https://doi.org/10.1016/j.jth.2021.101291

# Abstract

*Introduction:* Previous studies have found a positive association between cycling injury risk and residential deprivation. However, most of these studies focused on serious and fatal injuries, children, and a specific point in time. This study explores i) inequalities in cycling injury risk by residential deprivation for all recorded casualties (slight, serious, and fatal) in England, ii) whether these inequalities vary by sex and age, and iii) how they have changed over time. *Methods:* Using the STATS19 database of road traffic casualties in Britain, the English National Travel Survey, and population estimates for England over the six-year period 2014-2019, we estimated the ratio of slight, serious, and fatal cycling casualties per billion kilometres cycled by residential Index of Multiple Deprivation (IMD) quintile; by residential IMD quintile and sex and age group; and by residential IMD quintile and year. *Results:* We found that the higher the level of residential deprivation, the higher the slight and serious cycling injury risk. The fatal cycling injury risk was also higher in individuals from the most deprived areas. Inequalities were particularly large for children, with slight and serious rates three times higher for children from the most deprived areas than for children from the least deprived areas. We also found that the linear trend lines of the slight and serious injury rates between 2014 and 2019 declined in the least deprived quintiles but not in the most deprived quintiles, which suggests that inequalities in slight and serious cycling injuries may have grown over the last years. *Conclusion:* This study found that people from deprived areas are at higher risk of cycling injury for all types of severity; that children from deprived areas are most at risk; and that these inequalities may have increased over the last years.

**Keywords**: Cycling; Road traffic injury; Deprivation; Inequalities; Trends.

## 4.1 Introduction

Cycling has important health benefits (Oja et al., 2011), but it also involves injury risks. Although in Western countries such as the UK, the Netherlands, and Denmark it has been shown that benefits outweighed the risks (Hartog et al., 2010; Andersen et al., 2018), safety concerns are still one of the main barriers to cycle (Horton, 2007; Jacobsen et al., 2009; Pooley et al., 2013). Neither the benefits nor the risks of cycling are evenly distributed (Mackett and Thoreau, 2015; Rebentisch et al., 2019). People living in the most deprived areas in the UK have been found to cycle less than people living in less deprived areas (Parkin et al., 2008; Steinbach, Green, et al., 2011; Vidal Tortosa et al., 2021b; Vidal Tortosa et al., 2021a). Research also suggests that people living in the most deprived areas are at a higher risk of injury while cycling (and also while travelling by other modes) (Edwards et al., 2008; Feleke et al., 2018; O'Toole and Christie, 2018).

Most studies that have explored the association between residential level of deprivation and cycling injury risk focus on serious and/or fatal injuries, children, and a specific point in time. For example, Edwards et al. (2008) analysed serious road traffic injuries in children (aged 0 to 15) using Hospital Episode Statistics (HES) data. They found a higher risk of being seriously injured in child cyclists from deprived areas (child cyclists seriously injured/100.000 children) than in child cyclists from less deprived areas in England. O'Toole and Christie (2018) compared fatal and serious road traffic injuries between children aged 4 to 10 and children aged 11 to 15 using the STATS19 database. This study found that child cyclists aged 4 to 10 from the most deprived areas in England were particularly at high risk of being killed or seriously injured (child cyclist KSI/100.000 children). It also found that this risk was much higher in male than in female child cyclists, particularly in the most deprived areas. Feleke et al. (2018), who analysed inequalities in fatal road traffic injuries not only in children but also in adults using Office for National Statistics (ONS) data, found that child cyclists from the most deprived areas in England had higher risk of being fatally injured adjusting for both distance and time (child cyclist fatalities/billion km cycled and child cyclist fatalities/million hours cycling). They did not find, however, significant differences between adult cyclists of any age group.

Nonetheless, several questions remain unanswered. First, there has been little research into socioeconomic inequalities in minor cycling injuries. Previous studies focused on serious and/or fatal casualties. This is mostly because these studies compared the injury risk among different modes of transport and given that minor cycling injuries are exceptionally under-reported (Mindell et al., 2012; DfT, 2018b), they are not directly comparable. Second, little is known on whether there are socioeconomic inequalities in serious cycling injuries in adults. Feleke et al. (2018) found no significant differences in the risk of dying while cycling in adults, however, the number of cycling fatalities might be too small to show whether cycling is overall more dangerous for a specific socioeconomic group of adults. Third, it is also unknown whether potential socioeconomic inequalities in cycling injury risk in adults vary by sex and age, as it does in children (O'Toole and Christie, 2018). Finally, no prior study has explored, to the best of our knowledge, trends of socioeconomic inequalities in cycling injury risk.

This study explores: i) inequalities in cycling injury risk by residential deprivation for all recorded casualties (slight, serious, and fatal) in England, ii) whether these inequalities vary by sex and age, and iii) how they have changed over time. Better understanding socioeconomic inequalities in cycling safety can support evidence-based policies to make cycling safer for all, and given the importance that safety concerns have on the choice of people to cycle, it could also be critical in addressing existing inequalities in cycling levels. Effective interventions to make cycling safer among people living in deprived areas could, therefore, have a double positive impact on the health of these groups: reducing their disproportionately high risk of being injured in traffic collisions and increasing their participation in transport and leisure cycling.

## 4.2 Data and methods

### 4.2.1 Data

Three datasets for the six-year period 2014-2019 were used for this study: the STATS19 database of road traffic casualties in Britain, the National Travel Survey Special Licence Access (NTS), and population estimates for England from the Office of National Statistics (ONS).

To prepare the casualty data, we transformed two variables of the STATS19 database: Residential Index of Multiple Deprivation (IMD) decile[1] into residential IMD quintile (Q1 (most), Q2, Q3, Q4, Q5 (least)), and age into age group (<16, 16-29, 30-64, >64). This was done to increase the sample size. Next, we removed all casualty records with no residential IMD decile, sex, and age; and due to a change in the systems for severity

[1] Residential IMD deciles refers to the level of deprivation of small administrative areas (Lower-layer Super Output Areas) of England where casualties lived at the time of the incident. IMD scores are based on seven domains of deprivation: Income Deprivation, Employment Deprivation, Education, Skills and Training Deprivation, Health Deprivation and Disability, Crime, Barriers to Housing and Services, and Living Environment Deprivation (DfCLG, 2015).

reporting in 2016, we performed an adjustment on the slight and serious casualties. For this, we used a method developed by the ONS (ONS, 2019a). Then, we aggregated the slight, serious, and fatal cycling casualties[2] by residential IMD quintile, sex/residential IMD quintile, age group/residential IMD quintile, and year/residential IMD quintile.

To prepare the exposure data (billion kilometres [Bkm] cycled), we calculated the weekly miles cycled per individual (weighted for drop-off in recording observed). For this, we used the file ‘Stage’ from the NTS. Then, we aggregated this variable by residential IMD quintile, sex/residential IMD quintile, age group/residential IMD quintile, and year/residential IMD quintile (weighted to adjust for non-response). Next, we divided each of these figures by the number of individuals in the NTS sample for each of these groups, and multiply them by the population estimates for England. To scale the weekly miles cycled to the full year and covert it into kilometres, we multiplied these figures by 52.14 and 1.61. Finally, we divided them by 1 billion.

There is a debate in the literature about which unit of exposure is the most appropriate for calculating road traffic injury rates. Distance travelled and time spent travelling are the most commonly used (Vanparijs et al., 2015). Distance travelled does not seem the most appropriate unit to compare the injury risk of different modes of transport. This is because it does not capture the substantial differences in average speed by modes of transport (Mindell et al., 2012). In other words, if we compare, for example, the risk of driving and cycling based on distance travelled, the former will be somewhat under-estimated because the average speed of drivers is much higher than that of cyclists. However, if we compare the risk of the same modes based on time spent travelling, this will be more equal because the average travel time of drivers and cyclists are more similar (and constant over time). Furthermore, it is conceivable that it is not the distance travelled but the actual time in a risky environment that determines one’s risk, although time spent travelling may be harder to calculate accurately and in many cases is not available. We use, however, distance travelled as the unit of exposure in this study for three reasons. First, we do not compare the injury risk of different modes of transport. Second, distance travelled can be directly obtained from the NTS. Third, distance travelled is the most commonly used denominator in official documents (ETSC, 2020; e.g. DfT, 2020b), which

[2]Slight casualties are individuals involved in a road collision who as a consequence had an injury not requiring medical treatment. Seriously casualties are individuals involved in a road collision who as a consequence were detained in hospital as an “in-patient”, or had any of the following injuries whether or not they were detained in hospital: fractures, concussion, internal injuries, crushings, burns (excluding friction burns), severe cuts, severe general shock requiring medical treatment and injuries causing death 30 or more days after the accident. Fatal casualties are individuals involved in a road collision who sustained injuries from the collision which caused death less than 30 days after the incident (DfT, 2017c).

makes our findings more comparable.

### 4.2.2 Analysis

To examine inequalities in cycling injury risk by residential deprivation, we estimated slight, serious, and fatal cycling injury rates as the ratio of slight, serious, and fatal cycling casualties per Bkm cycled by residential IMD quintile. To explore whether these inequalities vary by sex and age, we stratified these rates by sex and age group. Numerators and denominators of these rates combined the six-year period 2014-2019 to increase the accuracy of estimates. Finally, to analyse how inequalities in cycling injury risk by deprivation level changed over time, we calculated slight, serious, and fatal cycling injury rates by residential IMD quintile and year from 2014 to 2019.

Ninety-five percent confidence intervals (95% CIs) of each of these rates were computed using exact Poisson confidence limits based on the link between the Chi square and the Poisson distributions, in line with previous research (e.g. Bouaoun et al., 2015). The NTS sample of cyclists used for calculating the denominators (Bkm cycled) was in all cases 35 or over.

## 4.3 Results

### 4.3.1 Cycling injury rates by residential IMD quintile

Table 4.1 shows the number of slight, serious, and fatal cycling casualties as well as the Bkm cycled by residential IMD quintile for the entire period 2014-2019. Figure 4.1 depicts the resulting rates.

The slight cycling injury rate increases with deprivation, with almost twice the number of slight casualties per Bkm cycled in the most deprived quintile (Q1) than in the least deprived (Q5) (Figure 4.1A). The serious cycling injury rate also increases with deprivation, although, in this case, the gradient is slightly less pronounced (Figure 4.1B). The fatal cycling injury rate does not gradually increase with deprivation, although the highest is in people from the most deprived quintile (Q1) (Figure 4.1C). Note that the small number of fatal injuries makes the results of the fatal rate less reliable, and, as we can see in Figure 4.1C, the 95% CIs overlap, indicating that the differences among quintiles are most likely not significant.

Table 4.1: Slight, serious, and fatal cycling casualties and Bkm cycled by residential IMD quintile, 2014-2019.

| IMD quintile | Slight cycling casualties | % | Serious cycling casualties | % | Fatal cycling casualties | % | Bkm cycled | % |
|---|---|---|---|---|---|---|---|---|
| Q1 (most) | 15242 | 23.1 | 4514 | 21.2 | 82 | 18.7 | 4.9 | 16.5 |
| Q2 | 15823 | 24.0 | 4479 | 21.0 | 72 | 16.4 | 6.1 | 20.6 |
| Q3 | 12536 | 19.0 | 4005 | 18.8 | 84 | 19.1 | 5.8 | 19.6 |
| Q4 | 11408 | 17.3 | 4128 | 19.4 | 101 | 23.0 | 6.4 | 21.4 |
| Q5 (least) | 10978 | 16.6 | 4192 | 19.7 | 100 | 22.8 | 6.5 | 21.9 |

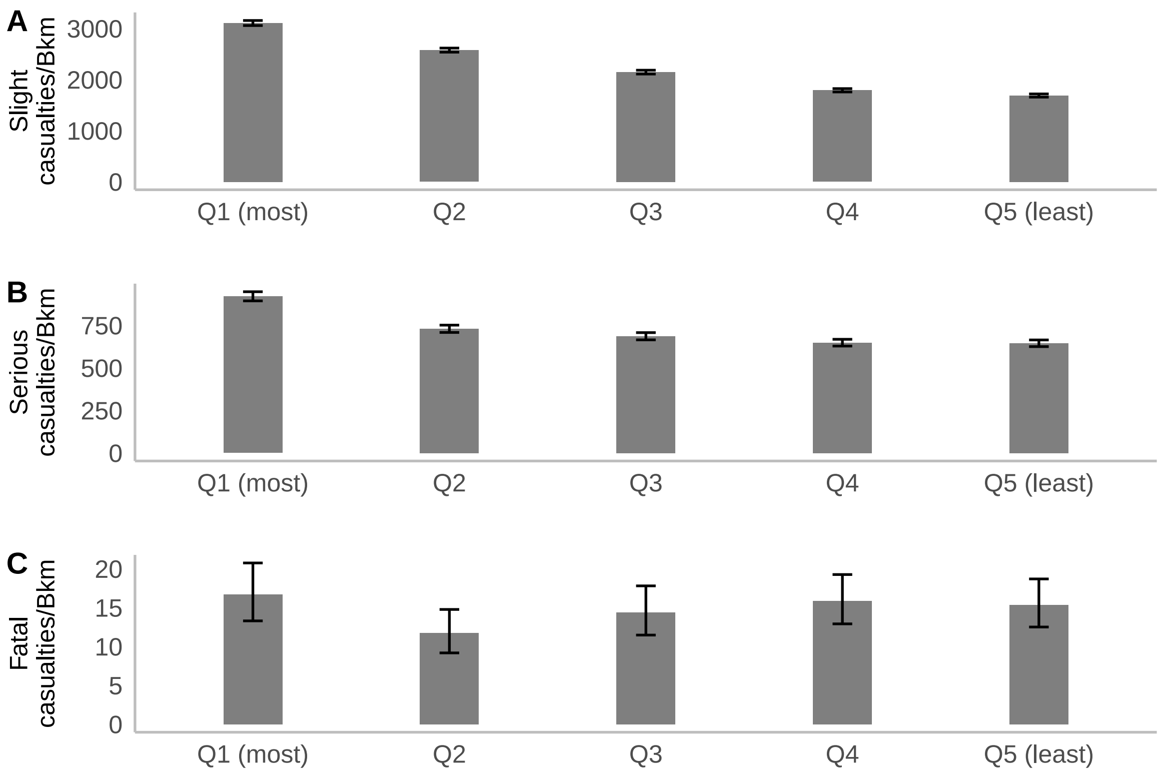


Figure 4.1: Slight, serious, and fatal cycling injury rates by residential IMD quintile, 2014-2019. The error bars show 95% confidence intervals.

### 4.3.2 Cycling injury rates by residential IMD quintile and sex and age groups

Tables 4.2 and 4.3 present the number of slight, serious, and fatal cycling casualties and the Bkm cycled by residential IMD quintile and sex, and by residential IMD quintile and age group for the entire period 2014-2019. Figures 4.2 and 4.3 show their associated cycling injury rates.

The slight cycling injury rate is very similar for males and females (Figure 4.2A). The serious cycling injury rate is higher for males but across all the quintiles, the difference being significant in Q1, Q4, and Q5 (Figure 4.2B). The fatal cycling injury rate is higher for males in most quintiles, although, as the 95% CIs indicate, the differences among quintiles may not be significant (Figure 4.2C).

Table 4.2: Slight, serious, and fatal cycling casualties and Bkm cycled by residential IMD quintile and sex, 2014-2019.

| IMD quintile | Sex | Slight cycling casualties | % | Serious cycling casualties | % | Fatal cycling casualties | % | Bkm cycled | % |
|---|---|---|---|---|---|---|---|---|---|
| Q1 (most) | Female | 2920 | 19.2 | 697 | 15.4 | 12 | 14.6 | 0.9 | 19.0 |
| | Male | 12322 | 80.8 | 3817 | 84.6 | 70 | 85.4 | 4.0 | 81.0 |
| Q2 | Female | 3334 | 21.1 | 858 | 19.2 | 14 | 19.4 | 1.2 | 20.0 |
| | Male | 12489 | 78.9 | 3621 | 80.8 | 58 | 80.6 | 4.9 | 80.0 |
| Q3 | Female | 2709 | 21.6 | 764 | 19.1 | 17 | 20.2 | 1.2 | 20.4 |
| | Male | 9827 | 78.4 | 3241 | 80.9 | 67 | 79.8 | 4.7 | 79.6 |
| Q4 | Female | 2384 | 20.9 | 761 | 18.4 | 19 | 18.8 | 1.5 | 22.9 |
| | Male | 9024 | 79.1 | 3367 | 81.6 | 82 | 81.2 | 4.9 | 77.1 |
| Q5 (least) | Female | 2103 | 19.2 | 695 | 16.6 | 10 | 10.0 | 1.3 | 19.8 |
| | Male | 8875 | 80.8 | 3497 | 83.4 | 90 | 90.0 | 5.2 | 80.2 |

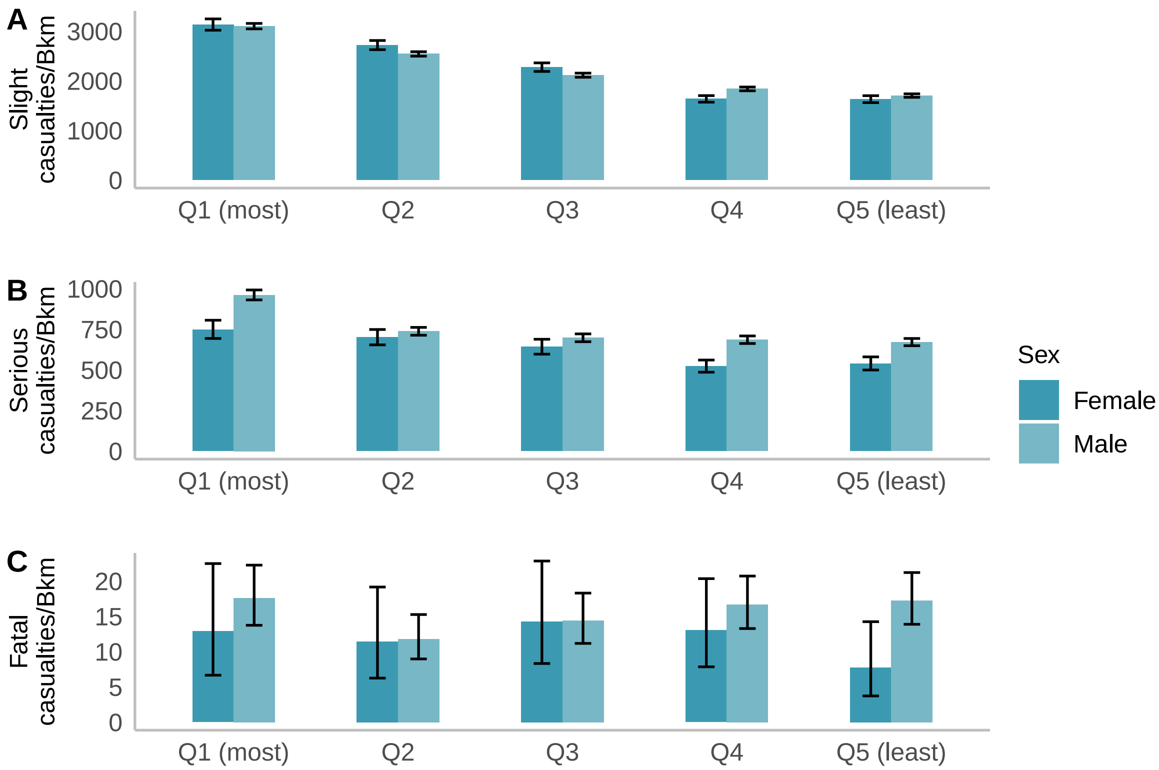


Figure 4.2: Slight, serious, and fatal cycling injury rates by residential IMD quintile and sex, 2014-2019. The error bars show 95% confidence intervals.

The slight cycling injury rate is higher in younger age groups and especially in those living in the most deprived areas. This rate is more than three times higher in children (aged <16) from the most deprived quintile (Q1) than in children from the least (Q5) (Figure 4.3A). The serious cycling injury risk seems more similar by age group, although the serious rate is still three times higher in children from the most deprived quintile (Q1) than in children from the least (Q5) (Figure 4.3B). The fatal cycling injury risk increases with age: the older the individuals, the higher the risk to die while cycling. Although, interestingly, this does not seem to be the case in the most deprived quintile (Q1), where all age groups have a quite similar fatality rate (Figure 4.3C). Notice also that the fatal injury rate in older people from the most deprived quintile (Q1) is lower than in older people from the rest of the quintiles.

Table 4.3: Slight, serious, and fatal cycling casualties and Bkm cycled by residential IMD quintile and age groups, 2014-2019.

| IMD quintile | Age | Slight cycling casualties | % | Serious cycling casualties | % | Fatal cycling casualties | % | Bkm cycled | % |
|---|---|---|---|---|---|---|---|---|---|
| Q1 (most) | <16 | 2343 | 15.4 | 662 | 14.7 | 9 | 11.0 | 0.4 | 7.5 |
| | 16-29 | 5384 | 35.3 | 1403 | 31.1 | 18 | 22.0 | 1.5 | 30.4 |
| | 30-64 | 7283 | 47.8 | 2311 | 51.2 | 49 | 59.8 | 2.8 | 56.4 |
| | >64 | 232 | 1.5 | 138 | 3.1 | 6 | 7.3 | 0.3 | 5.6 |
| Q2 | <16 | 1699 | 10.7 | 437 | 9.8 | 2 | 2.8 | 0.5 | 8.1 |
| | 16-29 | 5304 | 33.5 | 1210 | 27.0 | 9 | 12.5 | 1.6 | 26.3 |
| | 30-64 | 8489 | 53.6 | 2609 | 58.3 | 43 | 59.7 | 3.7 | 60.9 |
| | >64 | 332 | 2.1 | 222 | 5.0 | 18 | 25.0 | 0.3 | 4.6 |
| Q3 | <16 | 1197 | 9.6 | 318 | 7.9 | 3 | 3.6 | 0.4 | 7.4 |
| | 16-29 | 3697 | 29.5 | 977 | 24.4 | 11 | 13.1 | 1.0 | 17.5 |
| | 30-64 | 7229 | 57.7 | 2442 | 61.0 | 46 | 54.8 | 3.9 | 66.6 |
| | >64 | 413 | 3.3 | 268 | 6.7 | 24 | 28.6 | 0.5 | 8.5 |
| Q4 | <16 | 1022 | 9.0 | 306 | 7.4 | 6 | 5.9 | 0.4 | 6.0 |
| | 16-29 | 2993 | 26.2 | 794 | 19.2 | 13 | 12.9 | 1.0 | 16.3 |
| | 30-64 | 6876 | 60.3 | 2707 | 65.6 | 54 | 53.5 | 4.3 | 67.7 |
| | >64 | 517 | 4.5 | 321 | 7.8 | 28 | 27.7 | 0.6 | 10.1 |
| Q5 (least) | <16 | 996 | 9.1 | 263 | 6.3 | 7 | 7.0 | 0.5 | 7.5 |
| | 16-29 | 2407 | 21.9 | 673 | 16.1 | 7 | 7.0 | 1.0 | 14.6 |
| | 30-64 | 7010 | 63.9 | 2850 | 68.0 | 58 | 58.0 | 4.2 | 65.3 |
| | >64 | 566 | 5.2 | 405 | 9.7 | 28 | 28.0 | 0.8 | 12.6 |

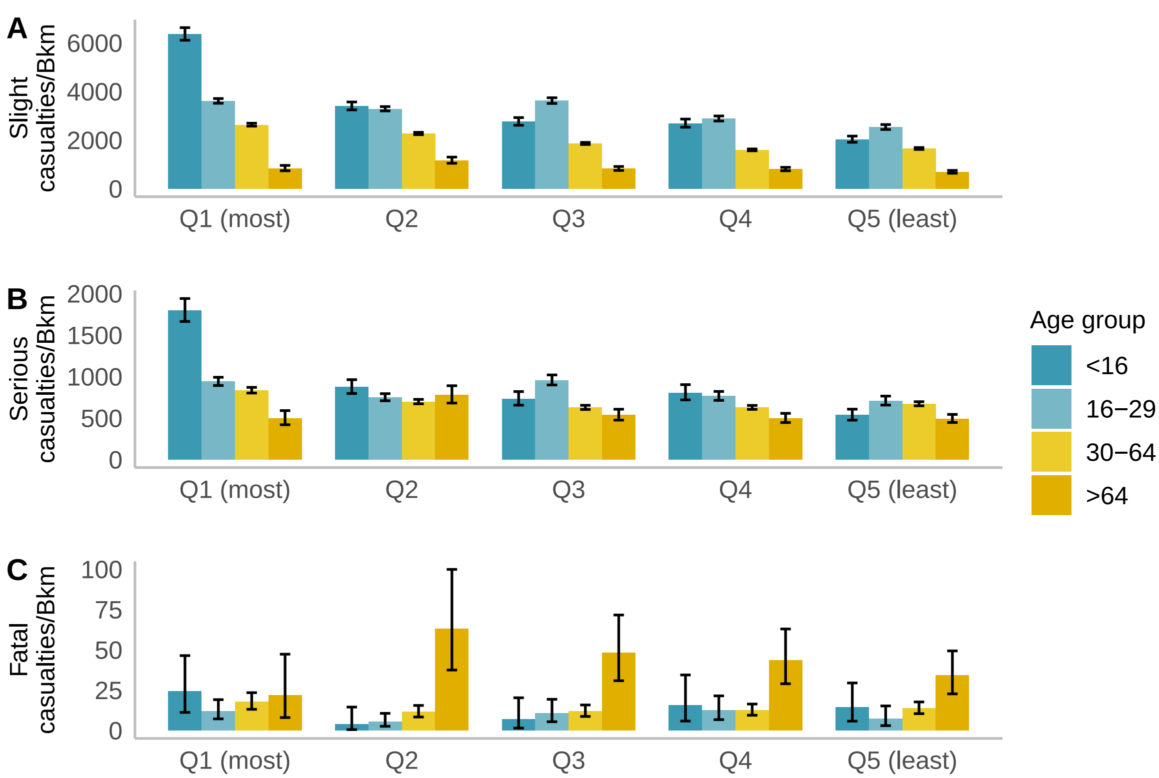


Figure 4.3: Slight, serious, and fatal cycling injury rates by residential IMD quintile and age group, 2014-2019. The error bars show 95% confidence intervals.

### 4.3.3 Time trend of cycling injury rates by residential IMD quintile

Table 4.4 shows the number of slight, serious, and fatal cycling casualties and the Bkm cycled by residential IMD quintile and year from 2014 to 2019. Figure 4.4 reveals the trends of their associated rates.

The linear trend lines of the slight injury rate decline in all the quintiles, except in the two most deprived (dots and triangles in blue) that remain flat (Figure 4.4A). Similarly, the serious injury rate seems to decline in most of the quintiles, but less in the second most deprived (Q2) and it slightly increases in the most deprived (Q1) (Figure 4.4B). The number of fatal cycling casualties broken down by IMD quintile and year is very small, and therefore it is impossible to draw any conclusions about their relative trends over time in different quintiles (Figure 4.4C).


Figure 4.4: Slight, serious, and fatal cycling injury rates by residential IMD quintile and year, 2014-2019. The error bars show 95% confidence intervals and the dashed lines the linear trends.

Table 4.4: Slight, serious, and fatal cycling casualties and Bkm cycled by residential IMD quintile and year, 2014-2019.

| IMD quintile | Year | Slight cycling casualties | % | Serious cycling casualties | % | Fatal cycling casualties | % | Bkm cycled | % |
|---|---|---|---|---|---|---|---|---|---|
| Q1 (most) | 2014 | 2902 | 19.0 | 821 | 18.2 | 11 | 13.4 | 0.8 | 15.8 |
| | 2015 | 2565 | 16.8 | 753 | 16.7 | 16 | 19.5 | 0.9 | 19.1 |
| | 2016 | 2482 | 16.3 | 721 | 16.0 | 11 | 13.4 | 0.9 | 17.6 |
| | 2017 | 2259 | 14.8 | 658 | 14.6 | 16 | 19.5 | 0.8 | 15.4 |
| | 2018 | 2532 | 16.6 | 788 | 17.5 | 16 | 19.5 | 0.9 | 18.0 |
| | 2019 | 2502 | 16.4 | 773 | 17.1 | 12 | 14.6 | 0.7 | 14.1 |
| Q2 | 2014 | 3001 | 19.0 | 845 | 18.9 | 13 | 18.1 | 1.3 | 20.8 |
| | 2015 | 2624 | 16.6 | 795 | 17.7 | 8 | 11.1 | 0.9 | 14.7 |
| | 2016 | 2635 | 16.7 | 709 | 15.8 | 13 | 18.1 | 0.7 | 11.8 |
| | 2017 | 2418 | 15.3 | 667 | 14.9 | 14 | 19.4 | 1.3 | 20.8 |
| | 2018 | 2601 | 16.4 | 743 | 16.6 | 13 | 18.1 | 1.0 | 16.8 |
| | 2019 | 2544 | 16.1 | 720 | 16.1 | 11 | 15.3 | 0.9 | 15.2 |
| Q3 | 2014 | 2441 | 19.5 | 780 | 19.5 | 17 | 20.2 | 1.0 | 16.5 |
| | 2015 | 2132 | 17.0 | 690 | 17.2 | 14 | 16.7 | 1.0 | 16.7 |
| | 2016 | 2026 | 16.2 | 640 | 16.0 | 16 | 19.0 | 1.0 | 16.8 |
| | 2017 | 1905 | 15.2 | 574 | 14.3 | 10 | 11.9 | 0.8 | 14.5 |
| | 2018 | 2070 | 16.5 | 663 | 16.6 | 12 | 14.3 | 0.9 | 16.1 |
| | 2019 | 1963 | 15.7 | 657 | 16.4 | 15 | 17.9 | 1.1 | 19.5 |
| Q4 | 2014 | 2216 | 19.4 | 774 | 18.7 | 18 | 17.8 | 0.9 | 14.8 |
| | 2015 | 1966 | 17.2 | 710 | 17.2 | 12 | 11.9 | 1.0 | 15.6 |
| | 2016 | 1914 | 16.8 | 678 | 16.4 | 17 | 16.8 | 0.9 | 14.7 |
| | 2017 | 1728 | 15.1 | 609 | 14.8 | 17 | 16.8 | 1.1 | 17.5 |
| | 2018 | 1853 | 16.2 | 704 | 17.1 | 17 | 16.8 | 1.3 | 21.1 |
| | 2019 | 1731 | 15.2 | 653 | 15.8 | 20 | 19.8 | 1.0 | 16.3 |
| Q5 (least) | 2014 | 2213 | 20.2 | 805 | 19.2 | 21 | 21.0 | 1.1 | 16.3 |
| | 2015 | 1916 | 17.5 | 734 | 17.5 | 21 | 21.0 | 0.9 | 13.4 |
| | 2016 | 1897 | 17.3 | 691 | 16.5 | 18 | 18.0 | 1.2 | 18.4 |
| | 2017 | 1559 | 14.2 | 598 | 14.3 | 9 | 9.0 | 1.2 | 18.8 |
| | 2018 | 1735 | 15.8 | 688 | 16.4 | 14 | 14.0 | 1.1 | 16.3 |
| | 2019 | 1658 | 15.1 | 676 | 16.1 | 17 | 17.0 | 1.1 | 16.7 |

# 4.4 Discussion

## 4.4.1 Summary of findings

The first aim of this study was to explore inequalities in cycling injury risk by residential deprivation for all recorded casualties (slight, serious, and fatal). Substantial inequalities were found. The risk of slight and serious injuries while cycling increased gradually with the level of residential deprivation. The gradient was greater in slight injury rates than in serious injury rates. The risk of cycling fatality was also higher in individuals from the most deprived areas. These findings support previous studies in England (e.g. Edwards et al., 2008; O'Toole and Christie, 2018).

A combination of environmental, social, and economic factors may explain these inequalities. Although this is an analysis based on the residence of the casualties, there is evidence that a large proportion of cycling injuries occur close to home (e.g. Steinbach et al., 2013). More intersections, homes without a play area, population density, street parking, road density, traffic volume, and a lack of safe crossing sites have been previously associated with higher road risk in deprived areas (Alwash and McCarthy, 1988; Christie et al., 2010; Green et al., 2011; Morency et al., 2012). However, deprived areas in England have been also found to have a higher density of traffic calming measures and cycle tracks (Rodgers et al., 2010; Steinbach, Grundy, et al., 2011; Vidal Tortosa et al., 2021b), previously linked to lower cycling injury risk (Teschke et al, 2012; Aldred et al., 2018).

Another element to consider is the driving behaviour of motorists in deprived areas. Much of the research in cycling safety focuses on the environment and the cyclist. However, research on how drivers' behaviour affects cyclists risk is often neglected, even though drivers are the ones who endanger cyclists. Some existing studies show that motorists from deprived areas drive in a more aggressive and antisocial way (Braver, 2003; Hasselberg et al., 2005). Further research is needed to examine the impact that urban environments and driving misbehaviour in deprived areas may have on the safety of cyclists from these areas.

Social and economic factors may play an important role too. People from deprived areas, most of them with low incomes, are possibly more likely to own bicycles of poorer quality (e.g. with worse brakes, tyres, and lights), which might make a difference when facing dangerous road traffic situations. Similarly, cyclists living in deprived areas have been found to have less access to safety equipment such as helmets (Kendrick, 2003; Sullins et al., 2014), which could increase the severity of their injuries considerably (Thompson et al., 1999).

The second aim of the study was to explore whether these inequalities vary by sex and age. We did not find important variations by sex; however, we found substantial variations by age group, particularly in children. Children from the most deprived quintile were found three times at a higher risk of slight and serious injury while cycling than those in the least deprived areas. This finding supports previous research on cycling injury risk in children (Edwards et al., 2008; Embree et al., 2016; Feleke et al., 2018; O'Toole and Christie, 2018). By contrast, we found that the differences in the slight and serious rates in young and middle-aged adults by level of deprivation are smaller; and that the fatal rate for older people in the most deprived quintile is, in fact, lower.

This raises a policy-relevant question: why are these inequalities greater in children than in adults? This could be because in deprived areas there are more environments especially dangerous for children (e.g., more intersections, street parking, and unsafe crossings sites). Also, children who grow up in deprived areas might have fewer opportunities to ride safely and learn how to ride safely (e.g. less ability to buy safety equipment, less access to green and off-road safe spaces, less parental supervision, etc.) (Towner et al., 2005), which might contribute to making them less skilled and confident when cycling, particularly in their initial years of riding. Previous research found higher cycling injury risk among younger than older children from deprived areas (O'Toole and Christie, 2018). Differences in the type of cycling could also partly explain these inequalities. Hagel et al. (2015) found that the odds of hospitalisation were lower for children and adolescents who cycled to school, work, or shopping (utilitarian cycling) than for children and adolescents who cycled for other purposes. Further research is needed to explain why children from deprived areas are particularly at high risk of injury while cycling.

The final aim of the study was to explore how these inequalities have changed over time. We found that between 2014 and 2019 the linear trend lines of the slight and serious injury rates slightly decreased in the least deprived quintiles, but not in the most deprived quintiles. This suggests that the inequalities in minor and serious cycling injuries may have increased in recent years. In other words, although since 2014 the risk of cycling injury in England overall declined (DfT, 2020b), according to our data it did decline among people from least deprived areas, but not among people from most deprived areas.

This finding may indicate that recent policies implemented to increase cycling safety have benefited more non-deprived than deprived populations. For instance, there may have been more investment in cycling infrastructure and traffic calming measures in less deprived areas in recent years. Steinbach, Grundy, et al. (2011) found that the implementation of 20 mph zones in London targeted at most deprived areas, which led to a reduction in socioeconomic differences in road injury. However, they suggested that the potential of the implementation of these zones for further mitigation of inequality was limited. It is possible that later (during the years analysed in this study) these facilities were installed more in less deprived areas, which could have led to widening the disparities again.

Another explanation could be that cycle-friendly infrastructure implemented in recent years, regardless of its distribution, is more suitable for non-disadvantaged than for disadvantaged groups. A recent study (Vidal Tortosa et al., 2021a) found that low-income groups in England cycle far less for commuting, which suggests that commuting-centric cycling infrastructure, such as 'cycle superhighways', may be less convenient for low-income than for middle- and higher-income cyclists. Further research is needed to investigate whether the increase in inequalities in slight and serious injuries can be attributed to changes in the underlying probabilities of such injuries, and if so, why this increase may have occured. It would be interesting to follow up on the trends in the coming years and, for example, analyse the impact that the 'emergency' Low Traffic Neighbourhoods, set up during Covid-19, have had on this regard.

### 4.4.2 Strengths and limitations

One strength of this paper is that it looked at four aspects not explored to date: socioeconomic inequalities in slight cycling injury risk; socioeconomic inequalities in serious cycling injury risk in adults; the variation of socioeconomic inequalities in cycling injury risk in adults by sex and age; and how socioeconomic inequalities in cycling injury risk have changed over time. Other strengths are that, for the calculation of the cycling injury rates, we adjusted for changes in the system for severity in 2016 and that we used Bkm cycled as a unit of exposure.

The paper has nevertheless several limitations. First, since cyclists have no obligation to inform the police about collisions (Mindell et al., 2012; DfT, 2018b), the number of cycling incidents in the STATS19 database is particularly under-reported. If levels of reporting vary by deprivation level, this may have included a bias in our estimates of rates. Second, the variable postcode (and associated variable residential IMD quintile) was missing in 12% of the casualties, which were consequently removed from the analysis. If completion of this variable varies by deprivation levels, then this may have also introduced bias in our results. Third, the variable residential IMD quintile refers to the level of deprivation of the area where individuals live, but not to the level of deprivation of individuals. Therefore, among the cycling casualties considered in each quintile, there might be some from a different individual deprivation level (e.g. young high-income professionals living in gentrified deprived areas). Finally, although as we mentioned before, Bkm cycled seems the most appropriate unit of exposure for the calculation of the rates of this study (because we do not compare different modes of transport, it is obtained directly from the NTS, and it is the most commonly used denominator in official documents), we should take into account that using this denominator we did not capture certain differences in the average speed by type of cyclist and trip.

## 4.5 Conclusions

This paper found substantial inequalities in cycling injury risk by residential deprivation level: the higher the level of residential deprivation, the higher the risk of slight and serious injuries while cycling. The risk of cycling fatality was higher in individuals from the most deprived areas too. The paper also reveals that these inequalities were particularly large for children, with slight and serious rates three times higher for children from the most deprived areas than for children from the least deprived areas. The differences in adults, however, were smaller, and older people from the most deprived areas presented a lower fatality rate than those from less disadvantaged areas. Finally, we also found that the linear trend lines of the slight and serious injury rates between 2014 and 2019 declined in the least deprived quintiles but not in the most deprived quintiles, which suggests that inequalities in slight and serious cycling injuries may have grown over the last years.

The reasons for these inequalities are likely to be multifaceted and involve a combination of environmental, social, and economic factors. Further research is needed to investigate the impacts of urban environments and driving misbehaviour, why children from deprived areas are particularly at high risk, whether the increase in inequalities in slight and serious injuries can be attributed to changes in the underlying probabilities of such injuries, and if so, why. Answers to these questions will help to find more effective policies to reduce the current safety gap between socioeconomic groups; and, in turn, make cycling more attractive among the disadvantaged.

## Acknowledgements

We would like to thank Emily Durrant (UK Data Service) for her assistance in getting access to the NTS (NTS Special Licence dataset SN 7553) and Andrew Kelly (Department for Transport) for his guidance on weighting the NTS for the calculation of Bkm cycled. EVT completed this work as part of a Doctorate funded by the Economics and Social Research Council [grant number ES/R501062/1]. RPM was supported by a UK Research and Innovation Future Leaders Fellowship [grant number MR/S032525/1].

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# Chapter 5

# Discussion and conclusions

## 5.1 Introduction

This thesis aimed to better understand the relationships between cycling and socioeconomic disadvantage in England from three perspectives: behaviour, environment, and safety.

To address this aim, three empirical papers using a varied range of datasets (NTS, ALS, STATS19, and population and environmental data from several sources) and quantitative methods (descriptive, regression, and multilevel regression analyses) were undertaken.

New and policy-relevant discoveries were made, contributing to the academic literature and understanding of cycling and inequalities.

This chapter presents a summary of the main findings of the papers, which answers each of the research questions of the thesis. Second, it discusses limitations and other issues to consider when interpreting the results of the thesis as a whole. Third, it indicates the implication of the findings for policy. Fourth, it recommends directions for further work. Finally, it concludes with a summary of the entire work across all elements of the thesis.

## 5.2 Main findings

This thesis consists of three research questions (Q1, Q2 and Q3), which were successively addressed in the papers in Chapters 2 to 4.

*RQ1. To what extent do income and other factors of socioeconomic disadvantage influence cycling behaviour?*

The paper in Chapter 2 addressed this first question by analysing the relationship between income and other factors of socioeconomic disadvantage (i.e. education, economic status, parenting, single parenting, driving licence holding, and car availability) and three cycling behaviours (cycling participation, cycling frequency, and cycling distance), distinguishing between utility and leisure cycling.

For this, using the NTS, descriptive statistics (bar graphs and contingency tables broken down by household income quintile) and three regression models that followed a hierarchical structure were estimated.

The results of the descriptive analysis revealed that people in the lowest household income in England make a quarter as many communing cycling trips as people in the highest household income quintile. However, cycling trips for visiting friends and education (n.b., children were not included in the analysis) were greater among people in lower household income quintiles (Figure 2.2).

The results of the multivariate analyses showed a significant positive association between household income and utility cycling (i.e., cycling for commuting, shopping, education/escort education, personal business, business, and other escort)(Table 2.2). However, contrary to our expectations, no significant association was found between household income and leisure cycling (i.e., cycling for visiting friends at private home, visiting friends elsewhere, entertainment / public activity, sport, holiday, and day trip)(Table 2.3). In addition, household income was negatively associated with leisure cycling frequency, but positively with leisure cycling distance.

The positive association between income and utility cycling corresponds with previous research in England that found lower levels of utility and commuting cycling among lower-income populations (Parkin et al., 2008; Green et al., 2010). Parkin et al. (2008) suggested that this could be due to higher crime, safe storage, bicycle availability and image issues among people from deprived areas. Steinbach, Green, et al. (2011) attributed it mostly to cultural and identity reasons. However, previous international research found a positive association between income and leisure cycling (Kamphuis et al., 2008; Heesch et al., 2014; Heesch et al., 2015).

Other significant associations found in these models were that: i) people with lower levels of education participate less in leisure cycling and cycle shorter distances for leisure; ii) part-time workers participate more in utility and leisure cycling and cycle more frequently for utility; iii) students participate more in leisure cycling but cycle less frequently and shorter distances for utility; and iv) people with no car participate and cycle more often for utility and leisure cycling, and cycle further for utility.

The studies in Chapters 3 and 4 also provided some insights into the relationship between socioeconomic factors and cycling behaviour. The paper in Chapter 3 investigated the relationship between the level of deprivation, education, occupation, and cycling participation and duration, disguising also between utility and leisure cycling. For this, using the ALS and environmental data, multilevel regression models were estimated.

The results of these multilevel models revealed a significant positive association between lower levels of deprivation and leisure cycling participation, but not between lower levels of deprivation and utility cycling participation[1]. However, a significant negative relationship between lower levels of deprivation and cycling duration for both utility and leisure cycling was found (Table 3.2). These models also found people with

[1]The association between lower levels of deprivation and utility cycling participation was significantly positive when controlling for 'individual' and 'environmental' factors.

low and medium levels of education negatively associated with both utility and leisure cycling participation, but positively associated with utility and leisure cycling duration. Finally, lower social populations (NS-SEC) were found negatively associated with leisure cycling participation, but positively associated with utility cycling duration (Tables 3.4 and 3.5).

In the study in Chapter 4, to calculate cycling injury rates by residential deprivation, Bkm cycled per residential IMD quintile were estimated. For this, the NTS and population estimates for England were used. This estimation shows that distance cycled decreases with deprivation. Specifically, people from the least deprived areas cycled 25% more km than people from the most deprived areas for the six-year period 2014-2019 (Table 4.1)[2].

This study also estimated Bkm cycled by residential deprivation and year. This calculation reveals that the socioeconomic inequalities per Bkm cycled may have increased between 2014 and 2019. This is because between these years people from the most deprived quintiles (Q1 and Q2) slightly decreased the distance cycled, while people from the least deprived quintiles (Q3 to Q5) cycled the same or more distance (Table 4.4).

*RQ2. To what extent do the environments in which socioeconomically disadvantaged populations live explain socioeconomic inequalities in cycling participation?*

The paper in Chapter 3 addressed this second question by examining i) the distribution of cycling levels and five environmental variables (cycle paths, cycle lanes, levels of traffic stress, population density, and hilliness) by area deprivation level, and ii) the associations between cycling levels, these five environmental variables, and deprivation level (controlling for other individual variables).

For this, using the ALS and environmental data from several sources, i) a barplot was drawn displaying the mean standardised scores of the area-level variables proportion cycling participation (total, utility, and leisure), cycle tracks, cycle lanes, levels of traffic stress, population density, and hilliness by deprivation quintile, and ii) multilevel logistic regressions were estimated to predict cycling participation adjusted for 'individual' and for 'individual' and 'environmental' fixed effects.

Contrary to expectations, the barplot indicated that deprived areas in England have, on average, a higher density of cycling infrastructure (cycle tracks and cycle lanes), lower levels of traffic stress, and are more densely populated and flatter than non-deprived

[2] Unlike the analyses in Chapters 2 and 3, in this analysis children were included. Nevertheless, no substantial differences were observed in the distance cycled by children per deprivation quintile.

areas (Figure 3.6).

The finding on a higher density of cycling infrastructure in deprived areas differs from most international research, which generally found that disadvantaged areas tend to have less access to cycling facilities (Teunissen et al., 2015; Wang and Lindsey, 2017; Arellano Yévenes and Saavedra Peláez, 2017; Tucker and Manaugh, 2018; e.g. Braun, 2019).

The multilevel logistic models adjusting for the 'individual' fixed effects showed a negative association between the level of deprivation and total cycling participation, with people from the least deprived areas participating in cycling 42% more than people from the most deprived areas. When adjusting these models for the 'individual' and 'environmental' fixed effects, the disparity increased to 52% (Table 3.3). That is, with the environments being equal (in terms of cycle tracks, cycle lanes, quietness, population density, and hilliness) people from least deprived areas were even more likely to participate in cycling compared to people from the most deprived areas.

This suggests, in accordance with the finding of the barplot, that deprived areas have on average more cycle-friendly environments (at least in terms of the factors that were associated with cycling participation, i.e., cycle tracks, cycle lanes, and hilliness) and that the existing distribution may contribute to reducing socioeconomic inequalities in cycling levels.

This finding answers the second research question of the thesis and rejects the initial hypothesis that the distribution of cycle-friendly environments could partly explain socioeconomic inequalities in cycling participation in England (at least in terms of the factors analysed in this paper, i.e., cycle tracks, cycle lanes, quietness, population density, and hilliness). This also suggests that the provision of infrastructure alone is not enough to reduce socioeconomic inequalities in cycling levels.

It should be taken into account, however, that this study did not account for three environmental elements that may negatively influence the decision of socioeconomically disadvantaged populations to cycle. These are: i) the quality (and maintenance) of the existing infrastructure, ii) whether the infrastructure serves disadvantaged groups (does infrastructure in deprived areas meet disadvantaged groups' needs and lead to their destinations?), and iii) additional environmental factors negatively associated with cycling levels such as road safety, attractiveness/aesthetics, crime, air quality (Mitchell and Dorling, 2003; Edwards, Green, et al., 2006; Timms and Tight, 2010; Kremers et al., 2012).

*RQ3. To what degree have socioeconomically disadvantaged populations a greater risk of being injured or killed while cycling than non-socioeconomically disadvantaged populations?*

The paper in Chapter 4 addressed this last question by exploring i) inequalities in cycling injury risk by residential deprivation for all recorded casualties (slight, serious, and fatal), ii) whether these inequalities vary by sex and age, and iii) how these inequalities have changed over time.

For this, using the STATS19 database, the NTS, and population estimated for England, the ratio of slight, serious, and fatal cycling casualties per Bkm cycled were estimated by i) residential IMD quintile, ii) residential IMD quintile and sex and age group, and iii) residential IMD quintile and year.

The results of these estimations revealed a gradual increase of slight and serious cycling injuries by residential level of deprivation in England. The fatal cycling injury risk was also found higher in individuals from the most deprived areas (Figure 4.1).

These inequalities were particularly large for children, with slight and serious rates three times higher for children from the most deprived areas than for children from the least deprived areas (Figure 4.3). This supports previous research on cycling injury risk in children in England (Edwards, Roberts, et al., 2006; Embree et al., 2016; Feleke et al., 2018; O'Toole and Christie, 2018).

This paper also revealed that the linear trend lines of the slight and serious injury rates between 2014 and 2019 declined in the least deprived quintiles but not in the most deprived quintiles, which suggests that inequalities in slight and serious cycling injuries may have grown over the last years (Figure 4.4).

## 5.3 Limitations and other issues to consider

### 5.3.1 Limitations

In addition to the limitations at the individual paper level (discussed in Chapters 2 to 4), there are some weaknesses that apply to the thesis as a whole. These are the potential low representativeness of socioeconomically disadvantaged populations in the ALS (due to its method of recruitment), the use of an unbalanced binary variable of education qualification in Chapters 2, and the use of different definitions of utility and leisure cycling in Chapters 2 and 3.

### Representativeness of the ALS

According to the 2017/18 ALS technical report (Ipsos MORI, 2019), the profile of the achieved sample by socioeconomic status (NS-SEC) in the 2017/18 ALS varies from the overall profile of the population. Individuals of higher NS-SEC were over-represented, with 54.3% of respondents in managerial, administrative and professional occupations (NS-SEC 1-2), compared to 31.3% in the general population (ONS, 2021). By contrast, full-term unemployed or never worked (NS-SEC 8) and full-time students and other/unclassified represent (NS-SEC 9) were under-represented, with 2.1% and 7.7% of respondents compared to 5.6% and 9.0% in the general population (Table 5.1).

Table 5.1: Percentage of sample (unweighted) 2017/18 ALS and general population by NS-SEC.

| NS-SEC | Online questionnaires (2017/18 ALS) | Paper questionnaires (2017/18 ALS) | Total questionnaires (2017/18 ALS) | General population (England 2011) |
|---|---|---|---|---|
| NS-SEC 1-2 | 57.6 | 48.7 | 54.3 | 31.3 |
| NS-SEC 3 | 11.1 | 10.8 | 11.0 | 12.8 |
| NS-SEC 4 | 6.5 | 8.2 | 7.2 | 9.4 |
| NS-SEC 5 | 6.7 | 8.6 | 7.4 | 20.9 |
| NS-SEC 6-7 | 9.1 | 12.4 | 10.3 | 11.0 |
| NS-SEC 8 | 1.8 | 2.6 | 2.1 | 5.6 |
| NS-SEC 9 | 7.2 | 8.6 | 7.7 | 9.0 |

Source: Prepared by the author based on Ipsos MORI 2019 and ONS 2021.

Two factors may have contributed to this mismatch (Ipsos MORI, 2019). First, the profile of survey respondents varies depending on survey topics. People from low socioeconomic status may not have a significant interest in the areas that the survey covers and so be less inclined to complete the questionnaire. Second, while the proportion of people online in England is high, low socioeconomic status populations may be less online and consequently less able to complete the survey. There is the possibility to fill a paper questionnaire, but survey fatigue may have set in by the time the second reminder arrives (with the paper questionnaire). This may have had some impact on the overall profile and the response rate of the survey (19%).

The recruitment method of the NTS, however, is based on face-to-face interviews and self-completion seven-day travel diaries, which may lead to a better representation of the socioeconomically disadvantaged populations. The 2017 NTS response rate is also much higher, 53% (DfT, 2018a).

### An unbalanced binary variable of education qualification in Chapter 2

The variable 'Educational qualifications', in Chapter 2, divides the sample size of the 2017 NTS (n= 11,897) into two rather uneven groups: those with any certificated educational qualifications (79.9%) and those with no certificated educational qualifications (20.1%). The variable 'Education', in Chapter 3, however, splits the sample size of the 2017/18 ALS (n= 16,7178) into three more homogeneous groups: those with high (50.9%), medium (15.1%), and low (33.9%) UK qualifications levels (Table 5.2).

Table 5.2: Sample size and percentage 2017/18 ALS and 2017 NTS by education level.

| Dataset | Variable | Category | n | perc. |
|---|---|---|---|---|
| 2017 NTS | Education qualifications | Yes[a] | 9513 | 79.9 |
| | | No | 2384 | 20.1 |
| 2017/18 ALS | Education | High[b] | 85098 | 50.9 |
| | | Medium[c] | 25258 | 15.1 |
| | | Low[d] | 56822 | 33.9 |

[a] 'Yes' indicates any certificated educational qualifications.
[b] 'High' (level 4 or above UK qualification levels).
[c] 'Medium' (level 3 and equivalents).
[d] 'Low' (levels 1 or 2 and equivalents or below, or 'No qualifications', or 'Another type of qualification').
Source: Prepared by the author based on Ipsos MORI 2019 and DfT 2018.

The use of a variable with multiple categories (more than two levels) in Chapter 2 would have helped to better understand the relationships between education and cycling behaviours in this study. For instance, it would have helped to see if there is a gradient in the associations or whether there are significant associations at an intermediate level. The use of a more balanced distribution of the sample between the different categories of the variable would have increased the reliability of the analysis results, particularly that of the cycling frequency and distance models based only on the sample of cyclists.

### Different definitions of utility and leisure cycling

Utility and leisure cycling in Chapters 2 and 3 do not mean the same. In Chapter 2, utility cycling means all cycling for 1) commuting, 2) business, 3) education/escort education, 4) shopping, 5) other escort, and 6) personal business; and leisure cycling refers to all cycling for 1) visiting friends at private home, 2) visiting friends elsewhere,

3) entertainment / public activity, 4) sport, 5) holiday, and 6) day trip. In other words, the distinction in Chapter 2 between utility and leisure cycling is based on the type of activity cyclists are travelling to or doing while cycling.

However, in Chapter 3, utility cycling means all cycling for travel (including cycling to travel to leisure activities such as visiting friends, going to the cinema, etc.); and leisure cycling includes all cycling for the sake of cycling such as 1) Mountain biking, 2) BMX, 3) road cycling and racing, 4) track cycling, 5) cycle cross, 6) cycle class, 7) exercise bike, and 8) other types of leisure cycling (Table 5.3).

Table 5.3: Definitions of utility and leisure cycling by dataset.

| Dataset | Utility cycling | Leisure cycling |
|---|---|---|
| 2017 NTS | 1) Commuting, 2) business, education/escort education, 3) shopping, 4) other escort, and 5) personal business. | 1) Visiting friends at private home, 2) visiting friends elsewhere, 3) entertainment / public activity, 4) sport, 5) holiday, and 6) day trip. |
| 2017/18 ALS | 1) Cycling for travel (including commuting). | 1) Mountain biking, 2) BMX, 3) road cycling and racing, 4) track cycling, 5) cycle cross, 6) cycle class, 7) exercise bike, and 8) other types of leisure cycling. |

Source: Prepared by the author based on Ipsos MORI 2019 and DfT 2018.

The use of one or another definition may have affected the results in each of the chapters. For example, in Chapter 2, the inclusion of cycling for visiting friends at private home in leisure cycling might have led to the no significant association found between income and leisure cycling (positively associated in Chapter 3), because low-income groups cycle more for visiting friends but less for a day trip or sport.

These definitions are important also regarding policy implications. Utility cycling as defined in Chapter 2, i.e., cycling for transport to utilitarian activities such as commuting, requires a fast and direct cycling infrastructure (e.g. cycling super-highways). However, utility cycling as defined in Chapter 3, i.e. all cycling for travelling, does not necessarily require a fast and direct infrastructure. For example, cycling to visit friends at private home or elsewhere, or to entertainment / public activity may require a fairly pleasant and well-connected rather than a fast and straightforward infrastructure.

### 5.3.2 Other issues to consider

There are two other issues that, although they cannot be considered limitations of the thesis (because they do not alter its results), should be taken into account when interpreting its results as a whole. These are the use of different proxies of socioeconomic disadvantage in each of the studies and some inconsistencies found between the results of Chapters 2 and 3.

#### Proxies for socioeconomic disadvantage

This thesis investigated the relationships between cycling and socioeconomic disadvantage. The decision to focus on socioeconomic disadvantage was due to two reasons. First, most of the previous research on inequalities in cycling focused on age, gender and, to a lesser extent, ethnicity and disability; however, less research has looked at cycling inequalities by socioeconomic levels. Second, socioeconomically disadvantaged populations are the social group that needs cycling the most, given their generally greater need for social opportunities and accessibility as well as physical activity and health.

The term *socioeconomically disadvantaged populations* in this thesis is defined as "all populations that experience disadvantages in terms of income, education and occupation". Consequently, for the review on inequalities in cycling levels (Chapter 1), academic papers on the associations between cycling levels and income, education, and occupation were analysed. However, in the empirical papers, different proxies had to be used depending on the datasets used.

Chapter 2 explored household income and other socioeconomic factors related to disadvantage, i.e., education, economic status, parenting, single-parenting, driving licence holding, and car availability. Chapter 3 examined education, occupation, and residential IMD, which refers to the level of deprivation of the LSOA (Lower-layer Super Output Areas) where individuals live and it is based on 7 deprivation domains: income deprivation, employment deprivation, education deprivation, skills and training deprivation, health deprivation and disability, crime, barriers to housing and services, and living environment deprivation. (DfCLG, 2015). Chapter 4 used residential IMD.

Therefore, when interpreting the results of this thesis as a whole, it should be taken into account that socioeconomically disadvantaged populations may refer to all populations that experience disadvantages in terms of income, education, and occupation, as well as to any of the proxies used in each of the papers e.g., people residing in deprived LSOA.

### Inconsistencies between the results of Chapters 2 and 3

Some inconsistencies were observed when comparing the results of the analyses of associations between socioeconomic factors and cycling participation from Chapters 2 and 3. In Chapter 2, household income was found significantly positively associated with utility cycling participation, but not with leisure cycling participation. However, in Chapter 3, lower levels of deprivation were found not associated with utility but positively associated with leisure cycling. Similarly, in Chapter 2, having educational qualifications was found positively associated with leisure cycling participation, but not associated with utility cycling participation. However, in Chapter 3, high education levels were found positively associated with both utility and leisure cycling. Table 5.4 summarises these inconsistencies.

Table 5.4: Associations of income/deprivation and education with utility and leisure cycling participation in Chapters 2 and 3.

| | Chapter 2 | | Chapter 3 | |
|---|---|---|---|---|
| | Utility cycling | Leisure cycling | Utility cycling | Leisure cycling |
| Household income quintile (highest) | + | o | | |
| Level of deprivation (IMD quintiles least deprived) | | | o | + |
| Educational qualifications ('Yes')[a] | o | + | | |
| Education ('High')[b] | | | + | + |

[a] Yes' indicates any certificated educational qualifications.
[b] Qualification level 4 or above.
Sign of association: '+' = positive, 'o' = no association.

Differences in the datasets and methods used in each of these studies may explain the differences. First, the dependent variable 'cycling participation' does not mean the same in each chapter. In Chapter 2, 'cycling participation' refers to cycling at least once a week on trips where cycling was the main mode and on a public road[3]. In Chapter 3, however, 'cycling participation' refers to cycling at least once in the past 4 weeks regardless of whether it was part of an inter-modal trip and on a public road.

Second, there are important differences in the datasets used in terms of sample size, method of recruitment, and response rates. The sample size of the NTS (Chapter 2) is around 12,000 respondents, while the sample size of the ALS (Chapter 3) is near 150,000. The method of recruitment used in the NTS is based on face-to-face interviews

[3] The NTS only collects data on public roads, excluding cycling travel across the open countryside and unsurfaced paths.

and self-completion seven-day travel diaries, while in the ALS on online and paper self-completion questionnaires (sent on a second reminder). Also, the response rates are considerably different, 53% in the NTS and 19% in the ALS.

Third, the independent variables ‘household income quintile’ and ‘level of deprivation’ are, as mentioned before, two different proxies of socioeconomic disadvantage. ‘Household income quintile’ refers to the level of income of the household where individuals live. However, ‘level of deprivation’ refers to the IMD quintile of the LSOA in which individuals live, and it is based on income and 6 other deprivation domains (employment deprivation, education deprivation, skills and training deprivation, health deprivation and disability, crime, barriers to housing and services, and living environment deprivation). The independent variables ‘educational qualifications’ and ‘education’ are, as also mentioned before, neither equivalent: ‘educational qualifications’ is a binary variable on whether individuals have or not a certificated educational qualification, while ‘education’ is a categorical variable with three levels based on the UK qualification levels.

Fourth, as previously discussed, the definitions of utility and leisure cycling in Chapters 2 and 3 are not the same. In Chapter 2, utility cycling is defined as cycling for travel to utilitarian activities (e.g. commuting, education, shopping, business); while in Chapter 3 utility cycling includes also cycling for travel to leisure activities such as visiting friends or going to the cinema (included as cycling leisure in Chapter 2).

Fifth, the control variables used in each chapter were also different. Whereas the study in Chapter 2 controlled for area type, age, sex, ethnicity, mobility difficulties, economic status, children in the household, single parent family, driving licence, and car access; the study in Chapter 3 controlled for type of area, gender, age, ethnicity, and occupation.

Therefore, as an overall conclusion of the thesis, it can be stated that socioeconomically disadvantaged people (in terms of income/deprivation and education) participate less in cycling; however, given the inconsistencies found between Chapters 2 and 3, it is not possible to determine with certainty whether this is the case in utility or leisure cycling.

The results between the cycling distance model in Chapter 2 and the cycling duration model in Chapter 3 are also conflicting. In Chapter 2, people from the highest income quintile were found to cycle for leisure significantly longer distances than people from the least income quintile. In Chapter 3, however, people from the least deprived areas were found to cycle for leisure fewer minutes on average than people from the most deprived areas. Although the dependent variables cycling distance and cycling duration are different measures and there may be important variations in speed between types of cyclists, it is reasonable to think that, generally, if you ride a bike for more time, you will cycle a longer distance. A similar contradiction occurs in terms of education. In Chapter

2, people with higher education levels were found to cycle for leisure longer distances. However, in Chapter 3, people with higher education levels were found to travel less time for both leisure and utility.

The use of different dependent variables, sample sizes (only cyclists in this case), method of recruitment, and response rates in the datasets, definitions of deprivation, education, and utility and leisure cycling, and control variables may explain these inconsistencies.

## 5.4 Policy implications

The findings of this thesis have policy implications that could help policymakers and practitioners to better enable socioeconomically disadvantaged populations to benefit from cycling. These policy implications can be grouped into three categories: bicycle ownership, access, and maintenance support; inclusive cycling infrastructure; and safety measures for those most at risk.

**Bicycle ownership, access, and maintenance support**

Chapter 3 showed that deprived areas in England have, on average, a more cycle-friendly environment (in terms of density of cycle tracks and cycle lanes, levels of traffic stress, population density, and hilliness). This suggests, that while infrastructure and environments are important for promoting cycling, they are unlikely enough to reduce socioeconomic inequalities in cycling levels. Therefore, complementary pro-cycling measures are required.

Chapter 2 found substantial differences in bicycle ownership and access by household income quintile, with only two in ten in the lowest household income quintile owning or having use of a bicycle, compared to five in ten in the highest household income quintile. This is supported by an analysis of the 2017 NTS, conducted during the preparation of this study, which revealed that 'bike broken/don't own a bike' is the second main perceived barrier to cycle among people from the lowest household income quintile in England (see Figure A.1). Hence, measures to provide access to working bicycles for low-income people via the implementation of Bike share schemes (BSS) and funding for bicycle purchase and repair are needed.

### Inclusive cycling infrastructure

The fact that deprived areas were found to have a higher density of cycling infrastructure does not necessarily mean that this infrastructure serves mostly individuals living in those areas. To increase cycling inclusion, policy should focus on the infrastructural needs and preferences of under-represented groups such as older people, women, children, but also socioeconomically disadvantaged people.

In this regard, Chapter 2 suggests that given that low-income populations were found to cycle more for non-commuting purposes, a broader focus on leisure and non-commuting utility cycling could serve more low-income populations. In other words, that interventions such as greenways and a dense, connected and permeable network created by LTN may be more beneficial to low-income populations than only major and direct arterial routes (cycle-superhighways) aimed at commuter cyclists.

### Safety measures for those most at risk

More infrastructure focused on the preferences and needs of residents of deprived areas could help reduce their higher risk of injury. In addition to this, and based on the conclusions of Chapter 4, the following measures could also help improve the safety of those most at risk.

First, since socioeconomic inequalities in cycling safety were found mainly in children, special attention should be given to urban environments that could be dangerous for children in deprived areas (e.g. unsafe crossing sites), particularly on routes to major children's destinations (e.g. schools, parks, playgrounds).

Second, previous studies show that motorists in deprived areas may drive in a more aggressive and antisocial way (Braver, 2003; Hasselberg et al., 2005). This finding, together with the higher injury risk among children from deprived areas, suggests that the implementation of LTN and other measures to reduce motorists' speeds in these areas should continue.

## 5.5 Research recommendations

This research addressed important questions about the relationships between socioeconomic disadvantage and cycling. However, it also brought to light new questions that need to be answered to better understand socioeconomic inequalities in cycling. In addition, two gaps identified in the review and not aimed by this thesis remain.

### Further research on cycling behaviour

The finding in Chapter 2 that people in low-income households in England cycle substantially more for non-commuting than for commuting purposes raises the question: why? Although this may be explained because low-income groups tend to be less economically active, research on the identification of potential barriers to cycle to work among low-income populations is needed.

More research on the relationship between education and cycling is also needed. For example, the finding from Chapters 2 and 3 that higher educated populations tend to cycle more raises the question: is this because more educated people are more aware of the benefits of cycling?

Change over time needs to be explored too. The study in Chapter 3 found that the socioeconomic inequalities per Bkm cycled may have increased between 2014 and 2019. A more detailed analysis of these trends and why the inequalities in cycling levels may have increased is required.

Finally, further research is needed to explore interaction effects: do the impacts of household income or residential deprivation depend on the state of a second social variable? In particular, the interactions between income and car ownership, having children and gender, income and education, education and ethnicity and cycling could offer interesting additional insights.

### Further research on cycling infrastructure and environment

Research is needed on what type of cycling infrastructure is best suited to the preferences and needs of socioeconomically disadvantaged populations. As Chapter 2 showed, the purposes of cycling trips differ substantially by socioeconomic level. This could influence their infrastructure preferences. For example, low-income cyclists, who were found to make more non-commuting trips, may prefer pleasant and well-connected over faster and straightforward cycling infrastructure. Also, since socioeconomically disadvantaged populations have been found at a higher risk of cycling injury, they may have stronger preferences for safer infrastructure.

Differences in the quality and maintenance of infrastructure should be also investigated. For example, is the cycling infrastructure in affluent areas of higher quality (wide and smooth) and better maintained?

More research is also necessary on how environmental variables additional to those studied in this thesis (e.g. road safety, crime, air quality, attractiveness/aesthetics) can affect socioeconomic inequalities in cycling.

#### Further research on cycling safety

Research is needed to examine the impact that urban environments and driving misbehaviour in deprived areas may have on the safety of cyclists from these areas. Further research is also needed to explain why children from deprived areas are particularly at high risk of cycling injuries; and to investigate why socioeconomic inequalities in cycling safety may have grown over the last years.

It would also be interesting to explore whether safety issues in deprived areas may be linked to inequalities in cycling levels. An overall greater risk of cycling injuries among residents from the most deprived areas could make their perception of insecurity of cycling greater than that of other groups, leading them to cycle less for safety concerns.

Another interesting link to investigate is between inequalities in cycling safety and inequalities in the quality of cycling infrastructure. This thesis found evidence that deprived areas have a higher cycling infrastructure density, but are these infrastructures of poorer quality? And how could this relate to inequalities in cycling safety?

#### Remaining gaps

The research questions of this thesis aimed to fill five research gaps identified in the review of Chapter 1. Two gaps not addressed in this thesis remain.

First, more research is necessary to identify non-spatial barriers to cycling among socioeconomically disadvantaged populations. Although there is some qualitative research on this topic (e.g. Bird, 2010; Steinbach, Green, et al., 2011; McNeil et al., 2017), it is still very limited. Filling this gap is especially important after finding evidence that deprived areas in England have a higher density of cycling infrastructure and yet their residents participate less in cycling. Second, further research is needed in each of the areas explored in this thesis in middle- and lower-income countries, particularly in countries like China or India, where transport disadvantage issues are generally greater and cycling has traditionally been one of the main modes of transport.

## 5.6 Conclusions

This thesis has shed new light on the under-researched topic of socioeconomic inequalities in cycling. It reveals that the socioeconomically disadvantaged in England, despite being the most in need of alternatives for transport and an active life, cycle less overall than the non-disadvantaged. Socioeconomically disadvantaged groups were also found to have much less ownership and access to bicycles, which may explain partly the inequalities in cycling levels. Contrary to expectations, the research also found that deprived areas have a higher density of cycling infrastructure, lower levels of traffic stress, and are more densely populated and flatter than non-deprived areas. This suggests that infrastructure alone is not enough to reduce socieconomic inequalities in cycling levels. Finally, it shows that socioeconomically disadvantaged populations are at a higher risk of being injured or killed while cycling, that the disadvantaged children are the most at risk, and that inequalities in cycling safety may have increased in recent years. These findings have policy implications, which put into practice may enable socioeconomically disadvantaged populations to cycle more and safer. The project also raises new questions for researchers and policy-makers to better understand socioeconomic inequalities in cycling.

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# Appendix A

# Barriers to cycle among socioeconomically disadvantaged groups

Since 2015/2016, the NTS includes the question 'which one of these (barriers to cycle) would you say was your main reason for not cycling more?'. It is a single-choice question, asked to all respondents, regardless of whether people currently cycled or not, and has nineteen possible responses.

To analyse whether these barriers differed by socioeconomic level, the responses to this question from the 2017 NTS were stratified by household income quintile. Figure A.1 presents the results.

'Ill health reasons' and 'Bike broken/don't own a bike' were the main barriers to cycle among lower-income groups (1st income quintile), while 'Lack of time/too busy' and 'Road safety concerns' were the main among higher-income populations (5th quintile).

There were also notable differences regarding the barriers 'easier / quicker to go by car' and 'too old'. The barrier 'easier / quicker to go by car' was considerably higher for the 3rd, 4th, and 5th household income quintiles. The barrier 'too old' was more than twice important for the 1st and 2nd household income quintiles than for the rest. This might be explained in part by the higher proportion of elder people among lower-income groups (see the tenth row in Table 2.1).

Unexpectedly, barriers related to the urban environment such as 'too much traffic / too fast traffic', 'personal security concerns', 'drivers attitudes towards cyclists', 'poor road surfaces maintained', 'no safe storage at destination', and 'poor public lighting' barely varied by household income quintile. It is also worth stressing that 'lack of cycle routes' is not among the main barriers and people from households in quintiles 4th and

5th scored it twice as high as people from households in the 1st quintile, which supports the findings in chapter 3 that deprived areas are generally provided with higher density of cycling infrastructure.

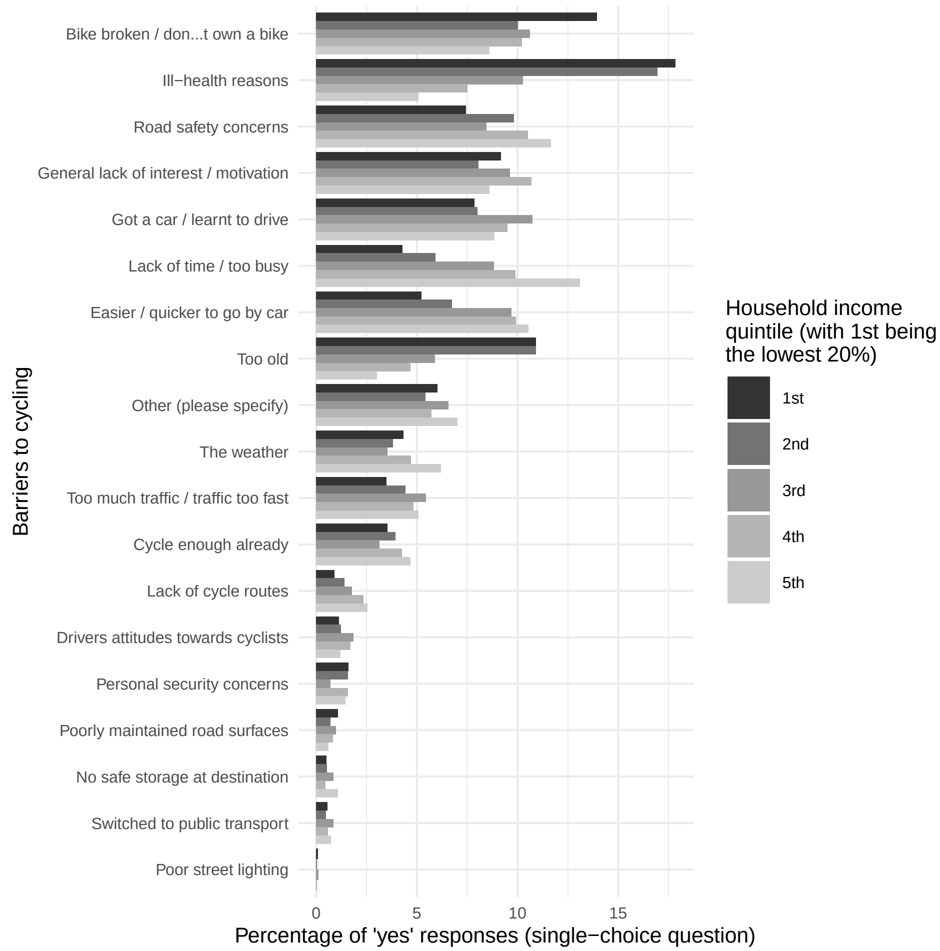


Figure A.1: Percentage of 'yes' responses to barriers identified as the main reason for not cycling more by household income quintile. Source: 2017 NTS

# Appendix B

# Curriculum vitae

I was born on 8 February 1977 in Ontinyent, Valencia (Spain). In 2002, I earned a bachelor's degree in Law; and in 2004 a master's degree in Environmental Management, both from the University of Valencia. The final dissertation of this master's degree was an action plan to improve transport sustainability in my hometown. This led to an important turning point in my career. After graduation, I started working as a transport planner trainee, and then as a transport planner in a transport consultancy specialised in active travel from Barcelona, Spain. In 2017, looking to expand my knowledge in the field of transport, I moved to Leeds and enrolled in an MSc in Transport Planning from the Institute for Transport Studies (ITS), University of Leeds. In 2018, I graduated and started my PhD on 'cycling and socioeconomic disadvantage' at Leeds Institute for Data Analytics (LIDA), University of Leeds. The PhD programme included an integrated MSc in Data Analytics and Society over the first two years (finished in 2020). I have contributed to and have led several publications in a variety of peer-reviewed journals, including Journal of Transport and Land Use, Transportation Research Part A, and Journal of Transport & Health. In addition to cycling inequalities, I am interested in active travel and particularly in how active travel can improve people's mental health.