Abstract

This study evaluated cyclist and driver compliance at cycling infrastructure at signalised intersections to determine the effectiveness of the infrastructure in creating a designated space for cyclists. A cross-sectional observational study was conducted during peak travel times at six sites in Melbourne in March 2009. Three types of infrastructure were observed: 1) bicycle storage box in front of left lane, 2) bicycle storage box in front of centre lane and 3) continuous green-painted bicycle lane. Two sites were observed for each infrastructure type, one morning and one early evening. A covert fixed position camera was used to film all road users, and the behaviour of cyclists and drivers who stopped at the intersection during the red light phase was coded. In total, 2670 cyclists and 1243 vehicles were observed. Compliance was highest at the continuous bicycle lane sites for cyclists (95.4%) and drivers (97.7%). At bicycle storage box sites, cyclists (60.4%) were more compliant than drivers (49.6%). The placement of bicycle storage boxes may contribute to lower rates of driver compliance and cyclists’ perceptions of safety and subsequently cyclist compliance. Driver and cyclist education campaigns may increase compliance.
Keywords
Cycling infrastructure, Driver compliance, Cyclist compliance, Bicycle storage box

Introduction
On-road cycling infrastructure is designed to create designated spaces for cyclists. Recent studies suggest that treatments give drivers confidence about interacting with cyclists [1], cyclists prefer routes with cycling infrastructure [2-4] and report feeling safer [5,6]. However, for the infrastructure to be effective, drivers and cyclists need to be compliant, and there has been little research into how cyclists and drivers use these spaces and whether the infrastructure creates a clear space for cyclists on the road.

The number of people cycling in Australia is increasing [7] and so too is the introduction of cycling infrastructure. During the last decade in metropolitan Melbourne, for example, there has been a substantial increase in the installation of cycling facilities in an effort to improve the overall safety of cyclists, increase their visibility and legitimacy, and improve traffic flow [8]. The principal bicycle network currently has 1200km of completed on-road and off-road cycling routes [9]. The most common bicycle infrastructure implemented in Victoria is a bicycle lane, typically a painted white line with a painted bicycle symbol along the left side of the kerbside lane. In some locations across Melbourne, the bicycle lanes are painted green to increase driver and cyclist awareness of the lane particularly, at busy or complex locations [10].

While cycle lanes are effective in providing separation of cyclists and vehicles, one of the major disadvantages is that they inevitably cross roads at various points, and interaction with vehicular traffic at intersections places cyclists at heightened risk. In many cases, bicycle lanes discontinue on approach to intersections. Indeed, along Melbourne’s most used on-road commuter cyclist route, St Kilda Road, most mid-block bicycle lanes discontinue on approach to the intersection, and cycling infrastructure is absent from the holding area and through the intersection.

In some locations a bicycle storage box (see description in next paragraph) is provided at the intersection bar. According to the Australian and Victorian traffic engineering guidelines, at points where the road narrows, cyclists are expected to defend their space among moving vehicular traffic by positioning themselves in the centre of the lane [11] as the priority for space allocation on the roads is to vehicles [12]. However, where there are feeder lanes into the bicycle storage box, cyclist behaviour has been found to be more predictable than when the bicycle lane discontinues [13].

Bicycle storage boxes have been widely installed in Melbourne. Also called advanced stop lines or head start areas, bicycle boxes originated in the Netherlands. They are painted on the road at the front of the vehicular traffic lane at intersections and aim to create a separate space for cyclists to wait during the red light phase. The position increases driver awareness of the cyclist, thus increasing cyclist safety [6,14].

Cycling infrastructure research in New Zealand identified the primary objectives of the boxes were to improve cyclists’ physical safety and reduce cyclists’ perceived risk at intersections. The study found a reduction in driver-cyclist collisions after the installation of the box, and cyclists reported feeling safer. However, the authors reported that drivers did not like cyclists ‘stacking’ ahead of them and felt unsure or non-committal about the purpose and function of the box [15].

In Victoria, an additional intention of the boxes was to formalise, and in doing so legitimise, the informal behaviour of cyclists of rolling through to the front of traffic during the red light phase [16]. In addition, the boxes have the advantage of locating cyclists away from vehicle exhausts while waiting in traffic, and provide an opportunity for them to leave from the traffic lights first, ahead of vehicular traffic [12,17].

For the bicycle storage box to be effective, the space must be kept clear for cyclists. Several studies have found that vehicle encroachment during the red light phase has created concern for cyclists. Newman found that driver intrusion did influence cyclist confidence and their position at the intersection. In video observations, cyclists were likely to use the box, whereas drivers were the least compliant and intruded on or obscured the cycling infrastructure [15]. A before-and-after observational study of bike storage box installations in the United States found that slightly more than half the vehicles observed (51.9%) encroached into the box [17]. In the United Kingdom, of 514 cyclists observed, 36% experienced a vehicle encroaching into the bike storage box [13].

Driver and cyclist education about how to interact with the cycling infrastructure also influence compliance [13,15,17]. In Victoria, the current graduated licensing system is underpinned by the Victoria drivers licence handbook Road to Solo Driving. There are numerous references to bicycle lanes and appropriate driving behaviour when sharing the road with cyclists. However, there is limited information on broader cycling infrastructure, with only one reference made to bicycle storage boxes, referred to as ‘head start’ areas, with no information about appropriate driver behaviour at a bicycle storage box [18].

More extensive information about driver and cyclist behaviour, including an increase of penalties for encroaching into a bicycle storage box, has been available on the VicRoads website since changes to the Victorian road rules in November 2009. Drivers may be fined up to 10 penalty points (currently $1168.20) [19,20]. There are detailed instructions about the correct positioning of drivers and cyclists on the road with a clear, instructive animated graphic. However, this information is located on a cyclist-specific road rule site, and it is not known how many non-cycling drivers view this page.

The aim of this study was to evaluate cyclist and driver compliance at different cycling infrastructure treatments at signalised intersections. Given the increasing number of cyclists in Australia and the lack of research focused on the safety implications of cycling infrastructure, it was anticipated that the findings would contribute to knowledge about infrastructure use and highlight potential solutions to improve cyclist safety.
Methods
This study was designed to assess the compliance of cyclists and drivers at signalled intersections with varied cycling infrastructure. The observation sites included three types of cycling infrastructure that have been implemented along the most frequently used on-road cyclist commuter routes in metropolitan Melbourne. A novel covert position was used to record the behaviours of all cyclists and drivers who entered the sites.

Research design
This was a cross-sectional observational study of on-road commuter cyclists. The study was conducted in March 2009 at six sites along popular on-road commuter cyclist routes on St Kilda Road and Swanston Street [21]. All sites were within five kilometres of the central business district (CBD), as measured from the Melbourne Town Hall. Each observation was a three-hour recording repeated over six non-consecutive days either at 7-10am or 4-7pm, resulting in 18 hours of recordings per site. Given the time of the observations, it was assumed that most cyclists and drivers were commuting to or from work. It was not necessary to observe multiple approaches, as the peak flow of commuter cyclists travelled in one direction at all observed sites.

Observation sites
Three types of cycling infrastructure at intersections were observed: a bicycle storage box in front of the left lane, a bicycle storage box in front of the centre lane and continuous green-painted bike lane. As the majority of the cyclist traffic flow is one way during peak hour travel times, only one approach was observed at each site. The three treatment types are illustrated in Figure 1.

Bicycle storage box in front of the left lane
Intersections with bicycle storage boxes in front of the left lane (Figure 1, diagram 1) were observed at two intersections on the most used on-road cycling commuter route in Melbourne, along St Kilda Road from the south-eastern suburbs of Melbourne [21]. Two sites were observed, one in the morning (in-bound) and one in the afternoon (out-bound). The signals at this intersection did not have a left-turn filter light. This is the most common bicycle storage box position along the selected route.

Bicycle storage box in front of the centre lane
The second type of bicycle storage box (Figure 1, diagram 2) was also observed along St Kilda Road, and at these sites the bicycle storage box was located in front of the centre vehicular lane. The intersections with this infrastructure had a dedicated left-turn vehicle lane with a left turn filter light. The position of the centre storage box placed cyclists ahead of drivers who were continuing straight through the intersection.

For all bicycle storage box sites observed, there was no bike lane on the approach to the intersection. The mid-block bike lane discontinued prior to each observed site.

Continuous bicycle lane
The third type was green-painted bicycle lanes that continued from midblock to the intersection; the lane did not continue through the intersection, as shown in Figure 1 (diagram 3). These sites were located along Swanston Street to the north of the CBD. The lanes were located kerbside, parallel to the vehicular traffic, and were continuous with the mid-block Copenhagen-style bike lane. These sites did not have a bicycle storage box at the intersections.

Procedures
A Sony DCR-SR62 video camera was positioned inside a small grey box and attached to a roadside signpost that gazetted parking time details. The camera position recorded the behaviours of all road users who entered the space, and continuous recording allowed detailed analysis of cyclist and driver behaviours. The covert positioning of the camera eliminated potential behavioural bias, as cyclists and drivers were unaware they were being filmed.

There were weather-related restrictions to the observations to minimise potential bias. Observations were not conducted on days over 35°C or when it rained during the morning observation period, as on these days there were lower numbers of cyclists and fewer female cyclists. Observations continued on the next suitable day.

Figure 1. Cycling infrastructure observed
Definitions of cyclist and driver compliance

Of interest was cyclist and driver compliance at the cycling infrastructure types when approaching a red light. At the bicycle storage boxes, cyclist compliance was defined as entering the bike storage box with at least one wheel in the box. For drivers, compliance was defined as stopping before the bicycle storage box, defined as the front wheels of the vehicle stopping before the white line of the box. It was possible that there may still be vehicle encroachment, with the bonnet of the vehicle entering the bicycle storage box; however, given the perspective recorded by the camera, the wheel-based classification was the only objective classification possible across all the sites. Only the first vehicle to approach the intersection was coded at all sites. Non-compliance was recorded when the wheels encroached into the box.

At the continuous bicycle lane, cyclist compliance was defined as staying within the bicycle lane. Cyclists who stopped in front of the continuous bicycle lane (i.e., in the pedestrian crossing or in the parallel vehicle lane) were coded as non-compliant. For drivers, compliance was defined as stopping parallel, with all wheels outside the bicycle lane. Drivers whose vehicle wheels encroached into the bicycle lane were coded non-compliant. It is possible that vehicle protrusions or mirrors may have entered the bicycle lane.

There is potential for coding bias in observational studies, particularly with a single researcher coding the data. In this study, compliance for both cyclists and drivers was coded separately by an independent research assistant for 6 hours (11.1%) of footage and analysed using the Kappa statistic. The inter-rater reliability was Kappa = 0.673 (p<0.001), 95% CI (0.585-0.761). This measurement of agreement is statistically significant and can be interpreted as substantial [22].

Results

Nine hours of footage was analysed for each of the six sites, for a total of 54 hours. A total of 2670 cyclists (including 1878 males and 792 females) and 1243 vehicles stopped at the intersection at the observation sites during the red light phase.

Descriptive statistics

Cyclist and driver compliance rates were cross-tabulated with the three cycling infrastructure types as summarised in Table 1. Compliance was greatest at the continuous lane location, with a high level of compliance by drivers and cyclists. In comparison, cyclists were more compliant than drivers at the bicycle storage box sites, regardless of the positioning of the box. Across the infrastructure types, the relative compliance was different for cyclists and drivers ($X^2 = 16.217$, p<0.001).

Binary logistic regression – cyclists

Site infrastructure type, time of day and cyclist gender were included in a binary logistic regression with compliance (yes/no) as the outcome variable (see Table 2). A cut-off for predicted probability of compliance of 0.07 was used in the classification tables for the fitted model. The overall correct predictive percentage of the model was 67.4%, with sensitivity 63.8% and specificity 78.1%.

Infrastructure type had the strongest association with cyclist compliance. In particular, the compliance odds at the continuous bicycle lane was 12.4 times the compliance odds at the left bicycle storage box infrastructure. There was also an association with time of day and compliance odds, with the compliance odds 39.3% less in the afternoon compared with the morning. There was no statistically significant association between compliance and gender.

Table 1. Descriptive statistics of cyclist and driver compliance at three cycling infrastructure types

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Cyclists</th>
<th>Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% compliant</td>
<td>Observed</td>
</tr>
<tr>
<td>Left bicycle storage box</td>
<td>64.9%</td>
<td>1005</td>
</tr>
<tr>
<td>Centre bicycle storage box</td>
<td>53.0%</td>
<td>614</td>
</tr>
<tr>
<td>Continuous bicycle lane (green)</td>
<td>95.4%</td>
<td>1051</td>
</tr>
</tbody>
</table>

Table 2. Relative odds of compliance-related factors in the model – Cyclists

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Relative odds of compliance</th>
<th>Statistical significance</th>
<th>95% C.I. for odds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centre vs left</td>
<td>0.686</td>
<td>0.000</td>
<td>0.556</td>
</tr>
<tr>
<td>Continuous vs left</td>
<td>12.494</td>
<td>0.000</td>
<td>9.059</td>
</tr>
<tr>
<td>pm vs am</td>
<td>0.607</td>
<td>0.005</td>
<td>0.496</td>
</tr>
<tr>
<td>Female vs male</td>
<td>0.926</td>
<td>0.478</td>
<td>0.749</td>
</tr>
</tbody>
</table>
Binary logistic regression – drivers

A second binary logistic regression was constructed for drivers, including infrastructure and time of day, with compliance as the outcome variable (see Table 3). A cut-off for predicted probability of compliance of 0.07 was used in the classification tables for the fitted model. The overall correct predictive percentage of the model was 67.6%, with sensitivity 52.9% and specificity 97.5%.

Again, infrastructure type had the strongest association with driver compliance. In particular, the compliance odds at the continuous bicycle lane were 43.9 times the compliance odds at the left bicycle storage box infrastructure. The time of day and compliance association was similar to the cyclist rate, with drivers having an odds of compliance 32.0% lower in the afternoon compared with the morning.

Discussion

Common cycling facilities such as bicycle lanes and bicycle storage boxes aim to separate cyclists and vehicles along mid-block and at critical locations; however, such infrastructure treatments are only effective if they result in appropriate behaviour. While there are some noted benefits of these treatments, little is known about their effect on behaviour. This study examined cyclist and driver compliance behaviour at three types of cycling infrastructure at signalled intersections.

Infrastructure type was the greatest predictor of compliance. Specifically, the continuous, green bicycle lane was associated with the highest levels of compliance by both groups of road users. A key point to note is that compliance creates different demands depending on the infrastructure type. The continuous bicycle lane was a continuation of the mid-block infrastructure, so drivers and cyclists continued to travel parallel with each other to the intersection. The only compliance requirements were that drivers did not encroach on the green lane when they turned left and cyclists maintained their position within the lane.

However, at the bicycle storage box sites, compliance does require a variation in travel behaviour between mid-block and intersection. Firstly, while drivers and cyclists travel in parallel when mid-block, compliance at the bicycle storage box requires drivers to stop behind the box, short of their ‘usual’ position at the intersection. Secondly, cyclists are required to move from travelling in parallel to the drivers to stop in front of the vehicle. This need for variation in behaviour may have contributed to non-compliance, and it may be that cyclist infrastructure is perceived as less legitimate when it displaces drivers.

At all bicycle storage box sites, the level of compliance of cyclists was higher than drivers. This may suggest that a high proportion of compliant cyclists perceived the boxes to provide a safe space to wait during the red light phase. It is not known why approximately half of drivers were non-compliant. Possible reasons may be lack of knowledge of the purpose of the boxes, disregard for the space if no cyclists are already present, failure to notice the infrastructure or acknowledge the space as legitimate, or failure to accept cyclists as legitimate road users.

In order to improve compliance we need a better understanding of the influencing factors. Recent changes to Victorian road rules increased the penalty for non-compliant drivers at bicycle storage boxes; however, there have been limited education and awareness campaigns about the changes, and to date the impact of the road rule changes on compliance is not known. It is likely that education and awareness programs that inform all road users of the function of the space will improve compliance.

Table 3. Relative odds of compliance related factors in the model – Drivers

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Relative odds of compliance</th>
<th>Statistical significance</th>
<th>95% C.I. for odds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centre vs left</td>
<td>0.956</td>
<td>0.767</td>
<td>0.712</td>
</tr>
<tr>
<td>Continuous vs left</td>
<td>43.866</td>
<td>0.000</td>
<td>22.436</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pm vs am</td>
<td>0.680</td>
<td>0.006</td>
<td>0.517</td>
</tr>
</tbody>
</table>
Compliance may be affected by additional factors such as vehicle type or the presence of other road users, and therefore available space, on arrival. This could be addressed with further analysis of the video observations. It is also possible that non-observable factors may also contribute to compliance, such as socio-economic status of the cyclist or driver, or perceptions of safety. Survey research is planned to explore these factors further.

**Conclusion**

This study has provided a baseline measure of cyclist and driver compliance for three commonly used cycling infrastructure treatments. Highest compliance rates for both cyclists and drivers were observed for continuous bike lanes and during morning observation times. It is recommended that future research be conducted to identify reasons for non-compliance and to explore potential treatments to enhance compliance, including coloured bicycle storage boxes and continuous bicycle lanes.

**Acknowledgements and declaration**

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**References**


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