Inequalities in usage of a public bicycle sharing scheme: Socio-demographic predictors of uptake and usage of the London (UK) cycle hire scheme

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Note: this is a personal version, created by Anna Goodman, of the text of the accepted journal article. It reflects all changes made in the peer review process, but does not incorporate any minor modifications made at the proof stage. The complete citation for the final journal article is:

- *Ogilvie, F. and A. Goodman (2012). "Inequalities in usage of a public bicycle sharing scheme: Socio-demographic predictors of uptake and usage of the London (UK) cycle hire scheme." Prev Med. 55 (1), p. 40–45*
- *DOI: 10.1016/j.ypmed.2012.05.002*

Abstract

Objective: Cycling confers individual and population-level health benefits, but uptake is not always equitable across socio-demographic groups. We sought to examine inequities in uptake and usage of London's Barclays Cycle Hire (BCH) scheme.

Method: We obtained complete BCH registration data, and compared users with the general population. We examined usage levels by explanatory variables including gender, small-area income-deprivation and local cycling prevalence.

Results: 100,801 registered individuals made 2.5 million trips between July 2010 and March 2011. Compared with residents and workers in the inner-London area served by the scheme, registered individuals were more likely to be male and to live in areas of low deprivation and high cycling prevalence. Among those registered, females made -1.63 (95%CI -1.74,-1.53) fewer trips per month than males. Adjusting for the fact that deprived areas were less likely to be close to BCH docking stations, users in the most deprived areas made 0.85 (95%CI 0.63,1.07) more trips per month than those in the least deprived areas.

Conclusion: Females and residents in deprived areas are underrepresented among users of London's public bicycle sharing scheme. The scheme's planned expansion into more deprived areas has, however, the potential to create a more equitable uptake of cycling.

Highlights:

- Public bicycle sharing schemes are a way of promoting physical activity
- We study the socio-demographic predictors of usage of a scheme in London, UK
- Women and those from deprived areas are under-represented among users
- Those from areas with high commuter-bicycling prevalence are over represented
- Expanding the scheme into more deprived areas could improve equitable uptake

Introduction

Cycling confers individual and population-level health benefits, including benefits from decreased cardiovascular risk, improved mental wellbeing, decreased air pollution and decreased exposure to road traffic collisions (Woodcock J, Edwards P et al. 2009; de Hartog JJ, Boogaard H et al. 2010; Pucher J, Buehler R et al. 2010; Lindsay G, Macmillan A et al. 2011; Rojas-Rueda D, de Nazelle A et al. 2011). Yet levels of cycling in the UK remain low (Department for Transport 2010). Promoting active travel is now high on the public health agenda (Douglas MJ, Watkins SJ et al. 2011), and public bicycle sharing schemes have become a popular intervention, with an estimated 375 schemes in 33 countries around the world (Midgley P 2011).

In the UK, London's public bicycle sharing scheme, the Barclays Cycle Hire (BCH) scheme, was introduced by the public body Transport for London in July 2010. It comprises of 3000 bicycles located at 315 docking stations throughout central London (Transport for London 2010). When registering, individuals pay £3 for a BCH 'key' and then choose between 1-day access (£1), 7-day access (£5) or annual access (£45). After paying the access fee trips of under 30 minutes are free but longer trips incur additional usage charges. Prior to 3rd December 2010, registration was compulsory, however since this date non-registered individuals have been able to buy 1-day or 7-day access as pay-as-you-go 'casual' users. A debit or credit card is required to pay for keys, access and usage charges (Transport for London 2010).

The BCH scheme is one of the Mayor of London's initiatives to increase London's modal share of cycling from 2% to 5% by 2026 (Transport for London 2010). There are, however, concerns that interventions to promote cycling may be inequitable, with levels of cycling uptake in the UK higher amongst affluent white men (Parkin J, Wardman M et al. 2008; Marmot M 2010; Steinbach R, Green J et al. 2011). While the aim of the BCH scheme was not to reduce inequalities (Transport for London 2010), it has been argued that health and equity impacts of all public investment projects should be evaluated (Ståhl T, Wismar M et al. 2006; Kahlmeier S, Racioppi F et al. 2010).

Despite public bicycle sharing schemes existing in many other European and North American cities, evidence reviews have identified few published evaluations (Pucher J, Dill J et al. 2010; Yang L, Sahlqvist S et al. 2010). A study modelling the benefits of Barcelona's scheme identified likely health and environmental benefits, but did not consider equity impacts (Rojas-Rueda D, de Nazelle A et al. 2011), while an evaluation of Montreal's scheme found that users were more likely to be young, well-educated, current cyclists (Fuller D, Gauvin L et al. 2011). An online customer satisfaction survey of 1297 BCH scheme users, found an overrepresentation of young, white, high-earning men (Transport for London 2010), however its validity was limited by a 5% response rate (personal communication, 2011).

This study uses complete registration data from the first seven months of the BCH scheme to compare personal and area-level characteristics of users with those of the general population, and to examine predictors of scheme usage.

Methods

Transport for London provided anonymised registration data for all users who registered between 30th July 2010 and 24th February 2011 (the most recent data then available). Registration data comprised of each individual's title; date of registration; initial access type (1-day, 7-day or annual); and postcode of registration debit or credit card. Registration data was linked to the total number of BCH trips made prior to 18th March 2011. Our dataset did not include data on pay-as-you-go 'casual' users who, since 3rd December, could use the BCH without registering.

We used titles to assign gender as 'male', 'female', or 'ambiguous'. As proxies for individual-level data, we used postcodes to assign deprivation, ethnicity and mode of commute data at the level of the Lower Super Output Area (LSOA, mean population 1500). We assigned small-area income deprivation using the 2010 English Indices of Deprivation (Department for Communities and Local Government 2011), and assigned the proportions of 'non-White British residents' and 'adult commuters who normally commute by bicycle' using the 2001 census (Office for National Statistics 2001). We used postcode centroids to generate distance to the nearest BCH docking station, and to calculate the number of docking stations within 250 meters. Our primary outcome was 'mean number of trips per month of registration' among individuals who registered for the scheme, with the denominator calculated to include fractions of months. As a secondary outcome we examined whether registering individuals ever, in fact, used the scheme Individuals with missing data for any variable (1.2%) were excluded from analyses.

We compared personal and area-level characteristics of registered users with area-level characteristics of two populations: residents of Greater London and residents and workers in the BCH 'Zone'. We defined this Zone as all LSOAs where part or all of the LSOA is within 500 meters of a BCH docking station, and identified the home postcodes of workers in this Zone using CommuterFlows data from the 2001 census (Office for National Statistics 2008). We characterised the comparator populations using Office for National Statistics mid-2010 population estimates (Office for National Statictics 2011), and area-level deprivation, ethnicity and mode of commute data as described above. We report comparator characteristics of the Zone population as weighted averages, weighting each Zone LSOA by its total population of residents living in that LSOA plus non-residents commuting to that LSOA.

Statistical Analysis

We used linear regression to examine correlates of 'mean number of trips' (primary outcome), and logistic regression to examine correlates of 'ever use' (secondary outcome). We hypothesised that the association between socio-demographic explanatory variables and outcome variables might be affected by the geographical positioning of the scheme in relation to users, and by users' decisions of when and how to register for the scheme. We therefore adjusted for these variables, using a hierarchical modelling approach (Victora CG, Huttly SR et al. 1997). Model one includes the socio-demographic

variables (gender; place of residence; and area-level income-deprivation, ethnicity and commuter behaviour); model two also adjusts for distance and density of BCH stations from the registered address; and model three further adjusts for month of registration and access type.

We accounted for spatial autocorrelation using maximum likelihood estimation to fit three-level linear and logistic random intercept models, of individuals nested within LSOAs nested within boroughs (further details in supplementary material). STATA 11 was used for all statistical analyses and ARC GIS 9.2 was used to create a map. Ethical approval was granted by the London School of Hygiene and Tropical Medicine's ethics committee.

Results

Between 30th July 2010 and 23rd February 2011, 100,801 individuals registered to use the BCH scheme. Data was complete for 99,615 individuals (98.8%). A total of 2,497,919 trips were made between 30th July 2010 and 17th March 2011, however one quarter (25.4%) of registered users made no trips in the recorded period. The mean total number of trips per registered user was 24.8, (standard deviation 47.9; 95%CI 24.5-25.1), with a mean of 4.15 (standard deviation 7.9; 95%CI 4.10-4.20) trips per user per month of registration. Among those whose gender was known, less than one fifth (18.4%) of the total number of trips were made by females.

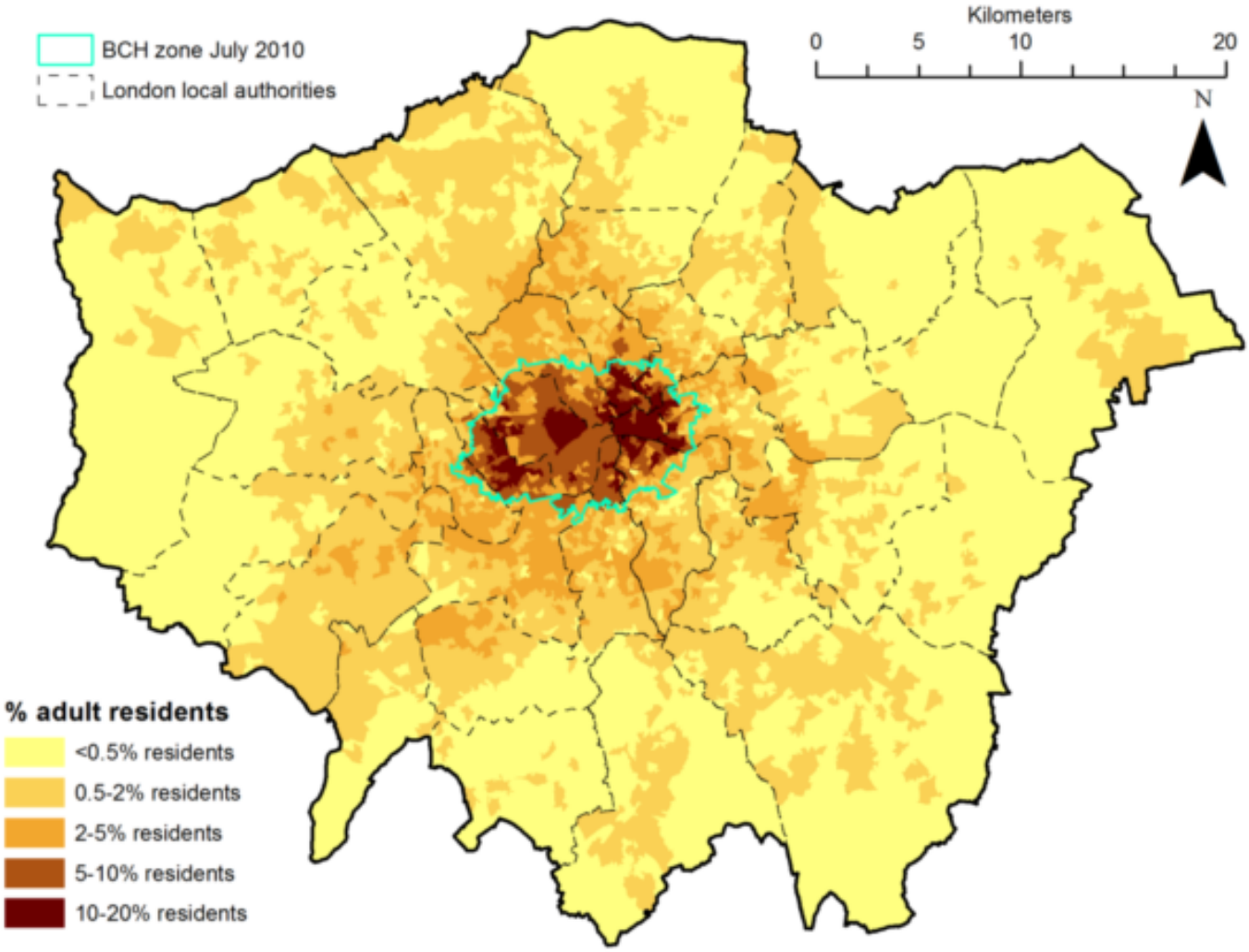
Over two-thirds (69.6%) of registered users were male, and approximately three-quarters (77.5%) had London postcodes. One-third (34.3%) lived within 500 meters of a BCH docking station, and one-quarter (27.3%) had one or more BCH docking stations within a 250-meter radius of their address. Half (50.5%) registered within the first two months of the scheme, with registrations declining over time, possible due to the transition to winter. 58.7% of users registered for 1-day access and 37.1% registered for annual access. Males were more likely than females to be non-London residents (25.7% versus 13.9%) and to choose annual access (39.5% versus 30.6%). Table 1 presents full results, while Figure 1 shows the geographical distribution of London users in relation to the BCH Zone.

Table 1: Characteristics of those who registered for London's BCH between July 2010 and February 2011, n=99,615

Variables		Total number of registered users (column %)	Column percentages by gender		Column percentages by place of residence	
			Male	Female	London	Non-London
Gender	Male	69,293 (69.6)	-	-	66.7	79.4
	Female	27,199 (27.3)	-	-	30.3	16.9
	Ambiguous	3,123 (3.1)	-	-	3.0	3.7
Place of residence	London	77,230 (77.5)	74.4	86.1	-	-
	Non-London	22,385 (22.5)	25.7	13.9	-	-
Income deprivation fifth of residential LSOA[a]	1 (least deprived)	26,248 (26.4)	27.5	23.4	20.6	46.0
	2	16,304 (16.4)	17.0	14.5	13.3	26.9
	3	19,596 (19.7)	19.5	20.0	20.5	16.8
	4	21,673 (21.8)	21.0	23.6	25.7	8.3
	5 (most deprived)	15,794 (15.9)	15.0	18.5	19.9	2.0
Percentage of residential LSOA population who are non-White British	0-24.9	28,704 (28.8)	32.5	19.3	9.7	94.9
	25-49.9	44,090 (44.3)	42.3	48.9	55.9	4.6
	50-74.9	25,760 (25.9)	24.1	30.8	33.3	0.4
	75-100	1061 (1.1)	1.1	1.0	1.4	0.1
Percentage of residential LSOA population who commute by cycling	0-2.49	38,028 (38.2)	40.4	32.9	30.9	63.3
	2.5-4.99	42,310 (42.5)	41.3	45.8	47.4	25.4
	5-7.49	14,976 (15.0)	14.3	16.8	17.8	5.4
	over 7.5	4301 (4.3)	4.1	4.6	3.9	6.0
Distance from residence to nearest cycle hire docking station	0-499m	34,173 (34.3)	31.8	41.0	44.3	0
	500-999m	5653 (5.7)	5.2	6.9	7.3	0
	1000-1999m	6529 (6.6)	6.1	7.8	8.5	0
	over 2000m	53,260 (53.5)	57.0	44.3	40.0	100
No. cycle hire docking stations within 250m of residence	0	72,467 (72.8)	74.6	67.8	64.9	100
	1	12,521 (12.6)	11.7	14.9	16.2	0
	More than 1	14,627 (14.7)	13.7	17.4	18.9	0
Month of registration[b]	Jul / Aug-10	50,347 (50.5)	51.1	49.4	51.8	46.1
	Sep-10	24,868 (25.0)	24.7	25.7	24.7	26.1
	Oct-10	12,631 (12.7)	12.4	13.4	12.5	13.2
	Nov-10	6359 (6.4)	6.3	6.5	6.0	7.9
	Dec-10	1567 (1.6)	1.6	1.4	1.5	1.8
	Jan / Feb-11	3843 (3.9)	3.9	3.7	3.5	5.0
Access type	1-day	58,508 (58.7)	56.6	64.4	58.9	58.1
	7-day	4186 (4.2)	3.9	5.0	4.2	4.3
	Annual	36,921 (37.1)	39.5	30.6	36.9	37.6

BCH=Barclays Cycle Hire, LSOA=lower super output area. Registered individuals with one or more items of missing data (n=1186) excluded from analysis. [a] Deprivation fifths defined relative to England as a whole. [b] Jul & Aug 2010 combined and Jan & Feb 2011 combined as data only recorded from 30th Jul to 23rd Feb

Figure 1: Map of London showing LSOAs of residence of BCH users with London postcodes (London, 2010-2011)



In comparison with residents and workers in the BCH Zone (Table 2), registered users were more likely to be male (69.6% versus 48.7%), less likely to live in LSOAs with income deprivation scores in the most deprived fifth (15.9% versus 22.7%) and more likely to live in LSOAs with income deprivation scores in the least deprived fifth (26.4% versus 20.4%). The ethnic diversity of registered users' areas was slightly greater than the average for residents and workers in the BCH Zone (mean percentage of populations who are 'non-White British' 36.1% versus 34.3%), and the prevalence of commuter cycling in registered users' areas was higher than the average for the home areas of BCH Zone residents and workers (mean percentage of population commuting by cycling 3.4% versus 2.6%). All comparisons were statistically significant at the $p<0.001$ level.

Table 2: Comparison of the characteristics of the general population with those of registered BCH users (London, 2010-2011)

Variables		General population		Registered BCH users		
		BCH Zone residents and workers	Greater London residents	All BCH users	Greater London residents	Non-London residents
Percentage of population by gender	Male	48.7	49.8	69.6	66.7	79.4
	Female	51.3	50.2	27.3	30.3	16.9
	Ambiguous	-	-	3.1	3.0	3.7
Percentage of population by small-area income deprivation fifth	1 (least deprived)	20.4	11.3	26.4	20.6	46
	2	15.8	12.1	16.4	13.3	26.9
	3	18.1	16.8	19.7	20.5	16.8
	4	23.2	27.3	21.8	25.7	8.3
	5 (most deprived)	22.7	32.6	15.9	19.9	2.0
Mean percentage of area population who are 'non-White British'		34.3	40.1	36.1	43.7	9.8
Mean percentage of commuters in area population who usually commute by cycling		2.6	2.3	3.4	3.6	2.9

BCH=Barclays Cycle Hire, LSOA=lower super output area. All differences between 'BCH Zone residents and workers' and 'All BCH users' were significant at $p<0.001$, using chi-squared tests for gender and area deprivation and t-tests for ethnicity and cycling prevalence.

For our primary outcome of 'mean number of trips made by BCH bicycle per month', female gender was associated with making fewer BCH trips in both unadjusted and adjusted analyses (Table 3; fully-adjusted regression coefficient for mean number of trips -1.63, 95%CI -1.74,-1.53). Living outside of London was associated with making more trips by BCH bicycle in both adjusted and unadjusted analyses (fully-adjusted regression coefficient 1.37, 95%CI 1.02,1.72).

Mean number of BCH trips per month did not vary by income deprivation in unadjusted analysis, but after adjusting for the distance and density of BCH docking stations (model 2), those in more income-deprived areas were likely to make more trips (regression coefficient 0.60, 95%CI 0.37,0.84 for the highest versus the lowest deprivation fifths). This reflected the fact that, on average, those in more deprived areas were less likely to live very close to BCH docking stations (32.3% versus 37.5% living within 500m of a docking station, for the highest versus the lowest deprivation fifths). The magnitude of the association with income deprivation increased further after adjusting for month of registration and access type (model 3). This reflected the fact that area deprivation was associated with a reduced likelihood of choosing annual access (30.9%, 37.2% and 42.0% chose annual access in the highest, middle and lowest deprivation fifths) but that there was a higher level of usage among those in deprived areas who did have annual access (8.8, 7.7 and 6.8 trips per month for the highest, middle and lowest deprivation fifths)

Those living in areas where 25 to 50% of the population were non-White British made fewer trips (fully-adjusted regression coefficient -0.55, 95%CI -0.78,-0.31 for 25-49.9% versus 0-24.9% non-White British); otherwise there was little systematic association with area ethnic composition. Commuter cycling prevalence in area of residence was not

associated with the number of trips made per month after adjusting for the fact that high-cycling areas tended to be further from the BCH Zone. By contrast, shorter distance to the nearest docking station was associated with making progressively more trips per month, as was having more docking stations within 250m of the residential address.

There was no clear trend between month of registration and number of trips made per month during the early months of the BCH scheme. Mean number of trips was however higher among individuals registering after the option of pay-as-you-go 'casual' usage was introduced as an alternative to registered usage (fully-adjusted regression coefficient 3.47, 95%CI 3.23,3.71 for January/February 2011 versus July/August 2010). This finding was unchanged in sensitivity analysis using months not individuals as the units of analysis in order to take seasonality more fully into account (further details in supplementary material). Having 7-day or annual access was also associated with likely to make more trips per month.

Many of these findings were replicated for our secondary outcome of 'ever making a BCH trip' (Table 4). Once again, females were less likely ever to make a trip, while those from outside of London, those living close to a cycle hire docking station, and those with 7-day or annual access were more likely. In contrast to our findings for mean trip usage, however, area deprivation and ethnic composition were not associated with ever making a trip. There was also some evidence that those living in areas of high commuter cycling prevalence were more likely ever to make a trip, despite the fact that this had not been associated with mean number of trips.

Table 3: Predictors of mean number of trips made by BCH bicycle per month, among registered users (London, 2010-2011)

Variables		Mean number of trips made per month	Linear regression coefficients (95% CI) for mean number of trips made by BCH bicycle per month			
			Unadjusted	Model 1	Model 2	Model 3
Gender	**Male**	4.7	0	0	0	0
	Female	2.7	**-2.06 (-2.17, -1.95)**	**-2.06 (-2.16, -1.95)**	**-2.06 (-2.17, -1.96)**	**-1.63 (-1.74, -1.53)**
	Ambiguous	4.4	-0.30 (-0.57, -0.02)	-0.28 (-0.56, -0.01)	-0.29 (-0.56, -0.01)	-0.34 (-0.60, -0.08)
Place of residence	**London**	4.1	0	0	0	0
	Non-London	4.5	**1.14 (0.74, 1.55)**	**0.90 (0.46, 1.34)**	**1.57 (1.15, 2.00)**	**1.37 (1.02, 1.72)**
Income deprivation fifth of LSOA	**1 (least deprived)**	4.2	0	0	0	0
	2	4.1	0.00 (-0.22, 0.21)	0.03 (-0.17, 0.24)	0.16 (-0.02, 0.34)	0.28 (0.11, 0.45)
	3	4.2	0.06 (-0.16, 0.28)	0.18 (-0.04, 0.40)	0.32 (0.14, 0.51)	**0.45 (0.28, 0.63)**
	4	4.1	-0.15 (-0.39, 0.08)	-0.01 (-0.25, 0.23)	0.29 (0.10, 0.49)	**0.51 (0.33, 0.69)**
	5 (most deprived)	4.2	-0.01 (-0.27, 0.26)	-0.08 (-0.36, 0.20)	**0.60 (0.37, 0.84)**	**0.85 (0.63, 1.07)**
Percentage of LSOA who are non-White British	**0-24.9**	4.2	0	0	0	0
	25-49.9	3.7	**-0.72 (-0.98, -0.46)**	-0.43 (-0.71, -0.14)	**-0.58 (-0.83, -0.33)**	**-0.55 (-0.78, -0.31)**
	50-74.9	4.8	0.02 (-0.29, 0.33)	0.38 (0.03, 0.73)	-0.39 (-0.69, -0.10)	-0.22 (-0.50, 0.05)
	75-100	4.5	0.43 (-0.27, 1.13)	0.72 (0.00, 1.44)	-0.62 (-1.24, -0.01)	-0.38 (-0.96, 0.20)
Percentage of LSOA who commute by cycling	**0-2.49**	4.0	0	0	0	0
	2.5-4.99	4.5	0.09 (-0.09, 0.27)	0.16 (-0.01, 0.34)	0.10 (-0.05, 0.25)	0.15 (0.01, 0.29)
	5-7.49	3.9	-0.28 (-0.54, -0.01)	-0.11 (-0.37, 0.16)	-0.05 (-0.27, 0.16)	-0.02 (-0.22, 0.18)
	over 7.5	3.1	**-0.97 (-1.37, -0.57)**	**-0.80 (-1.20, -0.41)**	-0.16 (-0.49, 0.17)	-0.16 (-0.48, 0.15)
Distance from residence to nearest cycle hire docking station	**0-499m**	6.1	0		0	0
	500-999m	3.4	**-2.91 (-3.19, -2.64)**		**-2.33 (-2.64, -2.02)**	**-1.88 (-2.17, -1.59)**
	1000-1999m	2.1	**-4.69 (-4.96, -4.41)**		**-4.01 (-4.33, -3.69)**	**-3.24 (-3.53, -2.94)**
	over 2000m	3.2	**-5.14 (-5.40, -4.89)**		**-4.49 (-4.79, -4.19)**	**-3.57 (-3.85, -3.29)**
No. cycle hire docking stations within 250m of residence	**0**	3.3	0		0	0
	1	6.1	**2.45 (2.24, 2.67)**		**0.79 (0.55, 1.04)**	**0.68 (0.45, 0.91)**
	More than 1	6.6	**2.87 (2.64, 3.10)**		**1.13 (0.88, 1.39)**	**1.01 (0.77, 1.25)**
Month of registration	**Jul / Aug-10**	4.0	0			0
	Sept 2010	4.0	-0.01 (-0.13, 0.10)			-0.03 (-0.14, 0.08)
	Oct 2010	4.2	0.22 (0.07, 0.37)			**0.26 (0.11, 0.40)**
	Nov 2010	3.2	**-0.71 (-0.91, -0.51)**			**-0.62 (-0.80, -0.43)**
	Dec 2010	5.4	**1.39 (1.00, 1.77)**			**1.01 (0.65, 1.37)**
	Jan / Feb-11	8.4	**4.24 (3.99, 4.49)**			**3.47 (3.23, 3.71)**
Access type	**1-day**	2.0	0			0
	7-day	5.0	**2.62 (2.39, 2.85)**			**2.59 (2.37, 2.82)**
	Annual	7.5	**5.18 (5.09, 5.28)**			**4.89 (4.79, 4.98)**

BCH=Barclays Cycle Hire, LSOA=lower super output area. Values shaded bold are different from the reference category with $p<0.001$

Table 4: Predictors of ever making any trip by BCH bicycle, among registered users (London, 2010-2011)

Variables		Percentage of users making at least one trip	Odds ratios (95% CI) for 'ever use'			
			Unadjusted	Model 1	Model 2	Model 3
Gender	**Male**	76.4	1	1	1	1
	Female	67.2	**0.59 (0.57, 0.60)**	**0.59 (0.57, 0.61)**	**0.59 (0.57, 0.61)**	**0.64 (0.62, 0.66)**
	Ambiguous	76.8	1.00 (0.92, 1.10)	1.00 (0.92, 1.09)	1.00 (0.92, 1.09)	1.01 (0.92, 1.11)
Place of residence	**London**	74.1	1	1	1	1
	Non-London	72.9	1.18 (1.07, 1.31)	1.09 (0.97, 1.22)	**1.24 (1.13, 1.36)**	**1.26 (1.16, 1.36)**
Income deprivation fifth of LSOA	**1 (least deprived)**	75.6	1	1	1	1
	2	73.6	0.97 (0.92, 1.03)	0.98 (0.92, 1.04)	0.99 (0.94, 1.04)	1.01 (0.96, 1.07)
	3	74.2	0.93 (0.88, 0.99)	0.95 (0.89, 1.01)	0.97 (0.92, 1.02)	1.00 (0.95, 1.05)
	4	73.4	**0.89 (0.84, 0.95)**	0.91 (0.85, 0.97)	0.94 (0.89, 0.99)	0.99 (0.93, 1.05)
	5 (most deprived)	71.3	**0.80 (0.75, 0.86)**	**0.80 (0.74, 0.86)**	**0.89 (0.83, 0.95)**	0.94 (0.88, 1.01)
Percentage of LSOA who are non-White British	**0-24.9**	71.9	1	1	1	1
	25-49.9	73.8	0.91 (0.85, 0.98)	1.00 (0.92, 1.08)	0.96 (0.90, 1.03)	0.97 (0.91, 1.04)
	50-74.9	76.4	0.94 (0.87, 1.02)	1.10 (1.00, 1.20)	0.94 (0.86, 1.01)	0.99 (0.91, 1.07)
	75-100	70.6	0.92 (0.77, 1.10)	1.07 (0.89, 1.30)	0.84 (0.71, 1.00)	0.88 (0.74, 1.04)
Percentage of LSOA who commute by cycling	**0-2.49**	72.7	1	1	1	1
	2.5-4.99	75.1	0.97 (0.93, 1.02)	1.00 (0.95, 1.05)	0.99 (0.95, 1.03)	1.01 (0.97, 1.06)
	5-7.49	74.0	0.98 (0.92, 1.05)	1.03 (0.96, 1.11)	1.04 (0.98, 1.11)	1.07 (1.01, 1.14)
	over 7.5	71.7	0.90 (0.81, 1.00)	0.94 (0.85, 1.04)	1.10 (1.00, 1.20)	1.13 (1.03, 1.23)
Distance from residence to nearest cycle hire docking station	**0-499m**	82.3	1		1	1
	500-999m	74.9	**0.65 (0.60, 0.70)**		**0.72 (0.66, 0.79)**	**0.77 (0.70, 0.85)**
	1000-1999m	68.3	**0.46 (0.43, 0.49)**		**0.50 (0.46, 0.55)**	**0.56 (0.51, 0.62)**
	over 2000m	69.0	**0.40 (0.37, 0.43)**		**0.42 (0.38, 0.45)**	**0.48 (0.44, 0.52)**
No. cycle hire docking stations within 250m of residence	**0**	70.5	1		1	1
	1	82.0	**1.61 (1.51, 1.72)**		1.10 (1.02, 1.19)	1.07 (0.98, 1.16)
	More than 1	83.5	**1.78 (1.66, 1.90)**		**1.20 (1.11, 1.31)**	1.16 (1.07, 1.26)
Month of registration	**Jul / Aug-10**	76.7	1			1
	Sept 2010	75.2	**0.92 (0.88, 0.95)**			**0.91 (0.87, 0.94)**
	Oct 2010	70.7	**0.72 (0.69, 0.76)**			**0.71 (0.68, 0.75)**
	Nov 2010	56.7	**0.39 (0.37, 0.41)**			**0.37 (0.35, 0.39)**
	Dec 2010	64.7	**0.55 (0.49, 0.61)**			**0.46 (0.41, 0.52)**
	Jan / Feb-11	70.4	**0.70 (0.65, 0.75)**			**0.54 (0.50, 0.58)**
Access type	**1-day**	64.5	1			1
	7-day	70.7	**1.27 (1.18, 1.36)**			**1.23 (1.15, 1.32)**
	Annual	89.1	**4.31 (4.15, 4.48)**			**4.22 (4.07, 4.39)**

BCH=Barclays Cycle Hire, LSOA=lower super output area. Values shaded bold are different from the reference category with p<0.001

Discussion

Main findings

This study examined the personal and area-level characteristics of the 100,801 individuals who registered to use the BCH scheme in the first seven months of its operation. We found that females made up under a third of those registered with the BCH, were less likely than males ever to use the scheme after registering, and made fewer trips on average. The proportion of BCH scheme trips made by females (18.4%) is lower than the proportion of all cycling trips made by females (32.6%) reported in recent London Travel Demand Surveys (Transport for London 2009). A number of studies have explored the reasons for low uptake of cycling amongst women, citing reasons including perceived cultural inappropriateness, fear of road danger and trip complexity (Root A and Schintler L 1999; Dickenson JE, Kingham S et al. 2003; Garrard J, Rose G et al. 2008; Steinbach R, Green J et al. 2011). However as BCH cycling currently appears to be *less* gender-equitable than non-BCH cycling in London, further exploration is warranted into the barriers to registering for and using the scheme. The notable contrast between our findings and the apparently above-average gender equity of the equivalent Montreal cycle hire scheme (Fuller D, Gauvin L et al. 2011) also highlights the importance of context specific evaluations of interventions to promote cycling.

After adjusting for the fact that those living in income-deprived areas were less likely to live close to a BCH docking station, registered users from deprived areas made more trips on average than those from less-deprived areas. This suggests there may be a greater latent demand for cycling in deprived areas, perhaps due to low levels of bicycle ownership resulting from lack of affordability or storage facilities. It is therefore possible that a disproportionate increase in uptake would be seen among deprived populations if BCH docking stations were situated in more deprived areas, as is planned with the expansion of the BCH scheme in spring 2012. Exploration of other potential barriers to usage among deprived populations, including the cost of annual access and the need to pay using a debit or credit card is also warranted.

Limitations

The use of routinely collected registration data limited what could be studied. It was necessary to use area-level data as a proxy for individual socio-economic deprivation and ethnicity, and it is not known if the observed associations would hold true at the individual level. This is a particular limitation with respect to ethnicity data, which in addition was (like our commuter data) collected almost a decade before the period of this study. In addition, as access keys can be passed between individuals, it is likely that a small number of trips were made by individuals with different demographic profiles to those who registered. A further limitation is the lack of a clearly defined denominator population, as any individual with a UK debit or credit card could register to use the scheme. Having data for only a seven month period meant it was not possible to study temporal trends, particularly as usage levels are likely to be highly affected by the seasons.

Conclusion

The health benefits of cycling are well known, and public bicycle sharing schemes are becoming a popular way of promoting cycling in urban environments. Our study has shown that London's public bicycle sharing scheme is being well used, however usage is not equitably distributed throughout the population. Women and those living in deprived areas are less likely to register to use the scheme. However after adjusting for the fact that those in deprived areas were less like to live close to a BCH docking station, usage amongst individuals living in these areas was actually higher. This suggests the scheme may be meeting a currently unmet need for access to bicycling in deprived communities. Policy makers should consider the health benefits that could be gained from expanding the scheme into deprived areas, and from exploring measures to increase uptake among women and those on low incomes.

Conflict of interest

None

Acknowledgements

Many thanks to Clare Sheffield and colleagues at Transport for London for providing us with the data used for this study. FO conducted this independent research during an MSc funded by the UK National Health Service (NHS)'s postgraduate public health training programme. AG supervised the research during a post-doctoral research fellowship supported by the UK National Institute for Health Research (NIHR). The views expressed in this publication are those of the authors and not necessarily those of the NHS, the NIHR or the UK Department of Health. Census output is Crown copyright and is reproduced with the permission of the Controller of HMSO and the Queen's Printer for Scotland.

References

de Hartog JJ, Boogaard H, et al. (2010). "Do the health benefits of cycling outweigh the risks?" Environmental Health Perspectives **118**(8): 1109-1116.

Department for Communities and Local Government (2011). Indices of deprivation 2010: Income domain. English indices of deprivation 2010. London.

Department for Transport (2010). National Travel Survey 2009. National Travel Survey. London, Department for Transport.

Dickenson JE, Kingham S, et al. (2003). "Employer travel plans, cycling and gender: will travel plan measures improve the outlook for cycling to work in the UK?" Transportation Research Part D **8**: 53-67.

Douglas MJ, Watkins SJ, et al. (2011). "Are cars the new tobacco? ." Journal of Public Health **33**(2): 160-169.

Fuller D, Gauvin L, et al. (2011). "Use of a new public bicycle share program in Montreal, Canada." American Journal of Preventive Medicine **41**(1): 80-83.

Garrard J, Rose G, et al. (2008). "Promoting transportation cycling for women: The role of bicycle infrastructure." Preventive Medicine **46**: 55-59.

Kahlmeier S, Racioppi F, et al. (2010). ""Health in all policies" in practice: Guidance and tools to quantifying the health effects of cycling and walking." Journal of Physical Activity and Health **7**(S1): S120-S125.

Lindsay G, Macmillan A, et al. (2011). "Moving urban trips from cars to bicycles: impact on health and emissions." Australian and New Zealand Journal of Public Health **35**(1): 54–60.

Marmot M (2010). Fair society, healthy lives. A strategic review of health inequalities in England post-2010. London.

Midgley P (2011). Bicycle-sharing schemes: enhancing sustainable mobility in urban areas. Background Papers. New York, United Nations Department of Economic and Social Affairs, Commission on Sustainable Development.

Office for National Statictics (2011). Population Estimates for UK, England and Wales, Scotland and Northern Ireland, Mid-2010 Population Estimates, Office for National Statistics.

Office for National Statistics (2001). Office for National Statistics, 2001 Census: Standard area statistics (England and Wales), ESRC/JISC Census Programme, Census Dissemination Unit, Mimas (University of Manchester).

Office for National Statistics (2008). CommuterFlows - Destination communting statistics from the 2001 Census, Office for National Statistics.

Parkin J, Wardman M, et al. (2008). "Estimation of the determinants of bicycle modal share for the journey to work." Transportation **35**(1): 93-109.

Pucher J, Buehler R, et al. (2010). "Walking and cycling to health: A comparative analysis of city, state, and international data." American Journal of Public Health **100**(10): 1986-1992.

Pucher J, Dill J, et al. (2010). "Infrastructure, programs and policies to increase bicycling: An international review." Preventive Medicine **50**: S106-S125.

Rojas-Rueda D, de Nazelle A, et al. (2011). "The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study " British Medical Journal **343**: d4521.

Root A and Schintler L (1999). "Women, motorization and the environment." Transportation Research Part D **4**: 353-355.

Ståhl T, Wismar M, et al. (2006). Health in all policies: Prospects and potentials, Ministry of Social Affairs and Health, Finland and European Observatory on Health Systems and Policies.

Steinbach R, Green J, et al. (2011). "Cycling and the city: A case study of how gendered, ethnic and class identities can shape healthy transport choices." Social Science and Medicine **72**(7): 1123-1130.

Transport for London (2009). London Travel Demand Survey 07/08 to 09/10, Transport for London.

Transport for London (2010). "Barclays Cycle Hire costs." Retrieved 04.08.2011, from http://www.tfl.gov.uk/roadusers/cycling/14811.aspx.

Transport for London (2010). "Mayor's flagship cycling scheme - Barclays Cycle Hire - opens for business." Press Releases. Retrieved 04.08.2011, from http://www.tfl.gov.uk/corporate/media/newscentre/archive/16418.aspx.

Transport for London (2010). Mayor's transport strategy. London, Transport for London.

Transport for London (2010). Travel in London, Report 3. London, Transport for London.

Victora CG, Huttly SR, et al. (1997). "The role of conceptual frameworks in epidemiological analysis: A hierarchical approach." International Journal of Epidemiology **26**(1): 224-227.

Woodcock J, Edwards P, et al. (2009). "Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport " The Lancet **374**(9705): 1930-1943.

Yang L, Sahlqvist S, et al. (2010). "Interventions to promote cycling: systematic review " British Medical Journal **341**: c5293.

Supplementary material

Further details of multi-level random effects models

In the main manuscript, we examine the predictors of mean number of BCH trips by fitting three-level linear random intercept models, of individuals nested within LSOAs nested within boroughs:

$$Y_{ijk} = \beta_0 + \beta_1 x_{1ijk} + ... + \beta_p x_{pijk} + B_k + S_{jk} + e_{ijk}$$

Where Y_{ijk} is the modelled mean number of trips for the *i*th individual in the *j*th LSOA in the *k*th borough; $\beta_1 ... \beta_p$ are the parameters for the fixed effects of interest ($x_{1ijk} ... x_{pijk}$), for example gender; B_k is a random intercept for mean number of BCH trips in the *k*th borough; S_{jk} is a random intercept for mean number of BCH trips in the *j*th SOA in the *k*th borough; and e_{ijk} is the residual error term. Random intercepts were assumed to be normally distributed, allowing for different variance parameters for each random intercept and the residual error and were estimated using maximum likelihood estimation. Equivalent logistic regression models were fitted for our binary outcome.

Sensitivity analysis using months not individuals as the units of analysis

As a sensitivity analysis, we repeated our analyses using months not individuals as the units of analysis. We did this in order to check that our results were not affected by seasonal differences in levels of bicycle usage. For example, in Table 3 of the main text we show that mean levels of cycle hire usage were higher among those registering December 2011-February 2012 than among those registering in July-November 2011. Our interpretation of this is that people joining after December 2011 were those who expected to use BCH a lot (because those who expected to use it less often instead took advantage of the new option of 'casual use'). An alternative interpretation, however, could be that everyone uses BCH bikes more in December-February months and these late joiners simply used the cycle hire bikes at this same, higher level during those months. Our analyses cannot, as they stand, distinguish these hypotheses because our outcome is mean number of trips per individual across the whole of their registration period. Similarly, if men signed up to the scheme earlier than women and if both sexes used the scheme less often in the winter months, then this might create a spurious difference between men and women.

To conduct this sensitivity analyses, we examined the predictors of number of BCH trips using months as our level of analysis. We did this did this through fitting four-level linear random intercept models, of months nested within individuals nested within LSOAs nested within boroughs:

$$Y_{hijk} = \beta_0 + \beta_1 x_{1hijk} + ... + \beta_p x_{phijk} + B_k + S_{jk} + I_{hjk} + e_{hijk}$$

Where Y_{hijk} is the modelled number of trips in the *h*th month for the *i*th individual in the *j*th LSOA in the *k*th borough; $\beta_1 ... \beta_p$ are the parameters for the fixed effects of interest ($x_{1hijk} ... x_{phijk}$), for example gender; B_k is a random intercept for mean number of BCH trips in the *k*th borough; S_{jk} is a random intercept for mean number of BCH trips in the *j*th SOA in the *k*th borough; I_{hjk} is a random intercept for mean number of BCH trips per

month in the *i*th individual in the *j*th SOA in the *k*th borough; and e_{hijk} is the residual error term. Y_{hijk} was thus not an average across months, but rather derived from the observed total number of trips made in each month. We scaled this observed total to take into account the fact that some participants only were registered for part of each month. For example, a participant who joined the scheme half way through a month (e.g. on 16th September) and then made 10 trips would have their adjusted number of trips scaled to 20.

As shown in Supplementary Table 1, the results were generally very similar to those in our main analysis, and the substantive findings were unchanged. This included our conclusion that individuals registering after December 2011 used BCH bikes more often per month than those registering earlier. The only difference in our findings was that we no longer found evidence of a drop in usage among those registering in November 2011, but instead their seasonally-adjusted rates of use seemed very similar to those registering in earlier months. There was also a somewhat larger positive effect size among those registering in October 2011 which, speculatively, may relate to students joining the scheme at the start of the new academic year.

Supplementary Table 1: Predictors of number of trips made each month by BCH bicycle among registered users (London, 2010-2011)

Variables		Linear regression coefficients (95% CI) for number of trips made each month by BCH bicycle			
		Minimally-adjusted	Multivariable model 1	Multivariable model 2	Multivariable model 3
Gender	**Male**	0	0	0	0
	Female	**-1.86 (-1.96, -1.76)**	**-1.85 (-1.95, -1.76)**	**-1.86 (-1.96, -1.76)**	**-1.49 (-1.58, -1.40)**
	Ambiguous	-0.26 (-0.50, -0.01)	-0.24 (-0.48, 0.00)	-0.24 (-0.49, 0.00)	-0.30 (-0.53, -0.07)
Place of residence	**London**	0	0	0	0
	Non-London	**1.01 (0.66, 1.37)**	**0.81 (0.42, 1.20)**	**1.41 (1.04, 1.78)**	**1.21 (0.90, 1.52)**
Income deprivation fifth of LSOA	**1 (least deprived)**	0	0	0	0
	2	-0.02 (-0.21, 0.17)	0.01 (-0.17, 0.20)	0.13 (-0.03, 0.28)	0.23 (0.09, 0.38)
	3	0.02 (-0.17, 0.22)	0.13 (-0.06, 0.33)	0.27 (0.11, 0.43)	**0.39 (0.24, 0.55)**
	4	-0.15 (-0.36, 0.06)	-0.02 (-0.23, 0.19)	0.25 (0.08, 0.43)	**0.45 (0.28, 0.61)**
	5 (most deprived)	-0.03 (-0.27, 0.21)	-0.11 (-0.36, 0.14)	**0.51 (0.30, 0.71)**	**0.74 (0.55, 0.93)**
Percentage of LSOA who are non-White British	**0-24.9**	0	0	0	0
	25-49.9	**-0.63 (-0.87, -0.40)**	-0.36 (-0.61, -0.11)	**-0.50 (-0.72, -0.28)**	**-0.48 (-0.68, -0.27)**
	50-74.9	0.06 (-0.22, 0.33)	0.39 (0.09, 0.70)	-0.31 (-0.57, -0.05)	-0.18 (-0.42, 0.07)
	75-100	0.41 (-0.21, 1.03)	0.69 (0.05, 1.32)	-0.52 (-1.06, 0.03)	-0.32 (-0.83, 0.20)
Percentage of LSOA who commute by cycling	**0-2.49**	0	0	0	0
	2.5-4.99	0.06 (-0.09, 0.22)	0.14 (-0.02, 0.30)	0.08 (-0.05, 0.21)	0.12 (0.00, 0.24)
	5-7.49	-0.25 (-0.48, -0.02)	-0.09 (-0.32, 0.14)	-0.05 (-0.24, 0.14)	-0.02 (-0.20, 0.16)
	over 7.5	**-0.86 (-1.21, -0.50)**	**-0.70 (-1.05, -0.36)**	-0.13 (-0.42, 0.17)	-0.13 (-0.41, 0.14)
Distance from residence to nearest cycle hire docking station (meters)	**0-499**	0		0	0
	500-999	**-2.61 (-2.85, -2.37)**		**-2.08 (-2.35, -1.81)**	**-1.68 (-1.94, -1.42)**
	1000-1999	**-4.24 (-4.48, -4.00)**		**-3.62 (-3.90, -3.34)**	**-2.93 (-3.20, -2.67)**
	over 2000	**-4.64 (-4.86, -4.42)**		**-4.05 (-4.31, -3.78)**	**-3.24 (-3.48, -2.99)**
No. cycle hire docking stations within 250m of residence	**0**	0		0	0
	1	**2.20 (2.01, 2.40)**		**0.71 (0.50, 0.93)**	**0.62 (0.42, 0.83)**
	More than 1	**2.58 (2.37, 2.78)**		**1.02 (0.79, 1.24)**	**0.92 (0.71, 1.14)**
Month of registration	**Jul / Aug-10**	0			0
	Sept 2010	0.01 (-0.09, 0.11)			0.00 (-0.10, 0.09)
	Oct 2010	**0.66 (0.53, 0.79)**			**0.70 (0.57, 0.82)**
	Nov 2010	-0.07 (-0.25, 0.11)			0.01 (-0.16, 0.18)
	Dec 2010	**1.76 (1.40, 2.11)**			**1.42 (1.09, 1.76)**
	Jan / Feb-11	**3.44 (3.20, 3.68)**			**2.76 (2.54, 2.99)**
Access type	**1-day**	0			0
	7-day	**2.40 (2.19, 2.60)**			**2.38 (2.18, 2.58)**
	Annual	**4.57 (4.49, 4.66)**			**4.33 (4.24, 4.41)**

BCH=Barclays Cycle Hire, LSOA=lower super output area. Minimally-adjusted analyses adjust for only for month; multivariable analyses adjust for month plus all variables in the column. Values shaded bold are different from the reference category with $p<0.001$