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Evaluation of the Veloway 1:

A natural experiment of new bicycle infrastructure in Brisbane, Australia

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Abstract

Bicycle infrastructure is being constructed in Australia to encourage safer and faster cycling trips. However, there has been limited evaluation of the impact of infrastructure investments. This study examined the behavioural impact of a new segment of a dedicated bikeway (Veloway 1 [V1] Stage C) that links southern suburbs with Brisbane city centre. The V1 Stage C opened in June, 2013. Cyclists who used a pre-existing shared path that links southern suburbs with the city centre completed an intercept survey pre- and post-V1 Stage C opening. Cyclists who used the V1 Stage C after it opened completed the same survey at the same time post-V1 Stage C opening. Survey data were complemented by GPS bicycle count data from cyclists riding on the main cycle routes into the city centre from southern suburbs: the V1 Stage C, the pre-existing shared path and a major arterial road. Survey data showed that pre- to post-V1 Stage C opening, average bicycle trip distance of cyclists using the shared path decreased ($p=0.002$), and the main catchment area of that path narrowed to suburbs to the west of it ($p<0.001$). Compared to cyclists using the shared path post-V1 Stage C opening, those using the V1 were travelling longer distances ($p=0.02$) and were more committed to making their trip by bicycle ($p=0.001$). The GPS bicycle counts increased monthly on the V1 Stage C after it opened ($p<0.002$). GPS bicycle counts on the alternative routes did not change ($p=0.84$). There were greater increases in monthly counts of cyclists approaching Brisbane from the south post-V1 Stage C opening than pre-opening. The findings suggest that veloways like the V1 can attract cyclists travelling from outer suburbs into a city centre.

Keywords: active travel; bicycle; physical activity; evaluation; built environment; GPS

1. Introduction

Growing evidence supports the health, social and environmental benefits of transport cycling (cycling to get to and from places) and active transport more generally (Lindsay et al., 2011; Oja et al., 2011; Rojas-Rueda et al., 2011). At least half of the health benefits of active transport are due to increases in physical activity (Mueller et al., 2015), for which the cardiovascular and other chronic disease benefits are well established (Blair and Morris, 2009; Shiroma and Lee, 2010; Warburton et al., 2006). Recent evidence suggests that the health benefits gained from increasing levels of physical activity through increasing the number of people using active modes of transport far outweigh the health risks from increases in traffic accidents (Mueller et al., 2015). The evidence also indicates that the air pollution exposure is likely to have a small health impact, at the population and individual traveller levels (Mueller et al., 2015). Overall, an Australian study suggests that just a 3% increase in the number of people meeting physical activity guidelines by using active modes of transport can result in lifetime savings to the health sector \$AU1.5 million (Beavis and Moodie, 2014).

In Australia transport cycling rates have remained low: between the 2006 and 2011 censuses, the proportion of people who travelled by bicyle to work increased from 1.24% to 1.29% (Australian Bicycle Council 2013). In response, state governments have developed supportive cycling policies and strategies. These policies and strategies address environmental and individual-level correlates of cycling, in keeping with ecological models of health-related behaviour change (Sallis et al., 2006). At the national level, a key environmental strategy described within the 2011-2016 National Cycling Strategy is the provision of cycling infrastructure (Ausroads Ltd., 2010). The Organisation for Economic Co-operation and Development (OECD/International Transport Forum, 2013) reports that such investment in infrastructure is critical for providing safe cycling so that increases in cycling do not increase the number of cyclist crashes. In 2013-2014, \$AU111.2 million, or

$AU4.74 per head of population, was spent by state and territory governments for cycling infrastructure, mostly for off-road bike paths (Australian Bicycle Council, 2015). The State of Queensland, with a Cycling Infrastructure Policy requiring that new transport infrastructure include off-road bike paths and on-road bike lanes (Queensland Government Department of Transport and Main Roads, 2013), spent $AU6.14 per head of population over this time period, more than any of the seven other states and territories except the Australian Capital Territory (Australian Bicycle Council, 2015).

Evaluation of the impact of cycling infrastructure on cycling behaviour is limited in Queensland and elsewhere in Australia due to high costs and methodological complexities associated with such evaluations. Controlled trials are not typically feasible. Therefore, natural experiments and quasi-experimental designs are being used to inform policy. To date, few such evaluations have been conducted, and the results show small to moderate increases in cycling. Results from three US studies (Krizek et al., 2009; Mayne et al., 2015; Parker et al., 2011; Parker et al., 2013) showed that the introduction of cycling infrastructure in urban areas, either off-road cycle paths or on-road cycle lanes, significantly increased cycling rates. In contrast, another US study found that the introduction of a multiuse trail did not increase cycling among residents living near the trail (Burbidge and Goulias, 2009). In an evaluation of new walking and cycling infrastructure provision in three cities in the UK, small increases in the proportion of residents living near the infrastructure who cycled were noted pre- to post-infrastructure introduction (Goodman et al. 2013; Goodman et al., 2014). In Australia, counts of Sydney cyclists who used a bicyle and walking corridor increased significantly with the construction of a bikeway on the corridor and the promotion of the bikeway through an awareness campaign, although pre- to post-opening of the bikeway, self-reported cycling levels did not change significantly among residents living near the trail (Merom et al. 2003), likely reflecting the low number of people who reported to cycle.

Further evaluation of infrastructure is critical to add to the evidence base and to inform policy. The aim of this study was to examine the impact of a new segment of bikeway in Brisbane, Australia on cycling behaviour. Data collected from intercept surveys and bicycle counts from a GPS tracking system were triangulated to assess whether the new cycling infrastructure (Veloway 1 [V1] Stage C) changed cycling behaviour and in whom. The study sought to answer three questions. First, to understand the type of cyclists the V1 Stage C attracted, the first question was, which cyclists choose to use or not use the V1 Stage C? The other two questions were, did the V1 Stage C opening (the 'intervention') encourage cyclists away from other, less safe routes for cycling into the city centre, and did the intervention increase the number of cyclists who approach the Brisbane city centre from the south?

Before the intervention, cyclists had two main options for traveling toward the Brisbane city centre from the south (see Figure 1). One was travel on Logan Road, a major arterial road from the southern suburbs into inner suburbs of Brisbane. The road varies from four to six lanes with multiple driveway entry/exits, parking on the roadside and no dedicated or segregated infrastructure or lane markings for bicycles. The other option was the South East Freeway Bikeway (SEFB), a designated shared use off-road path that runs parallel to the South East Freeway on the western side as it approaches the city centre from the south. Most of the path is concrete, of older, inconsistent design and materials, and narrow in key sections. Although primarily an off-road exclusive bikeway, the SEFB has sections of path shared with pedestrians and sections of on-road Bicycle Awareness Zones on local streets. At the northern end, it links with a bike path heading towards the city centre. We hypothesised that cyclists who had been using these other routes into the city centre would shift to using the safer and faster V1 Stage C after it opened. We further hypothesised that the new bikeway would attract a greater diversity of cyclists than the SEFB had. For example, we anticipated that a higher proportion of cyclists using the new bikeway would be women compared with the proportion using the SEFB.

[INSERT FIGURE 1 ABOUT HERE]

The V1 is a dedicated 17-km long, 3-metre wide exclusive off-road bikeway. Roughly paralleling the South East Freeway, the V1 was intended to provide a safe bicycle commute into the city from southern suburbs (see Figure 1). The V1 has been delivered in stages with Stage A (about 1.4 km) completed in July, 2010, and Stage B (about 900 m) completed in May, 2011. Completion of these stages extended existing V1 bikeway infrastructure farther south. Stage C (about 2.3 km) is 7 km north of these earlier improvements via the existing V1 infrastructure. It opened June 25, 2013 to extend the V1 farther north towards the city centre. We hypothesised that the opening of Stage C, the latest intervention, would increase the number of cyclists travelling from the southern suburbs into the city centre, as it would provide a much safer and faster route than previously available, but that the increase would be incremental over the following months as there was minimal publicity given to its opening.

2. Methods

2.1. Data sources

Data sources for these analyses were field observations, de-identified intercept surveys and GPS tracking data provided by Queensland Department of Transport and Main Roads (TMR). Figure 2 shows a timeline of the data collection. The Queensland University of Technology Human Research Ethics Committee assessed this research as meeting the conditions for exemption from Human Research Ethics Committee review and approval in accordance with section 5.1.22 of the National Statement on Ethical Conduct in Human Research (2007).

[INSERT FIGURE 2 ABOUT HERE]

2.1.1 Field observations and intercept surveys

Griffith University students conducted field observations and intercept surveys on Thursday, August 20, 2009, 6:00 am–9:00 am, on the SEFB near the northern end (see Figure 1). This data collection occurred prior to completion of Stages A, B and C of the V1. Data collected from 136 cyclists between 6:00 am–8:30 am were used in these analyses for consistency with data collected post-intervention in 2013. In 2013, Queensland University of Technology students conducted similar field observations and intercept surveys on both the SEFB and V1. Data were collected from 301 cyclists on Wednesday, September 18, 2013, 6:00 am–8:30 am. Bike counts from automatic traffic monitoring stations in Brisbane show no seasonal differences in bicycle travel patterns between the months of August and September or between Wednesdays and Thursday for morning peak bicycle travel (data not shown). Procedures were developed and refined as previously outlined by Burke (2010). Advanced warning signage was positioned on the approach to signify safe intercept locations, and students wore high visibility vests. Students were supervised by a TMR project officer and colleagues from Brisbane City Council.

Field observations captured transport mode (cyclist or pedestrian), age, gender and trip composition of cyclists (alone; group of ≥2 cyclists). Cyclists were asked to complete intercept surveys, which were kept brief as participants were surveyed in process of making a trip. It is standard to keep intercept surveys brief for this reason. Cyclists were asked about their commitment to cycling (would they cycle or use another transport mode for the current trip if the cycling path being used were temporary closed; asked in 2013 only) and characteristics of the cycle trip (origin, destination). In 2013 cyclists surveyed on the V1 were additionally asked to report the transport mode for the current journey they used prior to the intervention, and cyclists surveyed on the SEFB were asked whether they were aware of the V1 (yes, no).

For each survey, the distance between origin and destination was calculated as the sum of the distances from the origin to the closest intercept point, the length of the respective bikeway, and the distance from the closest intercept point to the destination. The multi-mode road network of Brisbane was used for these computations. The centroid of the origin and destination suburb for each trip was projected to their nearest road segment, and the shortest path between them via the bikeway was calculated in order to compute the distance between the origin and destination point.

2.1.2 GPS bicycle counts

TMR commissioned Strava Inc. (San Francisco, CA) to provide GPS tracking information on cycle routes and volumes in the area surrounding the V1 from 1 January to 31 December, 2013. GPS tracking data were collected from cyclists who used the mobile phone application ‘Strava’. Strava collects raw GPS data on date, time and trip route of bicycle trips of its users and aggregates them with its Strava Metro product. This study used aggregated data that Strava provided TMR for four locations: on the V1 Stage C, the SEFB, inbound on Logan Road and outbound on Logan Road (see Figure 3). From these data, monthly bicycle counts were calculated for each location for each month of 2013.

[INSERT FIGURE 3 ABOUT HERE]

Strava also provided TMR with aggregated data on age, gender and trip purpose of Queensland Strava users. A preliminary analysis by TMR of Strava data showed that although only 10% of Brisbane cyclists were Strava users, the age and usage profile of Strava cyclists are typical of those of the adult cycling population across the Brisbane metropolitan area, although uptake by women was low (Munro, 2013). The analysis also showed that trip purpose for Strava cyclists was 68% for recreation and 32% for transport, which was similar to the proportions of cycle trips for recreation (73%) and transport (27%) in the broader Queensland cycling population (Munro, 2013).

2.2. Statistical analysis

Analyses to address the three research questions were conducted with STATA 13.0 (Stata Corporation, College Station, Texas). Table 1 overviews the data sources and analyses conducted to address each question.

[INSERT TABLE 1 ABOUT HERE]

2.2.1. Which cyclists chose to use or not use the V1?

The first step to address this question was to compare cyclists intercepted on the SEFB pre-intervention (before the V1 Stage C opened) in 2009 to those intercepted on it in post-intervention in 2013. Comparisons were made using tests of proportions for gender, riding composition (alone; group of ≥2 cyclists), and trip origin (Western suburbs, the main catchment for the SEFB; other suburbs), and the Mann-Whitney rank-sum test for trip distance (km). All intercepted cyclists were adults except one child on the SEFB in 2013, who was excluded from analysis.

Next, cyclists intercepted on the SEFB and V1 Stage C post-intervention were compared in fixed effects logistic regression modelling (Stata function xtlogit). Akaike's and Bayesian information criteria indicated that this modelling was a better fit to the data than were random effects or simple logistic models. Cyclists were nested within suburbs from which they originated to account for differences across suburbs, most notably in access to the SEFB and V1 Stage C. Given the large number of suburbs of origin (n=56) with most having <10 cyclists originating from them, the suburb variable was collapsed to represent four larger geographic regions from which cyclists travelled. The outcome variable was bike path used (SEFB or V1 Stage C). Predictor variables were gender, riding composition, trip destination (north towards city centre, which was the main destination; other suburbs), trip distance (km) and commitment to cycling. Cyclists who were intercepted on the SEFB and reported that they were unaware of the V1 (n=26) were excluded. First, univariate models with one predictor per model were computed and then all predictor variables were included in a multivariable model. Significance was set at p<0.05.

2.2.2. Did the V1 Stage C opening encourage cyclists away from other, less safe routes for cycling into the city centre?

To understand whether the intervention encouraged cyclists away from cycling on the SEFB or from the nearest arterial road, Logan Road (see Figure 1), changes in monthly bicycle counts, as recorded by Strava, were examined with a multiple-group interrupted time series model. This model is used to observe an outcome over equally-spaced time periods before and after the introduction of an intervention, to test whether the intervention "interrupted" trends over time in the outcome in intervention and control groups (Linden, 2015). For this analysis, bicycle counts recorded monthly served as the outcome. For months longer or shorter than 30 days, 30-day counts were calculated (e.g., for 31-day months: 30-day count=(monthly count/31)*30). Counts recorded from January to June, 2013, were pre-intervention outcomes and counts from July to December, 2013 were post-intervention outcomes. The opening of the V1 Stage C in June 25, 2013 was the intervention. "Controls" were the SEFB and Logan Road. Coefficients are estimated by OLS regression, and Newey-West standard errors are used to address auto-correlation and heteroscedasticity (Linden, 2015). The aggregation of the data over a month provided sufficient trip volumes and averaged out events, such as inclement weather and path disruptions. Seasonal effects served as a confounder.

2.2.3. Did the V1 increase the number of cyclists who approached the city centre from the south?

A single-group interrupted time series model was used for this analysis. As in the previous analysis, 30-day bicycle counts recorded from January to June, 2013, were pre-intervention outcomes and 30-day bicycle counts from July to December, 2013 were post-intervention outcomes. In this modelling, the count data from the V1 Stage C, SEFB and Logan Road were combined to test whether the trends in total counts of cyclists travelling between southern suburbs and the city centre (e.g., on any of the three routes) changed pre- to post-intervention. These data were cross-referenced with a survey question that asked cyclists intercepted on the V1 in 2013 about their mode of transport to their current destination before the V1 Stage C opened (bicycle, drive a car, car passenger, motorbike, bus, train, walk, other).

3. Results

Of the 136 adult cyclists observed on the SEFB pre-intervention in 2009, 13.5% were women (missing data from three) and 96.2% (missing data from four) were riding alone. Most (n=132; 97.1%) completed the survey. Post-intervention in 2013, 301 adult cyclists were observed on the SEFB. Gender and riding composition data were missing from three of the cyclists. Of the remaining cyclists, 23.2% were women and 94.0% were riding alone. In total, 100 (33.2%) cyclists completed the survey. Last, 211 cyclists were observed on the V1 Stage C in 2013; 15.6% were women and 86.3% were riding alone. Of these cyclists, 169 (80.1%) completed the survey. There were no significant differences in gender or riding composition between cyclists who completed the survey and those who did not, for any survey ($p>0.05$).

3.1. Characteristics of cyclists on the SEFB pre- and post-V1 Stage C opening

Some characteristics of cyclists intercept on the SEFB changed pre- to post-intervention (Table 2). The proportion of cyclists who were women increased but not significantly (13.6% [95%CI 7.8%, 19.5%] to 20.2% [95%CI 12.3%, 28.1%]; $p=0.18$). Few cyclists rode in groups at either time period (3.8% [95%CI 0.5%, 7.0%] to 4.0% [95%CI 0.2%, 7.9%]; $p=0.92$). The proportion of cyclists originating from suburbs to the west of the SEFB increased substantially (42.4% [95%CI 34.0%, 50.9%] to 72.7% [95%CI 64.0%, 81.5%]; $p<0.001$). The proportion who completed their trip at a location north of the SEFB (towards the city centre) decreased significantly (96.2% [95% CI 93.0%, 99.5%] to 84.8% [95% CI 77.8%, 91.9%]; $p=0.002$). Trip distance decreased from 11.8 km (IQR 10.2, 15.6) to 10.3 (IQR 9.9, 13.4; $z=3.05$, $p=0.002$). In summary, more cyclists using the SEFB during morning peak post-intervention than pre-intervention were originating from points west of the SEFB and V1, and fewer were traveling to the city centre. On average, they were not travelling as far.

[INSERT TABLE 2 ABOUT HERE]

3.2. Characteristics of cyclists on the SEFB and V1 post-V1 Stage C opening

Table 2 provides the characteristics of cyclists who were observed on the SEFB and V1 Stage C post-intervention and characteristics of their cycling trips. The proportion of cyclists who were women was slightly higher on the SEFB than on the V1 Stage C. This difference was not statistically significant (see Table 3). The proportion of cyclists who rode in groups on the V1 was over twice the proportion who rode in groups on the SEFB, but this difference was not statistically significant. The main catchment area of the SEFB was the western suburbs whereas the main catchment area of the V1 Stage C was the southern suburbs (see Table 2). The proportions of cyclists originating from eastern or northern suburbs were much higher for the V1 Stage C than for the SEFB. Significance testing was not conducted for trip origin as this variable was used as the clustering variable. High proportions of cyclists on both paths reported that they would continue to cycle if their preferred path were closed temporarily, but cyclists on the V1 Stage C were more likely then cyclists on the SEFB to report this commitment to cycling (see Table 3). Most of those who reported that they would use alternative transport modes if their respective path were closed temporarily reported that they would travel by car or public transport. Average trip distance was significantly longer for the V1 Stage C than for the SEFB. In short, cyclists on the V1 Stage C differed from those on the SEFB in their trip origin, in being more likely to cycle to their destination if their path were closed temporally, and in their trip being a longer distance. The catchment area for the V1 Stage C was also much larger than the one for the SEFB.

[INSERT TABLE 3 APPROXIMATELY HERE]

3.3. Movement of cyclists away from Logan Road and the SEF) onto the V1 Stage C

Strava counted 1041 bicycles on the V1 Stage C in July 2013, the month following the intervention. Counts were higher for the next 5 months than in July. Counts were highest in October (n=1874) and November (n=1856), which are peak cycling months in Brisbane according to data from automatic traffic monitoring stations positioned across the city, before decreasing in December (n=1548), the month when cycling numbers are usually at their lowest (followed by June). Adjustments were made in the modelling for such seasonal effects.

The analysis showed a significant time by group by intervention effect ($p=0.001$), meaning that the trend in bicycle counts changed significantly more pre- to post-intervention for the V1 Stage C than for Logan Road and the SEFB (see Figure 4). Post-intervention (after the V1 Stage C opened), bicycle counts increased monthly by an average of 213 on the V1 Stage C (95%CI 81, 346; $p<0.002$). An average decrease of 12 bicycle counts per month on the SEFB and Logan Road post-intervention was not significant (95% CI -102, 79; $p=0.79$). However, the 225 count difference in monthly increases between the V1 and monthly decreases on the SEFB and Logan Road post-intervention was significant (95%CI 78, 372, $p=0.004$). To verify that these findings held true for both the SEFB and Logan Road, comparisons between trends in counts between the V1 Stage C and SEFB were examined and then in a separate model, between the V1 Stage C and Logan Road. In these models, significant time by group by intervention effects were again observed ($p\leq0.01$) and increases in counts post-intervention on the V1 Stage C were significantly different from small, non-significant decreases on the control paths ($p=0.001$) as in the original modelling.

[INSERT FIGURE 4 APPROXIMATELY HERE]

Post-hoc, single-group interrupted time series models for the SEFB and Logan Road were run separately to better understand trends in monthly bicycle counts pre- to post-intervention on the alternative routes into the city centre. Pre-intervention, the modelling indicated an increase of 66 bicycle counts per month on average on the SEFB (95%CI 55, 77; $p=0.001$), and a time by intervention effect ($p<0.001$) resulting in a decrease of 92 bicycle counts per month on average post-intervention (95%CI -128, -57; $p=0.001$). Inbound on Logan Road there was no significant monthly change in bicycle counts ($\beta=15$; 95%CI -8, 38; $p=0.16$) pre-intervention and no time by intervention effect ($p=0.54$), which indicated that this trend did not change due to the intervention. Outbound on Logan Road, there was also no significant change in monthly bicycle counts pre-intervention (β=7, 95%CI -32, 46, p=0.68) and no time by intervention effect (p=0.43).

3.4. Increases in cycling from the south

The modelling showed a significant average increase of 88 bicycle counts per month (95%CI 35, 142; p=0.007) pre-intervention on the SEFB and Logan Road (before the V1 Stage C opened) and a significant time by intervention effect (p=0.04), meaning that the trend in bicycle counts changed significantly at the time of the intervention (Figure 5). Dips in counts were seen in June and December after the V1 Stage C opened, as seen in earlier modelling. Adjustments were made in the modelling for such season effects. Post-intervention, an average increase of 178 bicycle counts (95%CI 124, 232; p=0.0002) per month was observed. Therefore, across the major routes into the city centre from the south, there was a monthly doubling of bicycle counts (from 88 to 178 counts) pre- to post-intervention. Increases in cycling were also suggested by the survey data but not to the same extent. Of the 169 cyclists intercepted on the V1 Stage C post-intervention, 10% reported that they were not cycling before the V1 Stage C opened, in order to make the current trip.

[INSERT FIGURE 5 APPROXIMATELY HERE]

4. Discussion

This study evaluated whether an intervention, the opening of a new segment of a veloway (V1) from Brisbane's southern suburbs into the city centre, changed cycling behaviour and the diversity of people who cycle from these suburbs. Overall, the findings suggest some shifting of cyclists from another route into the city centre, some increases in cycling from the southern suburbs into the city centre, but little change in the diversity of people choosing to cycle from southern suburbs into the city centre.

We hypothesised that the V1 would attract a greater diversity of people to cycling. However, cyclists intercepted on the V1 Stage C were almost exclusively adults, and most were men. These characteristics reflect commuter cyclists more generally in Brisbane and Queensland (Munro, 2013; Sahlqvist and Heesch, 2012). This finding suggests that the V1 Stage C did not broaden the appeal of cycling to those groups less likely to cycle. Namely, its opening did not significantly increase the number of women cycling into the city centre. Consistent with findings from Melbourne and other low-cycling regions (Bopp et al., 2012; Garrard et al., 2006; Garrard et al., 2008; Gatersleben and Appleton, 2007; Jakicic et al., 1999; Krizek et al., 2005; Pucher and Buehler, 2008; Twaddle et al., 2010), few women were observed cycling during the morning commuter peak time on either the V1 Stage C or the older cycling infrastructure. It has previously been suggested (Heesch et al., 2012) that the focus in major Australian urban areas of investing in bicycle infrastructure, like the V1, which supports long cycle trips from outer suburbs into city centres, may not appeal to women, who are more likely to take shorter trips by bicycle. Evidence from the US (Krizek et al., 2005) and Japan (Japan Ministry of Land, 2008) indicate that women are more likely than men to cycle for transport to non-commute destinations, and therefore, a lack of infrastructure supporting short, safe cycle trips to destinations like nearby shops may be constraining women's cycling.

Given that the V1 was built to allow for long cycle trips, it is not surprising that cyclists attracted to the V1 Stage C were those travelling longer distances than those on the SEFB and those highly committed to cycling. Commitment was determined by asking cyclists whether they would continue to cycle to their destination if their path were temporarily closed, and almost all cyclists intercepted on the V1 Stage C (92%) agreed that they would continue to cycle. This finding could reflect that these cyclists were aware of cycle routes into the city centre as they may have used them before the V1 Stage C opened but also could reflect that only the most dedicated long distance cyclists were using this bike path.

After the V1 Stage C opened, the SEFB catchment decreased to be predominately the nearby suburbs to the west of the SEFB. With multiple entry points from the west along the length of the SEFB, it is not surprising that cyclists living in the western suburbs would select that path over the V1 Stage C. In contrast, the catchment areas for the V1 Stage C included suburbs due south, east and north of the SEFB and V1 Stage C, including suburbs farther away than had been included in the catchment area for the SEFB before the first stage of the V1 opened. Therefore, the findings suggest that the V1 Stage C expanded the catchment area for cycling into the city centre from southern suburbs. From points east, it is reasonable that cyclists would select the V1 Stage C, the path closest to them. However, from points north and south of the SEFB and V1 Stage C, both paths would be viable options with the V1 Stage C more difficult to enter from the south than the SEFB but the SEFB requiring multiple road crossings and sharing the path with pedestrians. The findings suggest, therefore, that cyclists from these directions preferred the wider, continuous and faster V1 Stage C.

We also hypothesised that the opening of the V1 Stage C would shift cyclists away from other routes into the city centre. The GPS bicycle counts and intercept survey data provide evidence that some cyclists were encouraged away from the SEFB. The shift of cyclists from the SEFB to the V1 Stage C has safety implications. The SEFB is narrow and windy in sections, with short sight distances, uneven surfaces and non-contiguous sections and segments on local streets and through intersections. It caters to both pedestrians and cyclists: of 401 users observed in 2013, 25% were pedestrians and the remainder were cyclists. Cyclist-pedestrian interactions are possible, and although such interactions have not been examined for the SEFB, research from New South Wales, Australia indicates that cyclist-pedestrian crashes can result in severe injuries requiring hospitalisation (Chong et al., 2010). In contrast, the V1 Stage C is a continuous, dedicated bikeway only. Therefore, shifting cyclists from the SEFB onto the V1 Stage C removes opportunities for cyclist-pedestrian crashes.

Evidence from the GPS bicycle count data suggests that the opening of the V1 Stage C did not shift cyclists away from the major arterial road, Logan Road. Cyclists-motorist crashes have been noted on Logan Road, and some have resulted in cyclists' hospitalisation (data not shown). As previous research suggests that such collisions result in a significant burden of injury in the population (Chong et al., 2010), efforts to encourage cyclists away from Logan Road are warranted. However, it is possible that the stable numbers of cyclists who use Logan Road are those who prefer to cycle on the most direct, high speed arterial roads. Literature from the US suggests that these 'strong and fearless' cyclists will cycle regardless of road conditions (Dill & McNeil, 2013; Geller, 2009). Therefore, convincing them to shift to an off-road bike path that they may not consider to be the most direct, highest-speed route into the city may be a challenge. As the remaining stages of the V1 are completed, evaluations of the impact of each stage's opening on these cyclists' behaviour could provide insight into the responsiveness of these cyclists to incremental changes in bicycle infrastructure.

The last hypothesis was that the V1 would increase the number of cyclists who travel between southern suburbs and the Brisbane city centre. The survey data indicated that 10% of cyclists travelling on the V1 Stage C during morning peak had switched to cycling as their mode of transport to their destination. As in the current study, intercept surveys of cyclists using new bicycle lanes installed in five US cities found that 10% would have made their trip by a different mode if the new infrastructure were not available (Monsere et al., 2014). This study was unique in using GPS tracking data to cross-reference intercept survey data. The GPS data indicated a doubling of monthly cycling trips from southern suburbs. Before the V1

Stage C opened, there was a steady rise already in cycling trips from southern suburbs recorded by the GPS tracking system but the increases accelerated after the V1 Stage C opened, indicating that the intervention may have been responsible for substantially increasing the monthly number of cyclists approaching the city centre from the south. The increases in GPS bicycle counts pre to post-intervention supports the increase in mean daily bike counts pre- to post-launch of the off-road Rail Trail in Western Sydney (Merom et al., 2003) and in field counts of neighbourhood walking and cycling after the introduction of an off-road urban greenway in Knoxville, US (Fitzhugh et al., 2010). Likewise, the finding supports increases in cycling observed with the installation of a bicycle lane in New Orleans, US (Parker et al., 2013) and increases in bicycle mode share of the journey to work, assessed by census data, with the introduction of new on-road and off-road bicycle infrastructure in Minneapolis-St. Paul, US (Krizek et al., 2009).

The main strengths of this study were the use of both objective and subjective measures for a practical evaluation of new cycling infrastructure. Notably, only data from bikeway users were collected. Without data from a random selection of residents within catchment areas of the SEFB and V1, the evaluation could not assess changes in population levels of physical activity. Such data collection would be a challenge given the low numbers of cyclists spread across 56 suburbs. A limitation of the survey data was that completion rates varied across surveys. However, no significant gender or riding composition differences were found between completers and non-completers for any survey. Also, 24-hour traffic cameras were set up at the same locations and same day that the surveys were administered in 2013. Because the cameras failed to capture large numbers of cyclists due to positioning (total captures: SEFB: n=82; V1: n=194), data generated from the cameras were not included in the analyses. However, the findings from that data support the findings in this analysis that most cyclists on the SEFB and V1 were male adults riding alone. It should also be noted that the age of cyclists was determined by observation and categorised crudely as adult, teenager or child. Too few teenagers or children were observed to include them in analyses. Without the ability to place cyclists within adult age groupings, it was not possible to explore associations between age and cycle path selected.

Limitations of the GPS bicycle count data were that it only included trips made by Strava users, and complete monthly counts for 2013 were only commissioned for the specific sites along the three main bicycle routes from Brisbane's southern suburbs into the city centre. Therefore, it was not possible to compare changes in counts examined in this analysis to possible changes at a comparison site elsewhere. TMR and Brisbane City Council collected data from automated bicycle traffic count monitoring stations at various Brisbane sites, but monitoring station malfunctions and vandalism resulted in missing data at some sites and at others, monitoring stations were only set up to capture counts prior to the V1 Stage C opening or only after it. Important as well, data on trips, rather than cyclists, were analysed. Therefore, it is unknown whether the same cyclists were travelling more frequently or more cyclists were travelling. The findings may also reflect in part increasing numbers of Strava users rather than more cyclists. However, other Strava data from Queensland (data not shown) show that monthly changes in Strava users at a single site is small although large yearly changes at the state level are evident. Moreover, if increases on the V1 Stage C were due to increases in Strava users, we would expect similar increases on the SEFB and Logan Road, which did not occur. Also noteworthy, Strava users were not representative of the broader cycling community, and thus in the analysis Strava was used in conjunction with survey data. As a tool, Strava appeals to cyclists wanting to monitor their speed and distance. Indeed, knowledge of the Strava user community in Brisbane suggests that Strava users tend to be more experienced riders who travel longer distances. Consequently, this form of user-generated data appears useful in examining impacts of a facility, such as the V1, in Australian cities, which are mostly used by long-distance commuter cyclists. These data are unlikely to provide information on large sub-sets of riders in other settings, and such data may have limited utility in Asian or European cycling markets where shorter-distance transport cycle trips dominate.

5. Conclusion

Bicycle super-highways like the V1, which are targeted at long distance riders, may help broaden the bicycle market beyond inner city cyclists. Continued investment is encouraged, but their importance should not be overstated. More attention is needed in cycling infrastructure provision and in overcoming other barriers to increase cycling's appeal, especially for groups under-represented in Australian cities, such as women and children, and to encourage shorter-distance cycling to a broader range of activities (Bonham and Wilson, 2011). The results are limited in that we have only looked at one major link in one Australian city, albeit a new facility that is representative of the kinds of segregated wide bicycle super-highways being proposed around the world at present. Replication of this research in other cities to look at effects across slightly different facility designs and across urban contexts would add to the findings of this study. Future research should also explore further uses for user-generated GPS data, and whether services such as Strava can be broadened in their appeal or whether populations can be specifically recruited to harness the potential of these services to provide useful data for planning purposes. Attention should also be given to identifying not just the effects of individual links in a network, such as the V1, but also the network effects that cycling infrastructure improvements create, which are under-researched at present.

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Table 1

Data collection and analysis used to address each of the three research questions

Comparisons	Data collection Pre-V1 Stage C opening	 Post-V1 Stage C opening	Analysis
Research question 1[a] comparisons			
Cyclists intercepted on SEFB before the V1 Stage A opened vs after V1 Stage C opened	20 Aug, 2009	18 Sept, 2013	Cyclist and trip characteristics compared with tests of proportions & Mann-Whitney rank-sum test
Cyclists intercepted on SEFB vs V1 after V1 Stage C opened		18 Sept, 2013	Cyclist and trip characteristics compared with fixed effects logistic regression modelling
Research question 2[b] comparisons			
GPS bicycle counts from V1 vs from SEFB and Logan Road before and after V1 Stage C opened	Jan-June, 2013	July-Dec, 2013	Changes in monthly bicycle counts with interrupted time series modelling, adjusted for seasonal effects
Research question 3[c] comparisons			
Combined GPS bicycle counts from V1, SEFB and Logan Road before and after V1 Stage C opened	Jan-June, 2013	July-Dec, 2013	Changes in monthly bicycle counts with interrupted time series modelling, adjusted for seasonal effects

Cyclists intercepted on V1	18 Sept, 2013	Intercept survey item on mode of transport pre-V1 Stage C opening used for descriptive purposes

Key. V1=Veloway 1. Stage C of the V1 opened 25 June, 2013.

[a]Research question 1: Which cyclists choose to use or not use the V1 Stage C?

[b]Research question 2: Did the V1 Stage C opening encourage cyclists away from the other, less safe routes for cycling into the city centre?

[c]Research question 3: Did the V1 Stage C opening increase the number of cyclists who approached the city centre from the south?

Table 2

Characteristics of adult cyclists intercepted on the SEFB and V1 Stage C and of their cycling trips.

	2009 SEFB (N=132)		2013 SEFB (N=99)		2013 V1 Stage C (N=169)	
	n	%	n	%	n	%
Gender						
Female	18	13.6	20	20.2	25	14.8
Male	114	86.4	79	79.8	144	85.2
Riding composition						
Alone	127	96.2	95	96.0	146	86.4
In a group	5	3.8	4	4.0	23	13.6
Trip origin suburb (direction from SEFB and V1 Stage C)						
West	56	43.4	72	72.7	18	10.7
East	8	6.1	3	3.0	34	20.1
South	59	44.7	19	19.2	97	57.4
North	9	6.8	5	5.1	20	11.8
Trip destination suburb (direction from SEFB and V1 Stage C)						
West	3	2.1	3	3.0	2	1.2
East	1	0.7	8	8.1	6	3.6
South	3	2.1	4	4.0	13	7.7
North	136	95.1	84	84.9	148	87.6

Commitment to cycling[a]						
Continue to cycle			69	69.7	156	92.3
Use a car (driver or passenger)			12	12.1	2	1.2
Use public transportation			16	16.2	8	4.7
Other			2	2.0	3	1.8
	median	IQR	median	IQR	median	IQR
Trip length (km)	11.8	10.2, 15.6	10.2	9.9, 13.4	13.4	10.2, 18.2

IQR=inter-quartile range; SEFB=South East Freeway Bikeway; V1=Veloway 1

[a]Commitment to cycling was measured only in 2013. Cyclists were asked about the mode of transport that they would use for the current trip if the cycling path being used were temporary closed. No cyclists reported that they would have walked or used a motorcycle to make the trip.

Table 3

Correlates of cycling on the V1 Stage C versus the SEFB post-V1 Stage C opening in 2013 (n=242).

	Univariate models		Multivariable model	
Characteristic	OR	95% CI	OR	95% CI
Male gender	1.35	0.54-3.35	1.16	0.43-3.13
Riding in a group[a]	2.91	0.80-10.51	5.26	0.99-27.84
Trip destination suburb was not the city centre[b]	1.00	0.35-2.84	0.81	0.24-2.77
Committed to cycling[c]	4.69	1.88-11.74	4.31	1.65-11.28
Distance travelled	1.14	1.02-1.29	1.15	1.02-1.30

Key. Trip origin suburb was not included as a possible correlate because individual level data were clustered within origin suburbs for the fixed effects modelling. The 26 cyclists who were intercepted on the SEFB and reported that they were not aware of the V1 Stage C were excluded.

[a] The referent group was riding alone.

[b] The referent group was riding north, towards the city centre.

[c] Commitment to cycling was treated as a dichotomous variable (1=would continue to cycle if the cycling path being used for the current trip were temporary closed; 0=would use another mode of transport).

Figure legends

Figure 1 Maps of the Veloway 1 Stage C, South East Freeway Bikeway, and Logan Road. The map on the bottom left is an inset map showing the location of the Veloway 1 (V1) Stage C, South East Freeway Bikeway (SEFB), and Logan Road within the greater Brisbane area. These routes offer the most direct routes for cyclists to access Brisbane's city centre from southern suburbs. The map on the right is a locality map of the three routes. The SEFB is on the west side of the South East Freeway. The V1, approximately 2.3 km in length, is located along the eastern side of the freeway and west of Logan Road. At its northern entrance, the V1 Stage C and the SEFB connect to an existing off-road bike path. The map on the top left shows the sites where intercept surveys were conducted on the SEFB in 2009 and 2013 and on the V1 Stage C in 2013. University students conducted the surveys at the locations indicated on the map.

Figure 2 Timeline of Veloway 1 (V1) stage completions and data collection time points

Figure 3 Locations on the Veloway 1 Stage C, South East Freeway Bikeway, and Logan Road where GPS bicycle counts were recorded.

Strava provided to TMR aggregated data produced from its Strava Metro product. These data included date, time and cyclist counts at the four locations shown on this map. From these data, monthly bicycle counts were calculated for each location for each month of 2013.

Figure 4 Comparison of monthly GPS bicycle counts on the Veloway 1 Stage C to average monthly GPS bicycle counts on alternative bicycle routes into the city centre from the southern suburbs of Brisbane.

After adjusting for seasonal effects, there was a significant upward trend in monthly bicycle counts on the V1 Stage C after that route opened on June 25, 2013, and this trend was significantly different from the trend seen on the alternative bicycle routes.

Figure 4 Total monthly GPS bicycle counts on the Veloway 1 Stage C and alternative bicycle routes into Brisbane city centre from southern suburbs.

After adjusting for seasonal effects, there was a 69% increase in monthly bicycle counts (from 112 to 189 counts), on average pre- to post-opening of the V1 Stage C in total on the major routes into the city centre from the south: the Veloway 1, the South East Freeway Bikeway and Logan Road.