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The unrealised potential of bike share schemes to influence population physical activity levels – A narrative review

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ABSTRACT

The recent proliferation of bike share schemes (BSS, also known as public bicycle use programs) in many cities has focused attention on their potential for reducing motorised traffic congestion, improving air quality and reducing car use. Since 2005, hundreds of bike share schemes have been implemented in many cities, with bike share usage patterns monitored in many of them. This paper assesses the development of BSS and provides a rationale for their potential health benefits. The key research question, as yet unanswered, is whether BSS themselves can contribute to improving population health, particularly through increasing population cycling, which would increase population levels of health-enhancing physical activity. This paper presents a framework for evaluating the contribution of BSS to population physical activity, and uses examples of new data analyses to indicate the challenges in answering this question. These illustrative analyses examine cycling in Australia, and [i] compares rates of cycling to work in BSS cities compared to the rest of Australia over time, and [ii] modelling trends in bike counts in Central Melbourne before and after introduction of the BSS in 2010, and compared to adjacent regions in nearby suburbs unexposed to a BSS. These indicative examples point to difficulties in attributing causal increases in cycling for transport to the introduction of a BSS alone. There is an evidence gap, and a need to identify opportunities to improve the health-related components of BSS evaluations, to answer the question whether they have any impact on population physical activity levels.

1. Introduction – the promise of bike share schemes (BSS)

Bike share schemes (BSS) are defined as the provision of accessible bicycles at bicycle stations throughout a defined urban area. These are also known as "bike share programs", "public use bicycles" or shared bicycles. Bicycles are available for short-term rentals and short trips, typically 1 to 5 km in length, and are accessed on an "as-needed" basis (Midgley, 2011). These have proliferated in recent years, with increasingly automated and web-link methods of accessing and returning bicycles. The need for BSS includes the exponential increase in car use in both industrialised and transitional countries, and the decrease in active travel and in public transportation. Just as a comparison, McClintock (1987) suggested that 40% of all trips in the United Kingdom in 1981 were made by bicycle, but current proportions of trips three decades later have declined by >20 fold.

In 2008 there were estimated to be 213 BSS globally, increasing to an estimate of 375 by 2011 (Midgley, 2011). The number of BSS globally is current estimated to be over 800 (Ricci, 2015; Frade and Ribeiro, 2015), with approximately 900,000 bicycles available for use. The largest BSS are in Paris, France (Velib, with 20,000 bicycles available) and in Hangzhou, China (60,000 bicycles), with other well-established programs in the USA and Canada, in London and other parts of the United Kingdom, in Dublin (Ireland), in Spain, elsewhere in France and in Chile. The aims of bike share schemes are [i] to improve air quality and decrease traffic congestion, [ii] to improve cycling levels in the community with resultant increases in total physical activity and consequent improvements in health and physical fitness, and reduce rates of chronic disease, and improve quality of life, [iii] to integrate and improve transportation options and choices (such as allowing for intermodal trip through integration with public transport), decreased travel time and possibly decreased travel costs, and [iv] to improve the image of the urban environment, including the promotion of tourism.

The first BSS were trialled in Amsterdam in the 1960s, then had a quiescent period in subsequent decades. They re-emerged in the early 21st century as a confluence of ideas from urban planning, urban space utilization, public transportation, air quality management and public health agencies, to promote active travel and active commuting within urban environments (Beswick, 2009). These programs were described as "a bike share boom" (Citylab, 2016) and have been compared to other elements of the post-millennial "sharing economy" (such as

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Zipcar, Uber, AirBnB). The proliferation of BSS now means that "bike sharing is in full bloom" (Birdsall, 2014). The epistemology of bike share programs originated with the concept "if you build it, they will come" (Cervero et al., 2013). These programs are also described as "tactical urbanism", part of a strategy to incrementally influence the urban landscape and also to promote physical activity (Marshall et al., 2015).

Despite the marked increase in published reports and papers on BSS, there is limited actual evidence on the ascribed, potential or hypothetical health benefits attributable to these programs. Many authors describe the promise of BSS in delivering improved health to populations, often described as the "collateral health benefits for participants" (Millard, 2012). This paper will review the usage and correlates of bike share schemes, but the primary purpose is to identify whether these programs actually contribute to public health gain, predominantly through increasing physical activity (PA).

2. The history and correlates of bike share schemes

It is beyond the scope of this paper to describe specific BSS in detail (see Fishman et al., 2013; Midgley, 2011). A number will be described briefly, in reference to their usage, patterns and correlates of users, and potential for health impact. Early programs in Copenhagen, starting in 1995 were abandoned by 2012 because the city bikes were vastly outnumbered by private bicycle commuters. This may show the potential of BSS for contributing to changing the culture of cycling in a city. One of the largest recent bike share programs is the Velib program in Paris, operating since 2007, with 20,000 bikes, and reportedly more than eight uses per bicycle per day (Basarić et al., 2012). Bike share trips represent 0.76% of all trips, and are mostly under 30 min. Similar proportions of all trips are reported by the Velov program in Lyon, with 0.92% of all trips attributable to the program. The 2007-launched program in Barcelona, known as Bicing has been widely adopted for short trips. The London bike share scheme (Santander Bikes) began in 2010, with 5000 bikes and 300 stations, with highest usage during morning and evening peak hours (Lathia et al., 2012). The largest bike share scheme in Hangzhou, (Shaheen et al., 2011), has rapidly increased to 60,000 bikes and 2400 stations, and more than five uses per bicycle per day. Similar large programs are in other parts of China including Wuhan and Shanghai. There are many programs across North and South America, with notable examples including Montréal (Bixi cycles), Washington DC (Capital Bikeshare) and New York (Citibike).

Many studies have examined factors associated with BSS usage and the characteristics of users, but almost no research has examined the effects of BSS on population levels of physical activity. Research has characterised BSS users, who are typically: (1) local residents who do not own a bike and use the BSS for utility, leisure or commuting, (2) residents who own a bike yet, use BSS to facilitate door-to-door transport between home, a transit hub and their workplace, and (3) tourists or visitors (O'Brien et al., 2014; Buck et al., 2013). A summary of the existing research suggests that BSS users are not typical of the general population, with most studies showing BSS are used more by men than women (Morabia, 2012) with variable usage by socio-economic status (Buck et al., 2013). Several studies have reported that BSS users are more affluent (Caulfield, 2014; Murphy and Usher, 2015) (Davis, 2014). The London BSS reported mixed use by socio-economic status (Ogilvie and Goodman, 2012), but that under-utilization by users from deprived areas was ameliorated by an extension to socially deprived regions in East London (Goodman and Cheshire, 2014). Others have reported that bike share users were younger, less likely to have a car, cycle for utilitarian purposes, and have a private bicycle for use in other settings (Buck et al., 2013; Caulfield, 2014). Few BSS have however, targeted low income populations (Stewart et al., 2011), due to both geography and cost. Other factors influencing bike share usage included hilly topography, climate and weather (El-Assi et al., 2015; Corcoran et al., 2014).

Bike share usage is more likely for people who live close to the bike share stations (Tripodi and Persia, 2015; Cole-Hunter et al., 2015; Bachand-Marleau et al., 2012). This means that access to BSS are usually located in the small central or downtown business area of cities (Vassi and Vlastos, 2014). Helmet wearing is thought to be a barrier to BSS usage, but only in a few countries, such as Australia, where bicycle helmet-wearing is compulsory (Fishman et al., 2013). In other countries, bike helmet wearing among BSS users was relatively low (Grenier et al., 2013; Ethan et al., 2015; Fischer et al., 2012; Friedman et al., 2016). Another barrier is cost, which alongside locational issues, often restricts BSS access to more advantaged populations (Ricci, 2015). Finally, many new BSS encourage casual usage, including tourists and visitors, which provides healthy transport options for these individuals but does not contribute to total physical activity for the resident populations (Ricci, 2015). A few BSS, such as Abellio in the UK and OV-fiets in the Netherlands, are making a concerted effort to engage door-to-door commuters, particularly those who live further from the City centre (Abellio). All of this research has profiled the attributes of users, their access to BSS and identified structural barriers to their use, but very little research examined the contribution of BSS to total health-enhancing physical activity.

3. The health benefits of cycling redux

To contextualize the primary purpose of this review, we briefly present the evidence base for cycling and health, as this underpins the argument for health outcomes attributable to BSS. The potential health benefits of cycling are related to chronic disease prevention, improving mental health and wellbeing, and contributing to reduced environmental air pollution. There is strong evidence that regular moderate- to vigorous-intensity PA contribute to population health, including improved physical health and reduced preventable deaths (Lee et al., 2012; Lim et al., 2013; HHS, 2008), and improved cognitive function in older adults (Bauman et al., 2016). Cycling for transportation is typically performed at sufficient intensity to be classified as moderate- to vigorous PA (Ainsworth et al., 2000). Based on longitudinal cohorts and intervention studies we summarize the health benefits of cycling for transportation and introduce the potential impact of increases in cycling required to attain the WHO physical activity recommendations for adults, of achieving "150 mins of at least moderate-intensity activity weekly" (WHO, 2010).

Several studies have demonstrated physiological responses to cycling that reduce chronic disease risk in adults and children (Hendriksen et al., 2000; Ried-Larsen et al., 2015). One was a population-based intervention study (Oja et al., 1991), which showed that a 10-week intervention of 3–4 days/week of cycle commuting for about 60 min/day showed improvements in cardiorespiratory fitness and HDL cholesterol. The first epidemiological study of cycling for transportation and all-cause mortality was from a prospective cohort study in Copenhagen (Andersen et al., 2000), and reported a 28% (95% CI 0.57–0.91) reduced risk of all-cause mortality when cycling 3 h per week in Copenhagen. A systematic review (Oja et al., 2011) showed that all but two prospective cohort studies demonstrated a consistent inverse relationship between commuter cycling and all-cause and CVD/CHD mortality, and cancer mortality and morbidity among middle-aged to elderly adults. Using a meta-analysis pooling seven studies Kelly et al. (2014), reported a pooled risk reduction of around 10% for all-cause mortality (95% CI = 6 to 13%) for around 2.5 h of moderate-intensity cycling per week.

The health benefits of walking and cycling outweigh the negative effects on health of air pollution, even in cities with high levels of air pollution (Tainio et al., 2016). This strengthens the case that cycling has a net benefit even in polluted cities - an effort that in turn can help reduce vehicle emissions. Only 1% of cities in the World Health Organization's Ambient Air Pollution Database had pollution levels high enough that the risks of air pollution might mitigate the benefits of physical activity after half an hour of cycling every day.

The specific benefits of cycling have been theoretically modelled in several studies. Substantially different health benefits are produced, with an assessment of the Bicing BSS in Barcelona (Rojas-Rueda et al., 2011) estimating health impacts more than ten-fold greater than from the London BSS (Ricci, 2015). This was partly due to increased bicycle accident rates estimated for London than for Barcelona. Nonetheless, it is clear that, increases in total cycling are likely to produce net health benefits, even when considering exposure to air pollution, and risk of injury, compared to other modes of travel (Woodcock et al., 2014). The proportion of these cycling-related benefits that are specifically attributable to BSS remains an unanswered question.

4. Approaches to examining the health consequences of bike share schemes

In order to review the evidence, we used the Scopus database (Title/abstract/keywords) from 1997 onwards for the search terms for bike sharing, bike shar*, city bikes, bike schemes and public bikes, and obtained 266 references; we read through all abstracts, and examined papers where health-related data might be mentioned. For this reason, we did not classify this as a systematic review, as almost no papers would have appeared in the search with health-related outcomes of BSS as the primary study purpose. This approach was consistent with a narrative review, with a larger selection of papers perused in full, and health-relevant information located within papers (with no keyword or search term indicating its presence). We also used documentary searches stimulated by reference lists, and by examining reports and references through Google Scholar.

Given the potential for health benefits, population approaches to increasing physical activity are warranted, but many sport promotion and structured exercise programs may only reach a small proportion of all adults. Recent policy interest has emphasised regular, incidental physical activities carried out as part of daily life, of which active travel [active commuting] comprises a substantial part. The most frequent forms of active commuting are *walking or cycling*, but the focus of this review is trip-related cycling for transport, rather than cycling for recreation or exercise. The health benefits of active cycle commuting are often cited (Pucher and Buehler, 2008) through contributing to total physical activity. Since many people do some, but insufficient physical activity (Garrard et al., 2012; Rissel et al., 2012), even a small increase in regular PA would allow them to reach the recommended health-enhancing PA threshold.

With respect to BSS, public health goals to date have mentioned clean environments, decreased traffic and increasing physical activity. Most evaluations of BSS focus on the first two goals, and for the third, researchers assess 'increases in trips' or BS usage as a proxy metric for measuring physical activity among those who participate in the BSS (de Chardon and Caruso, 2015). There are limited data on actual physical activity increases among BSS users, on the population prevalence of BSS usage, and on whether users were already an 'active group' meeting PA recommendations prior to using the BSS.

Data on BSS usage is seldom expressed as a population rate, but usually as the number of BSS users, or sometimes as the proportion of trips by a given transport mode. One example of this is transport-related data, which assess cycling trips in the population. It is well known that between a quarter and a half of all trips in cities such as Amsterdam or Copenhagen are made by bike (Fishman et al., 2013; Fishman, 2015), indicating that regular cycle commuting makes a major contribution to adult population levels of physical activity. However, in Australia and the USA, trips by bicycle are much less common. Using representative transport survey data, Merom et al. (2010) examined trends in active travel trips in metropolitan Sydney, Australia over a decade. Walking for transport significantly increased, but cycling rates remained very low. In 1997, 0.97% of the adult population reported one cycling trip on the randomly-chosen day of the survey, which increased non-significantly to only 1.18% by 2007. A comparative study, using national transport survey data from the USA and Germany, and comparable active travel measures (Buehler et al., 2011) examined the proportion of cycling-for-transport trips in 2001/2 and 2008/9. Cycling did not increase in the USA (0.9%, 1.0%), and Germany had much higher proportions (22.6%, 23.7%). These data show that both the proportion of trips and the absolute population rates of cycling for transport hovered around 1% or less in the USA and Australia, indicating that in total, cycling made little population impact on physical activity, compared to European cities.

A key challenge is determining the population prevalence of, and trends in BSS usage. This is difficult to establish from existing data, which mostly refer to active commuting through cycling. Using Copenhagen as an example of a high-cycling city, with an assumed 500,000 cyclists commuting daily to and from work. A city bike share program with 2000 bikes (Midgley, 2011), each used ~8 times per day (Basarić et al., 2012), will only contribute 16,000 trips, or around 1.6% of all Copenhagen cycle commuting trips. For a city like Paris, the much larger BSS fleet of 20,000 bikes could contribute to 160,000 trips (Basarić et al., 2012), which would comprise a larger proportion of all cycle commuting trips. However, it is not known how many of these trips are by tourists (Kaplan et al., 2015).

A greater challenge is the lack of information on the proportion of BSS users that are already sufficiently physically active from walking, other activity and sport. The profile of BS users in London, Barcelona and Dublin is reported (Murphy and Usher, 2015; Cole-Hunter et al., 2015; Lathia et al., 2012). They are younger, show different distributions of socio-economic status, more likely male, and less likely to own a car (Buck et al., 2013), all known correlates of increased walking and other leisure time physical activity (Bauman et al., 2012). Further, BSS users are more likely to be already cycling outside of BSS usage (Ricci, 2015). Only one study reports on other physical activity levels outside of BSS usage, in Barcelona where many BSS users were considered "much more likely to do other vigorous exercise, compared to non-cyclists" (Cole-Hunter et al., 2015). These limited data suggest that many BSS users are likely to already be physically active.

5. Towards an evaluation framework for assessing the population health impacts of bike share schemes

5.1. The potential for bike share schemes to increase the population prevalence of cycling

Population levels of cycling or physical activity are estimated from representative population survey data covering whole regions or communities. This has not been assessed in relation to BSS, but are central to understanding the impact of BSS on health. To explain the health effects attributable to BSS from a population perspective we need to know how a BSS scheme fits within the overall pattern of cycling within a city or area, and within transport modes more broadly. Future growth in a BSS is likely to be proportional to changes in cycling participation within the population and the environmental factors and social norms governing that participation.

Many BSS are evaluated by assessing increases in BSS usage or trips. These data are reported on websites, in administrative documents, and occasionally in published papers. A few have reported survey data that examined the perceptions of selected samples of BS users (Ricci, 2015; Damant-Sirois and El-Geneidy, 2015; Birdsall, 2014); these studies showed that responding BSS users liked the program, reported increased cycling themselves, and reported increased awareness of cycling (Murphy and Usher, 2015). These are process evaluations of the implementation of BSS and their acceptability, and do not provide information on population levels of cycling.

Ideally, BSS evaluations would enquire about total physical activity levels among users, and also provide fine-grained district level data on trip time-of-day, duration, origin and destination, allowing change to be modelled. Few BSS provide such detailed data. de Chardon and Caruso (2015) found that published metrics tend to be non-comparable and may be portrayed to reflect the BSS supplier positively. Without public access to usage data, it is not possible to rely on BSS findings as a reflection of urban cycling (Ravalet and Bussière, 2012; de Chardon and Caruso, 2015). More generic theoretical modelling of active commuting by bicycle does suggest that it could be contributing to physical activity (Donaire-Gonzalez et al., 2015).

One study examined pre-post changes in cycling behaviour following the introduction of the Bixi BSS in Montreal (Fuller et al., 2013). This study used three population-representative sample surveys of ~2000 adults and asked about bike usage, before and after the introduction of the scheme. Data showed seasonal changes in overall cycling, increases in trip-related utilitarian cycling close to the Bixi BSS stations, and no change in recreational cycling. This positive finding used an appropriate research design, and does suggest the possible population impact of a city-wide BSS.

The evidence of a shift in travel models from "inactive" to "active" is less clear. Most studies report a transfer from walking and public transport to BS usage, and only a few report decreased car usage (Midgley, 2011; Ricci, 2015; Murphy and Usher, 2015). One study, using good population survey data in Montreal, did show a small (0.3–0.4%) modal shift away from car use, but most of the apparent behavioural shift was seen from public transport, walking or private bike use to BSS (Fuller et al., 2013). Modal share for bike use overall was around 1% in the USA (Pucher et al., 2010), but higher in urban environments where BSS exist (around 3% in Dublin or Montreal). However, the proportion of these cycle trips attributable to BSS usage is not reported, but is likely to be a small fraction of total cycling trips (Ricci, 2015; Damant-Sirois and El-Geneidy, 2015). Other data from high volume BS communities, suggest up to 0.9% of trips are made by bike share users (Lyon, Paris; cited in Basarić et al., 2012).

5.2. A framework for characterising population cycling change due to BSS

A key question is how much BSS could contribute to population levels of physical activity. This is shown schematically in Fig. 1, but data are estimates, as no specific studies have provided information for all components of this conceptual model. In many developed countries, around 40–50% of adult populations are 'sufficiently active for health', meeting the WHO minimum recommendation of at least 150 min of moderate-vigorous physical activity per week (WHO, 2010). There are variable estimates of the proportion of the population that cycle in a given week, ranging 5–50%, but an estimate of 10% in this figure may be realistic. Of these, the majority will reach the physical activity guideline (PAG), shown as two-thirds of all cyclists in the figure. In other words, any additional cycling will most benefit the health of the one-third (3.3% of the population) that already cycle, but do not meet the PAG threshold.

The most difficult estimate is what proportion of the whole adult population are ever BSS users. This has been estimated in very few studies. One estimate in Montreal suggests that as many as 8–11% of inhabitants of central Montreal used the BSS at least once in a year (Fuller et al., 2011). Other population estimates are not reported in the literature, and most BSS programs are in central districts, accessible by many, but appear to be used by some thousands (at most), rather than hundreds of thousands of individuals. Hence, in the figure, a high-end estimate of up to 1% of the whole population might use a typical BSS, of which perhaps two-thirds will already be active from other cycling or other PA, and one third would be below the PA threshold (0.33%); of these below the threshold, half will own a private bicycle, and the remainder will not own their own bicycle and only use the BSS occasionally (0.16%), with both of these groups not meeting PAGs. In summary, if every BSS user who did not meet PAGs increased activity through BS usage, the prevalence of meeting PAGs would increase potentially by up to 0.33%; conversely, if all low volume cyclists increased their cycling, then the prevalence of meeting PAGs would be 3.3%, or up to ten-fold greater, suggesting that greater population health change in meeting PAGs results from increasing cycling overall, rather than from increasing BSS. The figure indicates the information needed on BSS users and non-users, both on total PA, other cycling and on BSS usage, in order to estimate the potential public health impact of BSS.

6. Illustrative data analyses

The kinds of data and evaluation research needed to assess BSS effects can be characterised as:

(i) Studies that provide trend data on bike share usage data (from service providers).

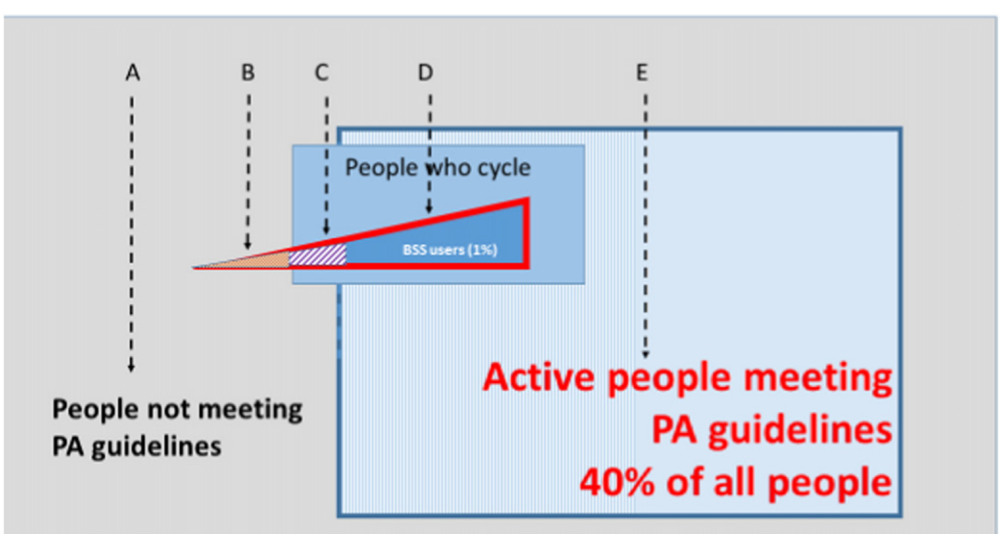


Fig. 1. A conceptual estimation of the potential impact of bike share schemes (BSS) on population level physical activity. Legend and explanation E [rectangle] is an estimate of all adults meeting physical activity (PA) guidelines [40%] D [solid filled rectangle] are all people who cycle, estimate of 10% of population; two thirds of whom also meet PA guidelines C [red triangle] represents all the users of a BSS, with an upper limit estimate of 1% of the total population. Sub group of BSS users: -two-thirds of BSS users also cycle, and meet PA guidelines [solid fill]. -approximately 16% BSS users are BSS users are also cyclists, but not meeting PA guidelines -another 16% of BSS users are casual users [don't have a private bike]; do not meet PAG [labelled 'B'] A [full box] in general 50–60% of a population may be inactive (not meeting physical activity minimum recommendations).

(ii) Population data on cycling prevalence and meeting PA guidelines (from representative surveys or Census data).
(iii) Bicycle volumes indicating usage counts over time (from counts or spatial GIS data).

As illustrative examples of the kinds of analysis that can inform BSS research, we provide examples of [ii] and [iii] above. The optimal method, using representative before and after population-representative surveys as a natural experiment requires substantial planning and resources, but has been reported for Montreal (Fuller et al., 2013). The two examples described below illustrate useful methods with public access data. Example 1 tracks changes in underlying cycling over time and the proportional increase in regions exposed to BSS can provide some evidence of the impact of bike share on population physical activity. We used Australian Census data that asked about "commuting to work" mode. In some instances, bicycle volume data, collected either using electronic count measures or observation counts can provide a proxy measure of overall cycling participation, but still does not identify population rates. This is used in Example 2.

Example 1. Using census data on trip mode.

In this example, we used population data on cycling for trips to work or study and for recreation in the Australian population and compared the growth in cycling across capital cities where a BSS has been introduced with those with no BSS (Fig. 2); this creates a quasi-experimental evaluation of the effects of BSS introduction. Using survey data on the main transport mode from 2006 to 2012 (ABS Australian Census data), we compared the average proportion of trips made by bicycle to work or study across all Australian capital cities compared with trips made by bicycle in Melbourne and Brisbane, both of which introduced BSS in 2010. Between 2009 and 2012 surveys, the share of cycling in Melbourne increased by 43% while the average rate of increase over the period in Australia was 6.3%. Brisbane showed no variation from the average rate of growth.

Focusing on the Melbourne BSS and using Census data available through the Victorian Department of Transport Statistics Portal (2016) from 1996 to 2011, we compared the aggregated change in cycling in the local geographic area of the city centre where the BSS was introduced with cycling changes in the surrounding suburbs (Fig. 3). In this example we compared the inner city suburbs of Yarra and Port Phillip which at the time of the Census did not have BSS stations. Fig. 3 illustrates the increase in trips made by bicycle to the city centre of Melbourne compared with trips made to other local areas. This graph indicates the extent of the growth in cycling to the city centre over the period and suggests that cycling norms increased steeply and far more quickly in Central Melbourne than anywhere else in the city, but started several years before (and unrelated to) the BSS.

Example 2. Modelling of bicycle volume data and background cycling.

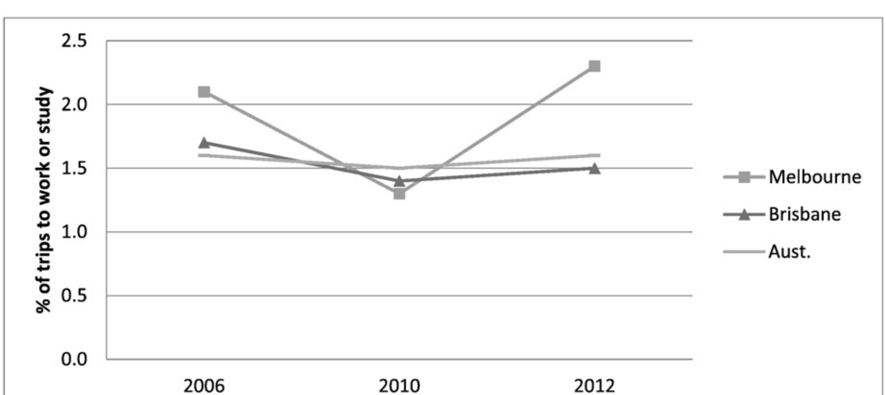
In this example, we model bicycle volume data to further explore the potential effects of the Melbourne BSS.

The Victoria State Government provide a dataset of bicycle volumes from 43 locations within the greater Melbourne area, spanning from 13 May 2005 to 21 January 2013. Bike count locations were added and retired throughout this period, so data is available for different periods in different locations. Volumes are reported daily, with counts available for the full 24 h period, 7 am to 7 pm, 12 pm to 4 pm ("off peak"), and the peak morning and evening hour. Data completeness is very good, with almost daily counts available for most locations. However, there are longer intervals where no data collected. This data is not missing at random, and could bias results if "missingness" patterns are not carefully considered.

Using Poisson regression, we compared inner city and outer suburb 24 h cycling counts (using STATA version 13.1. StataCorp, 2013). This is a quasi-experiment, with cycling volumes, objectively assessed, before and after the introduction of the BSS. Bicycle counters within the city centre ("Melbourne CBD"), and within proximity to docking stations, were compared with bicycle counters from outer areas of the city ("Outskirts"). We adjusted for seasonal, off-peak, and week-day variations were trialled, but results changed very little, so unadjusted estimates are reported. Because we were interested in commuting, analysis was restricted to weekday counts. We used locations with data from 1 Jan 2006 to 31 Dec 2011, however there were periods of missing data within these 6 years (see Table 1).

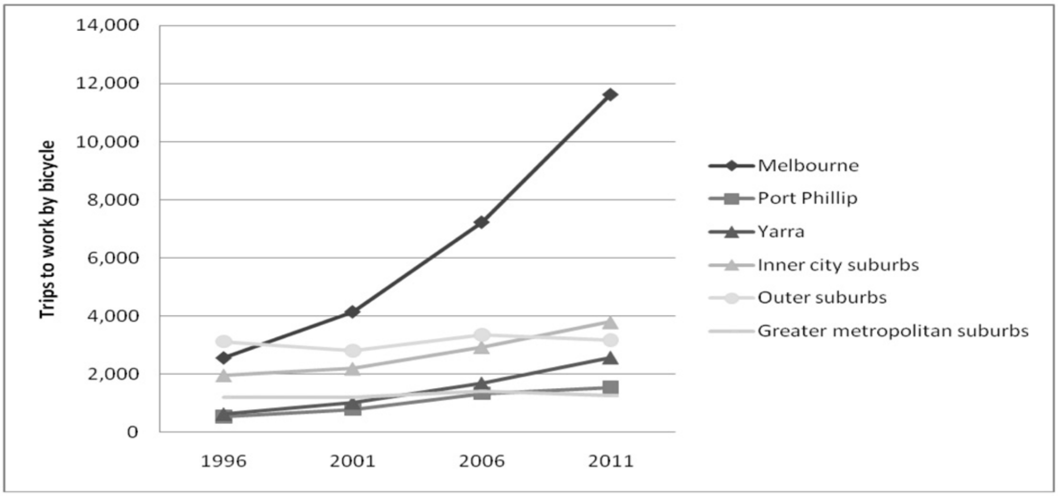
We hypothesised that if there was an effect of the BSS on cycling volume, we would expect to see a positive change in the relative increase in Melbourne city centre cycling volume, compared to cycling volume in the city outskirts after the BSS introduction in 2010. Year was fitted as a nominal categorical variable, with 2006 as the baseline. Interaction terms for year and location are sought for significance, and are included in the model to adjust for different yearly changes across locations. The results show no meaningful change in the interaction terms for 2008 through to 2011, and none are significant. The increase in cycling volume is faster in central Melbourne locations across the whole period (but not significantly so), but does not accelerate after the introduction of the Melbourne BSS.

A limitation of this analysis is the bias introduced by missing data, as two of the three locations in the Melbourne group had downwardly biased volume estimates in 2011 (due to missing data in high volume months), biasing the results towards showing no difference (data not shown). In these quasi-experiments, it is important to analyse



Vic- **Victoria (city of Melbourne BSS); Qld – Queensland (city of Brisbane BSS); Aust** – national data

Fig. 2. Comparison of cities with bike share schemes in Australia (Melbourne and Brisbane) with the rest of the country using journey to work data (2006–2012).



*BSS initiating in the city centre in Melbourne LGA in 2010, (BSS in Port Phillip and Yarra LGAs was not operational until 2014/2015)

Fig. 3. Comparison of journeys made to work by bicycle across Melbourne local government areas (LGAs) from 1996 to 2011).

comparable groups, and correct for meaningful differences in confounding variables. The potential confounders we had made little difference to results. Additional data, such as weather and traffic records, could be sourced and combined for a richer dataset yet were not included in the present analysis.

Non-independence of repeated measurements at each location and mild model misspecification were corrected for by using location as a cluster variable, and robust variance estimators. Mixed modelling could be explored as another way to correct for repeated measurements, however the limited number of clusters may be an issue.

6.1. Lessons from illustrative analyses

While these analyses illustrate the potential effect of bike share on cycling and physical activity, the ability to attribute changes in cycling to bike share is limited by the lack of or incomplete data. These are generalizable challenges to any evaluation of the effects of BSS. Functional volume data, complete operational BBS data and longitudinal population surveys are needed to allow more specific analysis of bicycle share data and clearer attribution of the effects to BSS. An evaluation framework for future investigation of the health effects of BSS will require good quality data from these three kinds of questions, and ideally use publically available data sources. Although there may be potential for BSS to contribute to physical activity, yet at present it may not be realised or may not be able to be measured.

Table 1
Estimated multiplicative increases (MI) in cycle counts in Melbourne Australia, by year and location group.

		MI	(SE)
Year	2006 (Ref)	1.00	
	2007	1.09	(0.05)
	2008	1.15	(0.10)
	2009	1.31	(0.11)**
	2010 [BS introduced]	1.29	(0.13)*
	2011	1.34	(0.15)*
Location group	Melbourne CBD	1.42	(0.41)
	Outskirts (Ref)	1.00	
Year * location group (interaction)	2007 * Melbourne CBD	1.02	(0.05)
	2008 * Melbourne CBD	1.10	(0.11)
	2009 * Melbourne CBD	1.12	(0.10)
	2010 * Melbourne CBD	1.11	(0.11)
	2011 * Melbourne CBD	1.07	(0.13)

Note: SE = Standard error.
* $p < 0.05$.
** $p < 0.01$.

7. Conclusions

The proliferation of BSS has occurred in many cities since 2010, with programs of various sizes introduced into urban centres. These programs aim to increase public transport, reduce traffic and improve air quality. The most important health goal is to increase population levels of cycling, thereby contributing to increased proportions of the population meeting physical activity guidelines and improve population health. Many studies have examined the logistics of BSS, modelled the flow of bicycles, and examined the characteristics of, and trends in usage. BSS users tend to be younger, male, and live close to BSS stations. It is likely that many BSS users are already physically active, and use BSS for utilitarian trips, and for additional physical activity.

The limitations of BSS evaluations preclude evidence of their population impact on physical activity. Studies have focused on trip outcomes, in limited central urban regions, and seldom considered whole population reach and uptake of BSS. Better data systems are required to evaluate the impact of BSS, including the process evaluation, bike flows and usage rates, but also the impact on underlying population cycling behaviour and physical activity levels (Ricci, 2015). A recent systematic review concluded that "no single bike share program of sufficient scale has been fully and independently evaluated", creating patchy evidence around their health impact (Ricci, 2015). Despite their media-portrayals and popularity, there is a lack of attributable benefit directly to BSS, although there is some evidence of increases in overall cycling, as part of the bicycle renaissance since 2000 (Pucher et al., 2011), which has resulted in many more (private) bicycles, and an emphasis in some communities on improving cycling infrastructure and bicycle facilities. Of nine case study cities reviewed to demonstrate best practice in fostering the "bicycle renaissance", only four had a BSS (Pucher et al., 2011). Whether BSS are sufficient to explain the overall increases in bicycle commuting has been questioned (Ravalet and Bussière, 2012). They may be part of the solution, but only where cycling volumes are low, cities are bicycle friendly, or are retrofitted to have cycling infrastructure, and in those settings where BSS are introduced on a large scale (such as Lyon, Lille and possibly Paris; Ravalet and Bussière, 2012).

In some settings, BS and cycling promotional efforts are trying to redress substantial declines in cycling and increases in car use. For example, in Hangzhou, the decade following 1997 noted a decline in bicycle mode share of trips from 64 to 34%. This led to the development of the large-scale Hangzhou BSS. Among Hangzhou BSS users, a third used the scheme regularly. Nonetheless, these BSS in China are substantially smaller than the mode shift away from cycling, and only produce small redistributions towards bicycle use. Further increases in BSS may be difficult, given funding restrictions, urban geography and road construction favouring car use (Yang et al., 2015).

In conclusion, BSS may make a contribution to broader strategies to increase urban cycling and total physical activity. There is the possibility of 'bike share programs showing some social contagion, spreading within social groups to increase their use' (Schoner et al., 2016), but to an insufficient degree and only in a small area, making population-level effects unlikely. Nonetheless, BSS could contribute towards the development of a pro-cycling culture in specific cities, and to changing attitudes towards cyclists, which is part of an overall cycling development strategy. To achieve sufficient participation for population change, BSS need to be scaled up, supported by urban cycling infrastructure developments, marketing of facilities, and concurrent encouragement of private bicycle use. Evaluations should consider measurement at the population level to detect these effects. In addition, evaluations should consider the economic benefits of BSS, which could reduce car use costs and transit time (Ricci, 2015). As part of the overall increase in cycling-related active travel, BSS could have a role to play.

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