Preventive Medicine Reports 4 (2016) 540–545

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: http://ees.elsevier.com/pmedr

Cycling in São Paulo, Brazil (1997–2012): Correlates, time trends and health consequences

Thiago Hérick Sá [a,*], Ana Clara Duran [b], Marko Tainio [c], Carlos Augusto Monteiro [a], James Woodcock [c]

[a] Núcleo de Pesquisas Epidemiológicas em Nutrição e Saúde, Faculdade de Saúde Pública, Universidade de São Paulo (FSP-USP), São Paulo, Brazil
[b] University of Illinois at Chicago, Chicago, USA
[c] UKCRC Centre for Diet and Activity Research (CEDAR), MRC Epidemiology Unit, University of Cambridge School of Clinical Medicine, Institute of Metabolic Science, Cambridge

ARTICLE INFO

Article history:
Received 27 June 2016
Received in revised form 26 September 2016
Accepted 3 October 2016
Available online 13 October 2016

Keywords:
Transportation
Motor activity
Cycling
Health promotion
Brazil
Urban health
Healthy city
Risk assessment

ABSTRACT

The purpose of the study was to describe cyclists and cycling trips, and to explore correlates, time trends and health consequences of cycling in São Paulo, Brazil from 1997 to 2012. Cross-sectional analysis using repeated São Paulo Household Travel Surveys (HTS). At all time periods cycling was a minority travel mode in São Paulo (1174 people with cycling trips out of 214,719 people). Poisson regressions for individual correlates were estimated using the entire 2012 HTS sample. Men were six times more likely to cycle than women. We found rates of bicycle use rising over time among the richest quartile but total cycling rates dropped from 1997 to 2012 due to decreasing rates among the poor. Harms from air pollution would negate benefits from physical activity through cycling only at 1997 air pollution levels and at very high cycling levels (≥9 h of cycling per day). Exposure-based road injury risk decreased between 2007 and 2012, from 0.76 to 0.56 cyclist deaths per 1000 person-hours travelled. Policies to reduce spatial segregation, measures to tackle air pollution, improvements in dedicated cycling infrastructure, and integrating the bicycle with the public transport system in neighborhoods of all income levels could make cycling safer and prevent more individuals from abandoning the cycling mode in São Paulo.

© 2016 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

The transport sector contributes to population level physical activity by facilitating active modes of travel, such as cycling (de Nazelle et al., 2011; Pratt et al., 2012; Shephard, 2008). Replacing motorized trips with cycling is a promising strategy to help tackle the global burden of non-communicable diseases (NCDs) due to the many positive effects of physical activity on health (Hamer and Chida, 2008; Saunders et al., 2013) as well as public health and environmental co-benefits (Hartog et al., 2011; World Health Organization, 2011). Enabling and facilitating cycling are key improvements in transport systems (Rojas-Rueda et al., 2012; Woodcock et al., 2009) towards healthier and more equitable cities (Rydin et al., 2012; World Health Organization, 2011).

Sao Paulo municipal government has implemented few initiatives to facilitate cycling, amidst a growing trend of similar policies across Latin America (Becerra et al., 2013). Public bike hiring schemes, exclusive network route for cycling on Sundays and holidays, and 'cyclable paths' are part of a plan to be fully implemented by the end of 2016 (Prefeitura de São Paulo, 2014). On the other hand, Sao Paulo remains highly segregated. Poorer segments of the population live in the peripheral neighborhoods and have to commute farther to work (Pereira and Schwanen, 2013; Prefeitura de São Paulo, 2013).

Little is known about cycling correlates and trends in the Sao Paulo Metropolitan Area (hereafter, just Sao Paulo), as well as the health consequences of cycling in the city. Most of the available data on active transportation combine walkers and cyclists, even though these two groups tend to have different socioeconomic characteristics (Reis et al., 2013). Using data collected by large household representative samples of Sao Paulo residents, we aimed to analyse the correlates, time trends and health consequences of cycling in the region.

2. Methods

2.1. Data source

We used data from the Sao Paulo Household Travel Survey (HTS), an ongoing household travel survey conducted every ten years, comprising the 39 municipalities in Sao Paulo metropolitan area – largest metropolitan area in the country (8500 km^2, approximately 21 million people) (Instituto Brasileiro de Geografia e Estatística, 2011). Given the rapid changes occurring in the region, a smaller HTS was also conducted in

* Corresponding author at: Av. Dr Arnaldo 715, – São Paulo 01246-907, Brazil.
E-mail addresses: thiagodesa@usp.br (T.H. Sá), anaduran@uic.edu (A.C. Duran), mkt@medschl.cam.ac.uk (M. Tainio), carlosam@usp.br (C.A. Monteiro), jw745@cam.ac.uk (J. Woodcock).

http://dx.doi.org/10.1016/j.pmedr.2016.10.001
2211-3355/© 2016 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

2012 (8115 households; 24,534 people; 46,861 trips), using the same strategy as for the HTS from 1997 (26,278 households; 98,780 people; 163,541 trips) and 2007 (29,957 households; 91,405 people; 169,665 trips). More details concerning HTS methods can be obtained elsewhere (Sá et al., 2015). Briefly, to select the households, Sao Paulo territory was divided into contiguous traffic analysis zones, from which primary study units (households) were randomly selected according to three levels of electricity consumption — a proxy for the number of individuals in the household and income. For all surveys, a sampling strategy was based on the roll of consumers served by the city electric companies, covering 98.4% of the population (Instituto Brasileiro de Geografia e Estatística, 2011).

Cyclist was any person for whom cycling was the chosen mode of transport for at least part of a trip (460 cyclists in 1997; 595 cyclists in 2007; 119 cyclists in 2012). A one-day diary was applied to every family member. Family information included the number of family members, home ownership, income, and number of assets. Individual-level data included age, gender, education, employment status, and income. Trip-level data consisted of one-way trips undertaken on the day before the interview, and included origin and destination, mode of transport, number of mode transfers, trip purpose, and times of departure and of arrival. The 2007 and 2012 HTS provided geocoded location for work and study places, trip origin, destination as well as straight-line distances for each trip.

2.2. Descriptive analysis

Crude rates of cyclists (per 1000 residents) were estimated by individual characteristics for 2012 (Table 1). We used multivariable Poisson regressions to identify individual correlates of cycling among travellers in 2012 (Table 1). Additionally, we estimated the person/day cumulative numbers of total and bicycle trips, total travel time and cycling time, and total travel distance and cycling distance for 2012 (Table 2). Rates of cyclists (per 1000 residents) for 1997, 2007, and 2012 were estimated by family income in quartiles (Fig. 1). We considered statistically different rates when point estimates were not contained in the confidence interval of the rate of comparison (Krzywinski and Altman, 2013). Data were weighted and sampling procedures accounted for to adjust for the selection probabilities at the individual level and to make the sample representative of the studied area. Analyses were conducted using Stata 12.1 using the command svy.

2.3. Health consequences — air pollution and traffic injury

To illustrate the potential health consequences of cycling in Sao Paulo we made scoping assessment of the magnitude and direction of health effects in the study area. For air pollution, we used the health impact modelling approach proposed by Tainio et al. (2016), in which benefits of physical activity were combined with the health risks of air pollution exposure. All-cause mortality reduction related to active travel was estimated through the conversion of time spent cycling to metabolically equivalent of task and the use of the dose-response function from Kelly et al. (2014), with a power transformation of 0.5. All-cause mortality increase related to air pollution was estimated through the estimation of the cycling exposure concentrations – considering ventilation rates and background fine particulate matter (PM2.5) levels – and a dose-response function assuming a relative risk value of 1.07 per 10 $\mu g/m^3$ change in exposure (World Health Organization, 2014).

PM2.5 levels for years 2007 and 2012 were obtained from official reports (Companhia de Tecnologia de Saneamento Ambiental, 2008, 2013), with an average concentration of 20.75 and 17.5 $\mu g/m^3$, respectively. Since no PM2.5 data was available for 1997, we assumed that to be equivalent to 60% of PM10 concentrations from that year (Companhia de Tecnologia de Saneamento Ambiental, 1998), resulting

Table 1
Crude rates of bicyclists in the São Paulo population and adjusted prevalence ratios according to individual characteristics. São Paulo, 2012.

Variable	Bicyclists (per 1000 residents)	95% CI		Adj PR[e]	95% CI		P[e]
Sex							
Women	1.4	0.5	2.3	Ref	Ref	Ref	
Men	9.7	6.7	12.6	6.5	3.6	11.8	>0.001
Age (years)							
0–18	3.5	2.1	5.0	Ref	Ref	Ref	0.005¢
19–39	9.1	6.2	11.9	6.8	3.5	13.3	>0.001
40–59	4.8	1.8	7.8	4.0	1.7	9.5	0.003
≥60	1.1	0.0	2.2	2.8	1.0	8.1	0.049
Education							
Less than high school	4.9	2.4	7.4	Ref	Ref	Ref	0.402¢
High school or some college	6.1	4.2	8.0	0.8	0.4	1.4	0.376
College	4.0	0.9	7.0	0.7	0.3	1.9	0.489
Quartiles of family income[$]							
Lowest Q1 (<R$ 1572)	6.0	4.0	8.0	Ref	Ref	Ref	0.394¢
Q2 (R$1572–R$2404)	6.4	3.6	9.3	1.0	0.7	1.4	0.997
Q3 (R$2404–R$3800)	4.0	1.7	6.2	0.8	0.5	1.2	0.230
Highest Q4 (>R$3800)	4.3	2.0	6.5	0.9	0.4	1.7	0.665
Distance to work or school ≤5 km							
No	3.9	1.7	6.1	Ref	Ref	Ref	
Yes	10.6	7.5	13.8	3.3	2.0	5.5	>0.001
Car ownership*							
No	8.3	5.9	10.7	–	–	–	–
Yes	3.2	1.9	4.5	–	–	–	–
Motorcycle ownership*							
No	5.3	3.7	6.9	–	–	–	–
Yes	6.3	3.1	9.5	–	–	–	–
Car or motorcycle ownership*							
No	8.4	5.9	10.9	Ref	Ref	Ref	
Yes	3.4	2.1	4.6	0.3	0.2	0.4	>0.001
Bicycle ownership*							
No	0.7	0.2	1.3	Ref	Ref	Ref	
Yes	15.3	10.8	19.7	21.1	9.2	48.6	>0.001

n = 24,534; *n = 24,295. $ = As of January 2012, US$ 1.00 = R$ 1.83; e = Statistical significance if $p < 0.05$. ¢ = p for Wald test.
Abbreviations: 95% CI: 95% confidence interval. Adj PR: Prevalence ratio from the fully adjusted model, including sex, age, education, income, distance to work/school ≤ 5 km, car or motorcycle ownership, and bicycle ownership.

Table 2
Characteristics of travel patterns among bicyclists. São Paulo, 2012 (n = 119).

Variables (per bicyclists/day)	Mean	95% CI		Median	IIQ (p25–p75)	
Total trips (n)	2.7	2.5	2.9	2.0	2.0	3.0
Bicycling trips (n)	2.2	2.0	2.3	2.0	2.0	2.0
Total travel time (min)	75.0	65.8	84.2	60.0	30.0	110.0
Bicycling time (min)	52.3	41.4	63.2	41.0	26.0	76.0
Total travel distance (km)	10.0	6.8	13.2	4.8	2.8	11.5
Bicycling distance (km)	7.9	4.7	11.1	4.0	2.0	8.9

Abbreviations: 95% CI: 95% confidence interval; IIQ (p25–p75): interquartile range.

in an average PM2.5 concentration of 37.47 μg/m^3. A study performed in 1997 about source apportionment for PM2.5, using data from one single collect station (Cerqueira Cesar), reported a slightly higher PM2.5 concentration (40 μg/m^3) (Companhia de Tecnologia de Saneamento Ambiental, 2002).

We also calculated two different rates for road traffic injury risk of cycling using exposure measures based on (1) the number of cyclists, and (2) the annual person-hours travelled by bicycle, both for 2007 and 2012, which were compared with population-based estimates for road traffic injury risk of cycling obtained through SAT-CET official report, available yearly from 2007 to 2012 (Companhia de Engenharia de Tráfego, 2014).

For the numerator, information about people injured in São Paulo was obtained by the SAT-CET in the Police records and the Institute of Forensic Medicine. Data for 1997 were not available. The SAT-CET is the official dataset of road traffic injuries in São Paulo. A 'fatal' injury is defined in the database as a death resulting from the collision (each year, around 93% of deaths occur up to 30 days after the collision). A 'non-fatal' injury is defined as any injury for which the victim needed medical assistance or was removed to a health service and had the injury reported in the police records. Given the definition used by the SAT-CET, we assumed all 'non-fatal' injuries to be serious injuries.

For the denominator, number of cyclists and total annual number of hours that people spent travelling by bicycle (person-hour) were estimated using straight line trip distances available in the 2007 and 2012 HTS.

The University of Sao Paulo School of Public Health Ethics in Research Committee approved the study.

3. Results

3.1. Population characteristics

In 2012, Sao Paulo's population mean age was 35.1 years (95% Confidence Interval (95%CI) 34.0; 36.2), women comprised 52.2% (95%CI 51.3; 53.1) of the study population, 11.9% (95%CI 8.9; 14.7) had college degree, and a mean household income of R$ 3235.7 (95%CI 2908.8; 3562.7), equivalent to approximately US$ 1.770,0 in 2012. Three quarters of Sao Paulo's residents (67.8%; 95%CI 65.0; 70.5) did not own a bicycle and 90.0% (95%CI 88.9; 90.9) did not own a motorcycle. However cars were found in 56.5% (95%CI 53.8; 59.2) of the households.

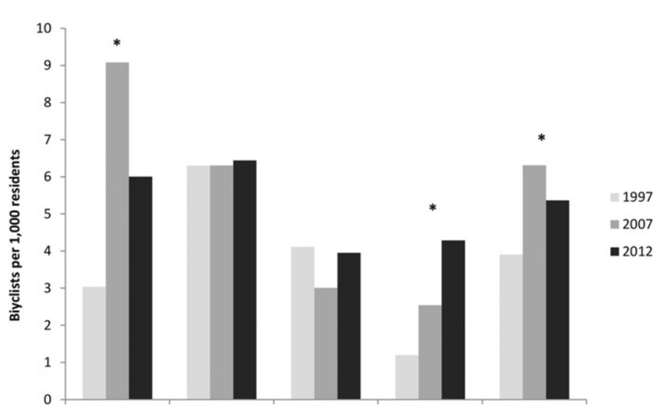

Fig. 1. Crude rates of bicyclists (per 1000 residents) according to quartiles of family income. São Paulo, 1997–2012. *Statistically significant differences.

3.2. Frequency and distribution of cyclists

Table 1 shows rates of cyclists in Sao Paulo population as well as the adjusted prevalence ratios. Crude models showed that, in 2012, men were almost seven times more likely to bicycle than women. Individuals who worked or studied closer to home (5 km or less) were almost three times as likely to bicycle in their daily commutes. No clear trend on cycling rates was observed for education ($p = 0.402$) or income ($p = 0.394$) in 2012. All differences observed in the crude models remained statistically significant after controlling for age and sex. In the fully-adjusted model (Table 1), there were no substantial changes in the magnitude, direction or significance of any association. Most of the time spent and distance travelled by cyclists on their daily travel was done through cycling (Table 2). Mean duration and distance of cycling trips were 24.1 min (95%CI 21.3; 27.0) and 3.8 km (95%CI 2.8; 4.9), respectively. Descriptive results from Table 1 and Table 2 were similar for 2007 and 1997. In all years, one quarter of cycling trips started between 6 am and 7 am, and another quarter between 5 pm and 6 pm.

Time trend analyses showed an increase in the rate of cyclists, from 3.9 (95%CI 3.2; 4.6) per 1000 residents in 1997 to 6.3 (95%CI 5.8; 6.8) per 1000 residents in 2007 but dropped to 5.4 (95%CI 3.9; 6.9) in 2012. The overall decline in 2012 was caused by a sharp drop in the rate of cyclists in the lowest income quartile from 2007 to 2012. However, the rate of cyclists/1000 individuals among individuals in the top income quartile increased from 1.2 (95% CI 0.6; 1.8) to 4.5 (95%CI 2.0; 6.5) (Fig. 1).

3.3. Health consequences — air pollution and traffic injury

Considering PM2.5 concentration in 2012, 1 h of cycling per day would reduce all-cause mortality by approximately 20% when risks of air pollution and benefits of physical activity are combined. The benefits would continue to increase until nearly 10 h of cycling per day making cycling beneficial to health in all practical cycling levels in Sao Paulo. For comparison, using PM2.5 levels in 1997, cycling would benefit health up to 2 h and 15 min of cycling per day. This indicates how the improvement in air pollution when 1997 is compared with 2012 has contributed to improving the health benefits of cycling (Fig. 2).

Between 2007 and 2012, there was a 39% reduction in the rates of cyclist deaths per 100,000 people in Sao Paulo versus a 27% reduction in the rates of cyclist deaths per 1000 person-hours travelled (Fig. 3a and b). Reductions in rates of cyclist injuries per 100,000 population and per 1000 person-hours travelled were 30% and 15%, respectively (Fig. 3a and b). When the number of cyclists is used in the denominator, reductions in rates of cyclist deaths and injuries per 100,000 cyclists nearly matched those per 1000 person-hours travelled (29% versus 27% and 18% versus 15%, respectively).

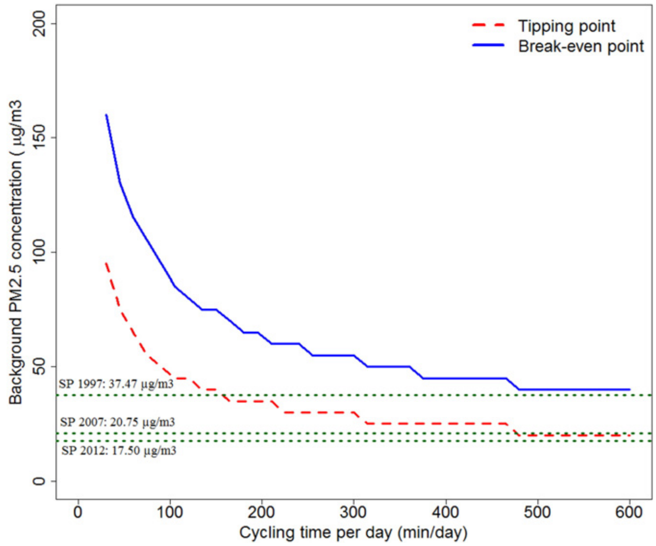

Fig. 2. Tipping and break-even points for different levels of cycling (red dashed line and blue solid line, respectively) (minutes per day, x-axis) and for different background PM2.5 concentrations (y-axis). Green dotted lines represent the background PM2.5 concentrations for São Paulo (SP) in 1997, 2007 and 2012.

4. Discussion

Using a representative sample from Sao Paulo, we found an increase in the number of cyclists from 1997 to 2007, but a decline in 2012. In 2012, the 25% richest segment of the population experimented an increase in the rates of cycling whereas a decline was observed for the 25% poorest. The health benefits of cycling-related physical activity increased due to notable reductions in PM2.5 concentrations and due to a reduction in injury risk. However, reductions in road injury risks between 2007 and 2012 were smaller than that estimated by population-based rates, a more commonly used estimate.

Of interest are the different trends in cycling by socio-economic group. One issue is access to motor vehicles, a factor negatively associated with levels of active transportation in the region (Sa et al., 2013). For instance, between 2007 and 2012, federal government developed a policy of tax exemptions and simplified loans for private vehicles purchase (Presidência da República, 2010) in order to tackle the economic crisis by warming up internal consumption. These initiatives fostered the automobile and motorcycle industry and contributed to an increase in car and motorcycle access in São Paulo. In the same time period, the proportion of families in the lowest quartile of income that did not own a car or motorcycle dropped from 76.6% (95%CI: 75.3 to 78.0) to 71.3% (95%CI: 69.2 to 73.4) whereas the same proportion of families in the highest quartile of income increased from 4.4% (95%CI: 3.4; 5.4) to 8.2% (95%CI: 6.2; 10.2) (data not shown).

Moreover, between 2007 and 2012, we observed improvements in other factors disproportionately affecting the poor, such as poorer access to public transport and higher rates of workplace informality – thus less likely to have their transportation costs subsidized by their employer (Instituto de Pesquisas Econômicas Aplicadas, 2013). Despite improvements, spatial segregation in the city remains high. For instance, in 2007, poor public transport network and high cost were the leading factors in respondents' choice to bicycle (Companhia do Metropolitano de São Paulo, 2008). Additionally, our results identified that living closer to work/school increases the chances of being a cyclist, independent of income. In Sao Paulo, lower income individuals are more likely to live in the peripheral neighborhoods and therefore they travel long distances to go work (Marques et al., 2012). Sao Paulo's central area concentrates two thirds of the jobs but <20% of the population (Prefeitura de São Paulo, 2013). Apart from its embedded status, cars and motorcycles are necessary alternatives for the poor segment of the population to overcome either the absence of a good public transport network or the high costs associated with it.

Time spent on the daily commute from home to work is lower among the highest (quintile 5) income strata of the population (see Fig. A1 to A3 in the supplementary material), since they can afford to live in more central areas of the city (Pereira and Schwanen, 2013; Prefeitura de São Paulo, 2013). In São Paulo, cycling is more frequent among lower income and lower educated individuals, men, young

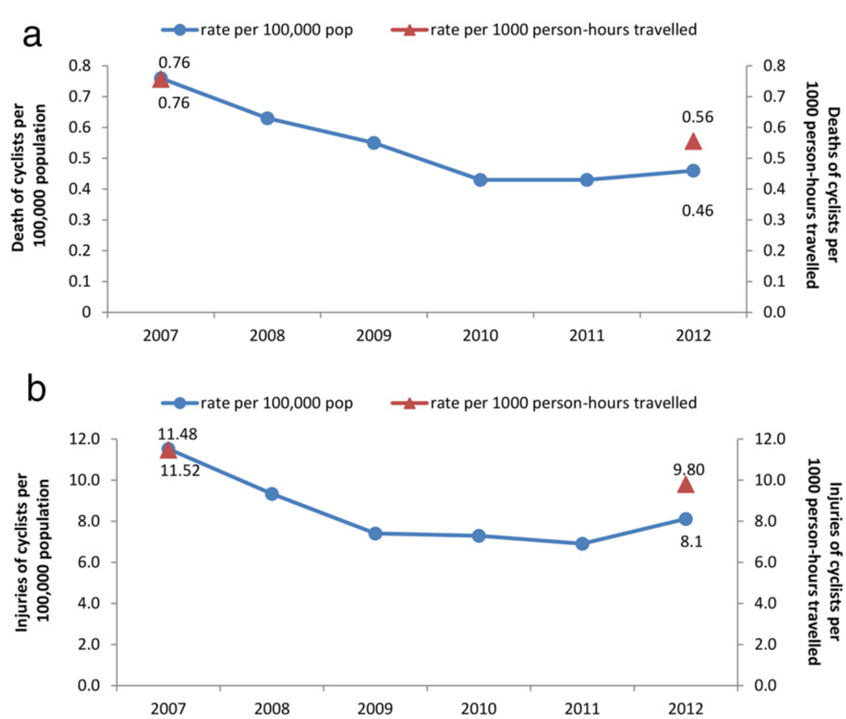

Fig. 3. Rates of road traffic deaths (3a) and injuries (3b) for cyclists in São Paulo between 2007 and 2012.

adults, and among those who do not own a car. Similar results were shown for other cities in Brazil (Hino et al., 2013; Kienteka et al., 2014; Reis et al., 2013; Teixeira et al., 2013). In Europe, a broader range of social groups bicycle for transportation, (Bassett et al., 2008; Pucher and Buehler, 2008) however figures are different in South (Hino et al., 2013; Reis et al., 2013; Torres et al., 2013) and North America (Pucher et al., 2011). In Bogota, where a large share of bike lanes have been implemented in the past years, users of bicycle paths are mostly male younger adults who did not own a car (Torres et al., 2013). The wide age gap observed in São Paulo is particularly concerning considering the increasing net benefits of cycling among older individuals (Woodcock et al., 2014).

The gender gap in Sao Paulo is also noteworthy. Sao Paulo is a very low cycling region with very high gender inequalities in cycling. We found that women were seven times less likely to bicycle than men. This fits with earlier studies in high-income countries which showed smaller (and eventually no) gender inequalities in cycling based on data both within (Aldred et al., 2015), and between countries (Pucher and Buehler, 2008). We did not find studies that explored the reasons for such a wide gender gap in Brazil, although we hypothesize that they might be similar to those in developed countries: lower perception of safety on the roads and a greater preference for segregated bike lanes among women (Beecham and Wood, 2013). Long commuting distances in Sao Paulo may also have a greater impact on women's cycling rates.

We found a very large contribution of cycling on cyclists´ daily commute, which may be associated with the lack of satisfactory transport mode integration. In 2007, one third of cyclists reported they chose the bicycle as their mode of travel because of problems with the public transportation system (data not shown). Along with interventions to improve affordability, comfort and travel time in public transport, initiatives to improve bicycle parking infrastructure near subway and train stations and allowing the transportation of bicycles on the public transport are promising and cost-effective initiatives to encourage bicycle use among those who would otherwise need to cover long distances on the bicycle. (Krizek and Stonebraker, 2011) Regardless of the reasons that would influence one to choose to use the bicycle, the reported number of cyclists and cycling trips in the city show substantial room for increase in all income strata. Optimum local climate conditions year round would contribute to providing the necessary conditions for higher cycling rates. Monthly temperature range in São Paulo is approximately 10 °C, with historical minimum and maximum range in July (12 °C to 22 °C) and January (19 °C to 27 °C), respectively. Historical mean rain precipitation varies from 40 mm in August to 237 mm in January (Climatempo, 2016).

Growing research linking environmental characteristics and cycling in Latin America sheds a light on the environmental interventions that could help increase the number of cyclists. Bicycle use has been associated with higher density of streets, lower rates of traffic collisions (Cervero et al., 2009) and residing in areas with a higher number of traffic lights and of greater mixed-land use (Hino et al., 2013). Proper cycling infrastructure is among the most effective interventions to impact cycling rates (Yang et al., 2010).

The health benefits of cycling may be reduced by exposure to air pollution and road injury risks. Our study revealed that benefits of cycling would only be negated by exposure to air pollution in São Paulo in extreme levels of cycling, potentially even higher than the levels of bike couriers or professional cyclists. This is similar to the observed in the vast majority of cities around the globe for which information is available (Tainio et al., 2016). A person with typical non-travel physical activity who cycles 1 h per day in the city would expect to have approximately 20% reduction in all-cause mortality, even if the risks posed by the air pollution are taken into account. Moreover, exposure-based rates of road traffic injury risks decreased between 2007 and 2012 in São Paulo although to a lesser extent than population-based rates, highlighting the importance of considering exposure levels in these estimates. This reduction may be related to the development of cycling infra-structure during that period along with a potential increased awareness in traffic for cycling. Nevertheless, there is still limited evidence around determinants of road traffic injury risk for cycling in São Paulo.

A strength of this study is the use of recent HTS data from the largest metropolitan area in Brazil. However, there are several limitations, including a smaller sample size and number of zones for 2012 in comparison to 2007 and 1997. Other limitations are the information only for one day, which compromises analysis of intrapersonal variation, and the validity of self-reported data. Self-reported trip duration may limit its accuracy, especially for shorter trips like cycling (Agrawal et al., 2008). The rounding that occurs in self-reports of duration may introduce additional measurement error (Yang and Diez-Roux, 2012). Despite being the best available source for information about road injuries and deaths for São Paulo, SAT-CET database also presents some limitations, such as underreporting, which may have underestimated road injury risks for cyclists (Companhia de Engenharia de Tráfego, 2014). Finally, it is important to note that we only assessed the long-term impact of the relation between cycling and exposure to air pollution in the general population, limiting the generalizability of our findings to vulnerable subgroups or to short-term consequences of cycling on days with high peaks of air pollution (Tainio et al., 2016).

We showed increasing rates of cycling for transportation when 1997 and 2007 São Paulo HTS data were compared, but a decline in 2012 because of a larger reduction among lower income individuals. We have also found positive results for the relationship between cycling and health. A better understanding of the cycling behaviour in the city may be used to inform more effective policy decisions towards active transportation in Sao Paulo. Policies to reduce spatial segregation, measures to tackle air pollution, improvements in dedicated cycling infrastructure, and integrating the bicycle with the public transport system in neighborhoods of all income levels could make cycling safer and prevent more individuals from abandoning the cycling mode.

Competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organization for the submitted work (except for the funding agencies already reported); no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgments

THS acknowledges funding from the Brazilian Science without Borders Scheme (Process number: 200358/2014-6) and the Sao Paulo Research Foundation (Process number: 2012/08565-4). ACD received a postdoctoral research fellowship from the Brazilian National Council for Scientific and Technological Development (249038/2013-7). MT and JW: The work was undertaken by the Centre for Diet and Activity Research (CEDAR), a UKCRC Public Health Research Centre of Excellence. Funding from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, the National Institute for Health Research, and the Wellcome Trust (MR/K023187/1), under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged. The views presented in this paper are those of the authors, and do not necessarily represent those of the study funders. Funders had no role in designing, conducting and reporting the study. The authors would like to thank Dr. Emilia Mayumi Hiroi for assisting in technical issues related to the São Paulo Household Travel Survey.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.pmedr.2016.10.001.

References

Agrawal, A.W., Schlossberg, M., Irvin, K., 2008. How far, by which route and why? A spatial analysis of pedestrian preference. J. Urban Design 13, 81–98.
Aldred, R., Woodcock, J., Goodman, A., 2015. Does more cycling mean more diversity in cycling? Transp. Rev. 1–17.
Bassett Jr., D.R., Pucher, J., Buehler, R., Thompson, D.L., Crouter, S.E., 2008. Walking, cycling, and obesity rates in Europe, North America, and Australia. J. Phys. Act. Health 5, 795–814.
Becerra, J.M., Reis, R.S., Frank, L.D., et al., 2013. Transport and health: a look at three Latin American cities. Cad Saúde Pública 29, 654–666.
Beecham, R., Wood, J., 2013. Exploring gendered cycling behaviours within a large-scale behavioural data-set. Transp. Plan. Technol. 37, 83–97.
Cervero, R., Sarmiento, O., Jacoby, E., Gomez, L.F., Neiman, A., 2009. Influences of built environment on walking and cycling: lessons from Bogotá. Int. J. Sustain Transp. 3, 203–226.
Companhia de Engenharia de Tráfego, 2014. Acidentes de Trânsito no Município de São Paulo - Relatório Anual 2013. Prefeitura de São Paulo, São Paulo.
Companhia de Tecnologia de Saneamento Ambiental, 1998. Relatório anual de qualidade do ar 1997. Governo do Estado de São Paulo, São Paulo.
Companhia de Tecnologia de Saneamento Ambiental, 2002. Modelo Receptor - Estudo de Caracterização de Aerossóis na Região Metropolitana de São Paulo - Cerqueira César. Governo do Estado de São Paulo, São Paulo.
Companhia de Tecnologia de Saneamento Ambiental, 2008. Relatório de qualidade do ar no estado de São Paulo 2007. Governo do Estado de São Paulo, São Paulo.
Companhia de Tecnologia de Saneamento Ambiental, 2013. Qualidade do ar no estado de São Paulo 2012. Governo do Estado de São Paulo, São Paulo.
Companhia do Metropolitano de São Paulo, 2008. Pesquisa Origem e Destino 2007: Síntese das Informações da Pesquisa Domiciliar. Governo do Estado de São Paulo, São Paulo.
de Nazelle, A., Nieuwenhuijsen, M.J., Anto, J.M., et al., 2011. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environ. Int. 37, 766–777.
Hamer, M., Chida, Y., 2008. Active commuting and cardiovascular risk: a meta-analytic review. Prev. Med. 46, 9–13.
Hartog, J.J., Boogaard, H., Nijland, H., Hoek, G., 2011. Do the health benefits of cycling outweigh the risks? Cien Saude Colet 16, 4731–4744.
Hino, A.A., Reis, R.S., Sarmiento, O.L., Parra, D.C., Brownson, R.C., 2013. Built environment and physical activity for transportation in adults from Curitiba, Brazil. J Urban Health 91 (3), 446–462.
Instituto Brasileiro de Geografia e Estatística, 2011. Censo 2010http://www.ibge.gov.br/home/estatistica/populacao/censo2010/default_resultados_universo.shtm.
Instituto de Pesquisas Econômicas Aplicadas, 2013. Indicadores de mobilidade urbana da Pesquisa Nacional por Amostra de Domicílios 2012. In: República, S.d.A.E.d.P.d. (Ed.), Brasília, p. 18.
Kelly, P., Kahlmeier, S., Götschi, T., et al., 2014. Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. Int. J. Behav. Nutr. Phys. Act. 11 (1), 132.
Kienteka, M., Fermino, R.C., Reis, R.S., 2014. Individual and environmental factors associated with bicycling by adults: a systematic review. Rev. Bras. Ativ. Fis. Saúde 19, 12.
Krizek, K.J., Stonebraker, E.W., 2011. Assessing options to enhance bicycle and transit integration. Transp. Res. Rec. 162–167.
Krzywinski, M., Altman, N., 2013. Points of significance: error bars. Nat. Methods 10, 921–922.
Marques, E., Bichir, R., Scalon, C., 2012. Residential segregation in comparative perspective: making sense of contextual diversity. In: Maloutas, T., Fujita, K. (Eds.), Segregation Around the World. Ashgate, London, p. 329.
Pereira, R.H.M., Schwanen, T., 2013. Commute time in Brazil (1992–2009): differences between metropolitan areas, by income levels and gender. Discussion Pap IPEA 1813a, 1–29.
Pratt, M., Sarmiento, O.L., Montes, F., et al., 2012. The implications of megatrends in information and communication technology and transportation for changes in global physical activity. Lancet 380, 282–293.
Presidência da República, 2010. Decreto número 7222, de 29 de junho de 2010. Altera a Tabela de Incidência do Imposto sobre Produtos Industrializados—TIPI, aprovada pelo Decreto número 6006, de 28 de dezembro de 2006. Seção 1—edição extra; 122. Diário Oficial da União.
Pucher, J., Buehler, R., 2008. Making cycling irresistible: lessons from the Netherlands, Denmark and Germany. Transp. Rev. 28, 495–528.
Pucher, J., Buehler, R., Seinen, M., 2011. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. Transp. Res. Part A-Policy Pract. 45, 451–475.
Reis, R.S., Hino, A.A.F., Parra, D.C., Hallal, P.C., Brownson, R.C., 2013. Bicycling and walking for transportation in three Brazilian cities. Am. Prev. Med. 44, e9–e17.
Rojas-Rueda, D., de Nazelle, A., Teixido, O., Nieuwenhuijsen, M.J., 2012. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: a health impact assessment study. Environ. Int. 49, 100–109.
Rydin, Y., Bleahu, A., Davies, M., et al., 2012. Shaping cities for health: complexity and the planning of urban environments in the 21st century. Lancet 379, 2079–2108.
Sá, T.H., Parra, D.C., Monteiro, C.A., 2015. Impact of travel mode shift and trip distance on active and non-active transportation in the São Paulo metropolitan area in Brazil. Prev. Med. Rep. 2, 183–188.
Sa, T.H., Salvador, E.P., Florindo, A.A., 2013. Factors associated with physical inactivity in transportation in Brazilian adults living in a low socioeconomic area. J. Phys. Act. Health 10, 856–862.
Saunders, L.E., Green, J.M., Petticrew, M.P., Steinbach, R., Roberts, H., 2013. What are the health benefits of active travel? A systematic review of trials and cohort studies. PLoS One 8, e69912.
Shephard, R.J., 2008. Is active commuting the answer to population health? Sports Med. 38, 751–758.
Tainio, M., de Nazelle, A.J., Götschi, T., et al., 2016. Can air pollution negate the health benefits of cycling and walking? Prev. Med. 87, 233–236.
Teixeira, I.P., Nakamura, P.M., Smirmaul, B.P.C., Fernandes, R.A., Kokubun, E., 2013. Factors associated With the bicycle use for transportation in a medium-sized city. Rev. Bras. Ativ. Saúde 18, 698–710.
Torres, A., Sarmiento, O.L., Stauber, C., Zarama, R., 2013. The Ciclovia and Cicloruta programs: promising interventions to promote physical activity and social capital in Bogota, Colombia. Am. J. Public Health 103, e23–e30.
Woodcock, J., Edwards, P., Tonne, C., et al., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet 374, 1930–1943.
Woodcock, J., Tainio, M., Cheshire, J., O'Brien, O., Goodman, A., 2014. Health effects of the London bicycle sharing system: health impact modelling study. BMJ 348, g425.
World Health Organization, 2011. Health in the Green Economy: Health Co-Benefits of Climate Change Mitigation - Housing Sector. World Health Organization, Geneva.
Yang, Y., Diez-Roux, A.V., 2012. Walking distance by trip purpose and population subgroups. Am. J. Prev. Med. 43, 11–19.
Yang, L., Sahlqvist, S., McMinn, A., Griffin, S.J., Ogilvie, D., 2010. Interventions to promote cycling: systematic review. BMJ 341, c5293.

Web references

Climatempo. URL: http://www.climatempo.com.br/climatologia/558/saopaulo-sp. Last access: June 22, 2016.
Prefeitura de São Paulo, 2013. Infocidade 2013 URL: http://infocidade.prefeitura.sp.gov.br/. Last access: June 22, 2016.
Prefeitura de São Paulo, 2014. Programa de Metas 2013–2016. URL: http://planejasampa.prefeitura.sp.gov.br/metas. Last access: June 22, 2016.
World Health Organization, 2014.WHO expert meeting: methods and tools for assessing the health risks of air pollution at local, national and international level. Meeting report. Copenhagen, Denmark. Available at: http://www.euro.who.int/__data/assets/pdf_file/0010/263629/WHO-Expert-Meeting-Methods-and-tools-for-assessing-thehealth-risks-of-air-pollution-at-local,-national-and-international-level.pdf.