Safety implications of e-bikes

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Safety implications of e-bikes

Authors

Dr Marilyn Johnson
Professor Geoff Rose

Acknowledgements

Dave Jones
Melinda Spiteri

PERFORMING ORGANISATION

Institute of Transport Studies
Civil Engineering, Monash University
Wellington Road, Clayton Victoria 3800

Abstract

E-bikes are bicycles that are fitted with an electric motor to provide the rider with power-assistance. While e-bike use is growing around the world, there is still limited research directed at this mode of travel. This study investigated the safety implications of e-bike use in Victoria, Australia, including perceptions of safety at various on-road and off-road locations along with the crash experiences of e-bike riders. The study includes a literature review on perceptions of safety, a review of the current infrastructure design standards and a survey of e-bike riders exploring their experiences and perceptions of safety. The survey found that hill climbing capability and spot speed are two potential e-bike performance capabilities that are different to pedal bikes in terms of how a rider interacts with on-road and off-road infrastructure. Wider lanes and paths, smooth and flat surfaces, adequate sight distance and better connectivity are some of the main requirements identified for e-bike riders. There is no significant difference between e-bike and pedal bike riders in perceptions of comfort, including safety, or on riders' perspective of cycling infrastructure. E-bike riders were found to be older riders with less riding experience and potentially lower cycling proficiency. It was found that priority should be given to the development of education materials or rider training programs, particularly for older e-bikes riders and potential e-bike riders.

Key Words

electric bikes, e-bikes, safety, perceptions of safety, Victoria

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RACV Research Report 15/02

Executive Summary

Electric bicycles or e-bikes are bicycles that are fitted with an electric motor to provide the rider with power-assistance. E-bikes offer performance characteristics that address some of the traditional barriers to cycling. In Victoria, Australia, e-bikes are legally defined as bicycles and riders can ride anywhere a bicycle is permitted. E-bike riders are therefore subject to the same rules and regulations as conventional pedal bike riders.

While e-bike use is growing around the world, there is still limited research directed at this mode. The purpose of this study was to investigate the safety implications of e-bike use in Victoria. The study explored the perceptions of safety at various on and off-road locations, along with the crash experiences of e-bike riders. The study provides important new insights into how e-bikes are being used, and a better understanding of the safety implications of e-bike use.

The study includes three components: a literature review, a review of the current infrastructure design standards and a survey of e-bike riders.

From the riders' perspective of cycling infrastructure, studies have found that there is no significant difference in perceptions of comfort, including safety, by bike type (i.e. pedal bike or e-bike). There were no studies identified in the literature review that directly addressed the cycling infrastructure design requirements for e-bikes or determined if the requirements differ from those of pedal bicycles. However, the main requirements identified for e-bike riders: wider lane and path widths, smooth and flat surfaces, adequate sight distance and better connectivity, have been found to be important when designing cycling infrastructure for both e-bike and pedal bike riders.

To investigate the experiences and expectations of e-bike users in on and off-road situations, an online survey was conducted. Most e-bike riders were found to be older riders with less riding experience and potentially lower cycling proficiency.

Consistent with the literature reviewed, survey respondents highlighted the importance of dedicated infrastructure in providing an environment in which they feel safe to cycle. While respondents indicated they felt very safe on facilities where they were separated from traffic, they felt unsafe in unprotected bicycle lanes. In addition, those e-bike riders who were not previously cyclists felt even less safe on unprotected bike lanes than their experienced counterparts.

The survey identified poor path surface, spot speed, the heavier bike and rider error as contributing factors to unsafe events involving e-bikes. This is consistent with past surveys. Those factors have implications for designers of bicycle facilities.

Australian bicycle facility guidelines currently make no reference to e-bikes. Two particular features of e-bikes need greater consideration by bicycle facility designers: their greater hill climbing capacity and their higher spot speed relative to the speed the rider would be travelling at if riding a conventional bicycle.

The particular features of bicycle facilities which may require closer attention from designers include:

- the higher hill climbing capacity when bicycle routes are being designated
- horizontal and vertical curve radii and lateral clearances, as well as widths for bicycle lanes and paths
- risks associated with loose path surfaces when path materials are being chosen and path maintenance is being undertaken
- better management of increased interactions by users through signage and education.

The experience profile of e-bike riders suggests there is a need for education for e-bike riders about the safe use of their e-bike. As e-bikes continue to grow as a proportion of the bicycle fleet it is recommended that priority should be given to the development of education materials or rider training programs, particularly for older e-bikes riders and potential e-bike riders.

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1 Introduction

Nationally, the popularity of cycling is increasing and in Victoria, the rate of cycling participation has consistently measured higher than the national average (Australian Bicycle Council and Austroads 2011, Australian Bicycle Council and Austroads 2013, Leavy and Denoury 2013). While more people are cycling, there is a growing understanding about the remaining barriers to cycling (e.g. lack of fitness/motivation, concerns about safety, hilly terrain) (Johnson 2013). Electric bicycles, or e-bikes offer performance characteristics which address many of the traditional barriers to cycling.

E-bikes, are bicycles that are fitted with an electric motor that provides the rider with power-assistance. In 2012 the Australian government adopted the European Union design standard which permitted e-bikes up to 250 watts, an increase from the previous 200 watts limit, and this opened the Australian market to a greater range of e-bikes (Australian Government 2012). Some models, which were legal under the earlier legislation, had a handgrip throttle which enabled the rider to engage the power-assistance without pedalling. Under the European standard now adopted in Australia, the power assistance on e-bikes over 200 watts can only be engaged when the rider is pedalling. E-bikes are legally defined as bicycles and riders can ride anywhere a bicycle is permitted and are subject to the same rules and regulations as conventional pedal bike riders.

While e-bike use is growing around the world there is still limited research directed at this mode. This study was funded by the RACV Road Safety Research Fund. The purpose of this study was to investigate the safety implications of e-bike use in Victoria. This study explored the perceptions of safety at various on-road and off-road locations along with the crash experiences of e-bike riders. The study was conducted in Victoria, Australia and provides important new insights into how e-bikes are being used in Victoria along with a better understanding of the safety implications of e-bike use.

1.1 Purpose of the study and structure of the report

Safety implications related to e-bike use have been addressed by international researchers (Spolander 2007, Davidse et al. 2013, Twisk et al. 2013). However, there has been no research conducted to date about the role of bicycle infrastructure in relation to e-bike safety particularly in relation to safety in Victoria. This research addresses that gap.

As the number of e-bike riders continues to increase, questions arise about how people are using e-bikes and their experiences in the existing road and cycling networks, including:

- Are safety issues related to cycling the same for both e-bike riders and pedal cyclists?
- Does the current cycling infrastructure cater for e-bikes?
- Does an increase in e-bike riders create new safety concerns?
- Are there new safety issues for people riding e-bikes who were not previously cyclists?

This study comprised three components:

- a review of the published literature on perceptions of safety
- a review of the current cycling infrastructure design standards
- a survey of e-bike riders exploring their experiences and perceptions of safety.

The following sub-section provides some background on the broader e-bike literature and what is known about e-bikes in Australia. The next main section (Section 2) presents the insight obtained from a systematic review of the literature. That literature review includes studies from the pedal cycling literature due to the paucity of publications that focus on e-bikes. In that chapter, the role of infrastructure design is also considered. Section 3 reviews current cycling facility standards and examines the implications of e-bikes for those standards. Section 4 presents the results from the online survey conducted with e-bike riders to explore their perceptions of different cycling infrastructure and the nature of any safety related incidents they have experienced when riding an e-bike. Finally the report concludes with a Discussion which considers how the research findings have addressed the questions about e-bikes and safety and concludes with reflections on how some of the safety concerns identified might be addressed.

1.2 E-bike research background

There is a growing body of research about e-bikes internationally. In China, it is estimated that in excess of 200 million e-bikes are owned and regularly ridden for transportation (Weinert et al. 2008, Wei and Benjamin 2012, Timmons 2013). Given the size of the Chinese market it is not surprising that much of the e-bike research has been conducted in China (Cherry 2007, Weinert 2007). As discussed later it is not appropriate to assume that the insights from Chinese research are transferable to Australia because of differences in enforcement of e-bike regulations.

In Europe, e-bike use is also increasing. In 2012 in the Netherlands, it was estimated that 1 in 20 Dutch citizens owned an e-bike (Twisk et al. 2013) while in Germany e-bikes accounted for 8 percent of all bicycle sales (Gehlert et al. 2012) and in Switzerland, e-bike sales are being actively promoted by local Swiss governments as a greener transport option (Weber et al. 2014). Studies conducted in Europe and Australia have found e-bike riders tend to be older than pedal cyclists.

To date, the scientific research on e-bikes has explored a range of themes:

- performance of the e-bike (Raute and Ertugrul 2005, Lin 2008, Watterson 2008, Timmermans et al. 2009, Qiu et al. 2011, Gudmundsson and Larsen 2012, Hsu et al. 2012, Qing and Chun 2012, Dukulis et al. 2013, Saleh 2014)
- e-bike conversions (Brand et al. 2003)
- physical effort of the rider (Welker et al. 2012, Mendes et al. 2014)
- e-bike crashes and rider injury outcomes (Zhiying 2010, Jiang et al. 2012, Du et al. , Zhang 2013, Zhang 2013, Hu et al. 2014, Schepers et al. 2014, Weber et al. 2014)
- environmental benefits of e-bikes (Cherry 2007, Parker)
- observations of e-bike rider behaviour, particularly at intersections (Wu et al. 2011, Bai et al. 2013, Du 2013, Mei et al. 2013, Huan and Yang 2014, Yang et al. 2014)
- the need for e-bike specific infrastructure including recharging stations (Brown 2002, Tal et al. 2013)
- the potential for e-bikes to improve transport efficiency through mode choice changes (Rose and Cock 2003, De Vries and Jenman 2006, Rose 2010, Dill 2012, Rose 2012, Langford et al. 2013, Liu et al. 2013, Zhang 2013, Flüchter et al. 2014, Lia et al. 2014, MacArthur et al. 2014, Popovich et al. 2014). In terms of mode shift in particular, Cherry et al (In Press) reported that in China, e-bikes interrupt people's transition from bicycle to bus or bus to car.

While there is a growing body of research about e-bikes internationally, little is known about e-bike use in Australia and few studies have investigated the safety concerns related to e-bike use and the implications of increased e-bike use for the design of cycling facilities.

Cycling participation also dramatically increases with e-bikes. In the first study of e-bike riders in Australia (Johnson and Rose 2014), use of e-bikes was high with the majority of owners riding their e-bike weekly (88.2%) and nearly half (48.7 %) reporting they used their e-bike on a daily basis. For people who were regular adult pedal cyclists, the e-bike offers a means to continue cycling after illness, injury or ageing conditions would have otherwise restricted their riding. E-bikes are also opening up cycling to a completely new segment of the population, people who rarely or never cycled as an adult. Even people who rarely/never rode a pedal bike as an adult, reported frequently riding their e-bike, particularly for local trips (e.g. to the shops, visit friends).

Our understanding of e-bike riders is that they are different to people who are currently pedal bicycle riders. E-bike riders are more likely to be older (Rose and Dill 2011, Gehlert et al. 2012, Wolf and Seebauer 2014, Johnson and Rose 2015), have reduced physical capacity due to injury, illness, age related conditions or lack of fitness (Johnson and Rose 2013, Johnson and Rose 2015), cycle for utilitarian trips (Rose and Dill 2011, Johnson and Rose 2013, Johnson and Rose 2015) and are more likely to ride frequently (daily or weekly) with less concern about hills or end of trip facilities.

It is against this background that the systematic review of the literature was conducted. The next section reports the insights obtained from that systematic literature review.

2 Systematic review of e-bike safety literature

A systematic review of the published literature related to e-bikes and safety was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols (PRISMA-P) statement (Moher et al. 2015). The focus was on the literature related to safety and the relationship and expectations of on and off-road facilities. As there is limited literature that specifically relates to e-bike use, the review was broadened to include cycling literature (i.e. related to pedal cycling). The outcomes of this stage of the study were to identify e-bike safety issues and examples of questionnaires used to explore e-bike safety. These questionnaires were of assistance when the survey that was undertaken as part of this study was being developed and were used to identify factors that informed the development of the survey used to explore experiences of Australian e-bike riders.

The PRISMA-P protocol was used in this systematic review. Application of that protocol led to the identification of 12 key papers which provided the foundation of this review. The literature review is presented in four sections:

- **cycling infrastructure**, this section reviews the literature related to cycling infrastructure from two perspectives, first from the riders' perspective and then aspects of cycling infrastructure design which may be relevant to e-bikes,
- **safety and e-bikes**, this section reviews the literature about safety issues that are specific to e-bike use
- **comparing crashes on e-bikes and pedal bikes**, this section considers the literature on different crash profiles between the two bicycle types, and
- **perceptions of safety**, this section reviews the literature related to objective and subjective risk and the role of driver behaviour in perceptions of safety.

2.1 Cycling infrastructure

From the riders' perspective of cycling infrastructure, studies have found that there is no significant difference in perceptions of comfort, including safety, by bike type (i.e. pedal bike versus e-bike). In a study of 29 physically separated bicycle paths in China, Li and colleagues (2012) investigated cyclists' feelings of comfort on fully separated bicycle paths built between the pedestrian footpath and the motor vehicle lane and separated by a barrier or planting strip. Bicycle path width and shoulder width were positively associated with perceptions of comfort however there was no statistically significant difference between perceptions of comfort by gender or bike type (i.e. pedal bike versus e-bike). Li et al did report a significant difference by age with cyclists aged under 30 years 10 percent more comfortable across all facility types.

The study by Li and colleagues also provides insight into the scale of e-bike use in China. Conducted in 2012 in Nanjing, the authors reported the flow rate of bicycles past the survey intercept point. The average flow per hour of e-bikes was 667 (range: 108-1488) and the average flow of pedal bikes was 520 (range: 108-984). The increase in e-bike flow was found to decrease cyclists' perception of comfort on the separated cycling facilities. This was the perception of all cyclists in the survey, regardless of whether they were riding a pedal bike or e-bike and the difference by bike type was not statistically significant.

From the perspective of cycling infrastructure design, no studies were identified in the literature review that directly addressed the requirements for e-bikes or determined if the requirements differ from those of pedal bicycles. However, studies have been conducted that examined other elements of e-bikes and cycling infrastructure. In a study in Nanjing China focusing on the level of service on shared paths for pedestrians, pedal cyclists and e-bike riders, wider shared paths were associated with fewer conflicts (overtaking, passing and meeting) (Chen et al. 2010).

Jin and colleagues (2015) examined cycleway capacity using video observations of 11 cycleway sites in Hangzhou China which captured over 40,000 bicycle, e-bike and motorbike riders. Cycleways, defined as non-motorised facilities that pedal bikes and e-bikes share, observed varied in width from 2.27m to 4.6m and cycleway capacity was calculated as bicycle per hour per metre (bicycle/h/m). Actual cycleway use varied from 1606 to 3023 bicycle/h/m averaging 2348 bicycle/h/m with an average proportion of 70 percent e-bikes. The observations were considerably higher than the recommended capacity in China (1600-1800 bicycle/h/m) and international recommendations (e.g. USA, 1300 bicycle/h/m). The authors suggest that the observations are due to peak flow at commuting times, the proportion of e-bikes travelling at higher average speed and a large proportion of young riders with good cycling skills. Up to 10 percent of riders were carrying objects (e.g. freight, passengers including children from school) and this was likely to have a lateral effect on other bicycles and decrease cycleway capacity. Female and elderly riders were observed to behave more cautiously than male and younger riders however this did not impact capacity.

Further, Jin et al (2015) also reported that cycleways would be more efficiently used by people using e-bikes than by pedal bikes. They estimated that the capacity for e-bikes on a cycleway is 1.5 times the capacity of pedal bicycles. However, this calculation needs to be considered with some caution as it is based on the premise that e-bike riders travel faster than pedal bike riders. E-bike regulations, specifically the maximum speed of these vehicles, are poorly enforced in China (Rose 2012) and this is believed to contribute to poorer e-bike safety outcomes there (Cherry, 2007).

For pedal cyclists, their fitness, the local topography and the facility on which they are riding are likely to have a significant effect on their riding speed. The literature provides limited insight into actual speeds of pedal cyclists and e-bike riders. In a study in China, Lin et al (2008) reported that the average speed of e-bikes is 22 km/h which they reported is 7km or 47.6% faster than the average speed of bicycles and this was used as the basis for the capacity calculations reported by Jin et al (2015).

A recent study of elderly e-bike riders by Vlakveld and colleagues (Vlakveld et al. 2014) found that in simple traffic situations, their speed was higher on the e-bike compared to the pedal bike but that their speed was comparable to cyclists in middle adulthood. However, in a naturalistic study of pedal bicycle commuter cyclists in the Australian Capital Territory, Johnson et al (2014) reported an average speed of pedal cyclists of 22.7 km/h (similar to the average e-bike speed in China as reported by Lin et al (2008)), calculated from GPS data generated over almost 9,000 km. Local observations of e-bike rider and pedal bike rider speeds would need to be taken to determine the role of speed in cycling facility level of service and capacity in Australia. While it is likely that there is an increase in speed for an individual e-bike rider, who may not have the physical capacity to ride a pedal bike at the same speed at the same location, it may be that the pedal cycling population are already travelling at speeds similar to or higher than an e-bike.

Research from the pedal cyclist literature shows that both cyclists and drivers prefer physically separated cycling infrastructure (CDM Research 2013, Sanders 2013) and cyclists rank physically separated infrastructure as safer than other road treatments (e.g. painted bike lane or shared lanes). These findings are also typical of non-cyclists and their perception of what is important in their consideration of cycling (Winters et al. 2011). The literature did not provide any insight into whether there are differences between pedal and e-bike riders in their preference for cycling infrastructure.

Recent research conducted in Brisbane, Queensland reported that cyclists would be willing to travel up to an additional 3.4 kilometres to access one of Brisbane's bikeways rather than take a more direct route (Proctor 2010). Bicycle Awareness Zones (BAZ) are an on-road bicycle treatment used often in Queensland at pinch points and typically in urban areas. A study by Smart (2011) found that while both drivers and cyclists agreed the markings made sharing the roads safer, there was a lack of understanding of the markings amongst drivers. Lack of compliance with cycling infrastructure was evidenced amongst drivers in Melbourne in an observational study of drivers at bike boxes at intersections where there was a considerable encroachment into the space even when cyclists were present (Johnson et al. 2010). It was not evident if the driver encroachment was because drivers disregarded the markings or due to lack of awareness of the purpose of the bike box.

Cyclists in Ireland, an emerging cycling country, reported that they would alter their route to make use of continuous bike lanes or to use quiet streets, as both were perceived as safe by cyclists (Lawson et al. 2012). A recent study by Chataway and colleagues (2014) compared cycling infrastructure in Brisbane to that in Copenhagen. They found that in both cities, cyclists felt safest in fully separated infrastructure and the least safe when they were 'sandwiched' between parallel parking bays and moving motor vehicle traffic. The researchers identified Brisbane as an 'emerging cycling city' and recommended the most effective means to increase cycling participation was increased investment in fully segregated, connected cycling paths. That conclusion is consistent with the insight from a study of the association between the built-environment and cycling conducted in Austria which reported that bike lane connectivity was an important factor in the likelihood of adults using a bicycle for transportation in city areas (Titze et al. 2008).

Improvements to the physical cycling environment were also found to be a motivating factor among UK families. In an in-depth study of families, all of whom cycle with various frequency, designated cycle networks enhanced the cycling experience for experienced riders (Clayton and Musselwhite 2013). Families with less experience reported that dedicated cycling infrastructure helped address objective and subjective safety fears and established a legitimate space for them on the road.

In the USA, another country which is seeing an increase in cycling, a study of residents who live on a bicycle boulevard, where bikes have priority over motor vehicle traffic, found they had a positive impact on home values and quality of life measurements (e.g. sense of community, noise, air quality). Over two third of residents enjoyed living on the bicycle boulevard 'a lot' and almost half were more likely to ride because of the infrastructure (VanZerr 2009). However, some residents who did not identify as cyclists at all, were negative towards the changes to the street with some openly hostile about cyclists having priority. Further, another study of pedal cyclists in the USA reported that cycling appears to be an individual choice and is only moderately associated with the neighbourhood environment (Moudon et al. 2005).

Speed, both posted speed limits and the spot speed of vehicles, was a factor that decreased cyclists' feelings of safety and people altered their routes where possible to ride on routes with lower speed limits (Lawson et al. 2012).

2.2 Safety and e-bikes

E-bikes are addressing some of the barriers to cycling with e-bike riders dramatically increasing their cycling participation and trip frequency. This has been shown in international studies (e.g. China (Cherry and Cervero 2007)) and a similar experience is being reported in Australia (Johnson and Rose 2014). In a national online survey of e-bike owners in Australia (n=529) nearly half the e-bike riders (46.8%) reported feeling safer riding their e-bike in traffic compared to riding a pedal bike (Johnson and Rose 2014). Respondents reported that the power assistance helped them to maintain a steady average speed that helped them to 'keep up with traffic' and for some riders, the power assistance had helped them to avoid crashes by allowing them to maintain speed or accelerate to avoid a potential collision. Some riders found the electric motor provided greater stability when starting from a stationary position reducing the 'wobbly' start and this increased their confidence when riding alongside vehicular traffic. Other riders felt less fatigued riding their e-bike and subsequently felt more alert and this too gave them more confidence about cycling.

This anecdotal experience has been confirmed by empirical evidence from Theurel and colleagues (2012) (France) who found that e-bikes reduce muscle strain and psychological stress compared to a pedal bike. However, this finding may not be applicable across all age groups. Vlakveld et al (2015) (The Netherlands) reported that among elderly e-bike riders, in complex traffic situations their cognitive workload was higher than that of middle adulthood pedal cyclists (who were travelling at a comparable speed). The authors caution that travelling at a higher speed in complex traffic environments may increase the risk of a crash for elderly e-bike riders.

In addition, from the same study, a quarter of the respondents had experienced a crash on their e-bike. Half of the crashes were the same event types as those experienced by pedal cyclists with the remainder more likely to be events contributed to by the e-bike itself. For example, crash circumstances that involved the surface (e.g. gravel, wet) could have been due to higher speed on an e-bike, user error (e.g. unintentional acceleration), fall because of the heavy bike/lost balance or mechanical e-bike failure. It is likely that the inexperience of some of the e-bike riders, who were not previously cyclists and reported having little/no training on operating the e-bike or bike handling skills, contributed to some of these crashes. Further, e-bike riders are more likely to be an older cohort (Johnson and Rose 2015) and this can have implications for injury outcomes, which typically are more serious amongst older people (Koppel et al. 2011).

While e-bikes have addressed some of the barriers to cycling, they have also introduced new safety considerations. Some of the safety concerns are the same as existing cycling related issues that are known and typical to all cyclists, while others are new to e-bikes and need to be better understood. To provide an understanding of these differences, the literature that described the crash profiles for e-bike riders was examined and is discussed in the following section.

2.3 Comparing crashes on e-bikes and pedal bikes

There is some disagreement in the literature about the severity of injury outcomes for e-bike riders compared to pedal cyclists. Research from China reports that e-bike rider injuries are more severe than pedal bike riders and that the injuries are increasing concurrently with e-bike sales (Feng et al. 2010, Du et al. , Hu et al. 2014). In 2013, almost one in ten road traffic fatalities were e-bike riders (Zhang and Zhang 2013), however e-bike crashes were often found to be due to actions by the counterpart driver and not the e-bike rider. It is likely that speed is a factor in the different injury profiles. While China has a lower maximum power assisted speed (20 km/h) compared to Europe (25 km/h), there is little evidence of enforcement of this limit in China and actual speeds are likely to be higher (Rose 2012). Indeed, Yang and colleagues (2014) recorded the speed of 800 e-bike users with hand-held radar speed detectors and reported that 71% exceeded the 20km/h speed limit for e-bikes.

In contrast, a recent study in the Netherlands analysed hospital data for cyclists who had crashed on a pedal bike compared to an e-bike and found there was no significant difference in crash outcome. That is, e-bike riders and pedal bike riders had similar injury outcomes (Schepers et al. 2014).

In Australia, a survey of e-bike safety related incidents (Johnson and Rose 2014) found that half of the incidents could have occurred on any bike type (e.g. car dooring, intoxicated cyclist). The road/path surface was a factor in one in five crashes and while these too may be considered typical of any bike crash, comments from the e-bike riders suggested that they may have been travelling too fast for the conditions. Lack of riding experience may have been a factor or different riding skills may be required for safe e-bike riding. Of the crashes experienced, a quarter of people reported the e-bike itself was a contributing factor (e.g. rider error including unintentional throttle/hand grip power engagement, destabilising power surges, fall due to heavy bike or loss of balance or mechanical failure typically related to self-assembly).

2.4 Perceptions of safety

Australia is an emerging cycling country (Kaplan and Prato 2013, Chataway et al. 2014). A key characteristic of an emerging cycling country is limited cycling infrastructure and the need for cyclists and drivers to share the road. While cycling infrastructure continues to be developed and implemented there is a mismatch between the increased number of people riding bikes and the availability of continuous, connected bike facilities that offer a space to cycle separate from motor vehicle lanes.

While still in its infancy as a field of research, e-bike riders' perceptions of safety is attracting increased research attention and is a small but growing field of research. From the international literature, there is evidence that some e-bike riders perceive e-bikes to be safer than pedal bikes (MacArthur et al. 2014, Popovich et al. 2014). However, as reported by Johnson and Rose (2012) given that some e-bike riders did not or rarely cycled prior to purchasing their e-bike, feelings of safety are likely to be biased by perceived safety/unsafety of the experience on a pedal bicycle as opposed to actual experience.

From the review of the literature, it is clear that there are two key components to the perception of the safety of cycling: objective versus subjective risk and driver behaviour. The cycling infrastructure, or lack of, was also a key component and is considered in the context of these two components and discussed in depth in Section 3. However these components are intertwined and the separation is somewhat artificial.

2.4.1 Objective versus subjective risk

In the cycling literature, a gap has been identified between objective risk (the real risk of a cycling crash or injury) and subjective risk (people's perception of risk). This misperception about the risks associated with cycling has been a major deterrent from cycling for many people and reduces the rate of growth of cycling in emerging cycling countries (Sanders 2013).

Concerns about safety, the negative emotions or fears about cycling, are well-documented barriers to cycling (Garrard et al. 2006, Daley et al. 2007, Parkin et al. 2007, Bauman et al. 2008, Pucher et al. 2011, Fishman et al. 2012, Kaplan and Prato 2013, Lawson et al. 2013, Chataway et al. 2014). These concerns are at a personal level and have been associated with an individual's perception of the possibility of a crash, particularly with a motor vehicle and the potential for injury (Fishman et al. 2012).

How attitudes about cycling are formed and the influence of these attitudes about cycling and desire to ride was recently explored by Lee and colleagues (2015). They also examined the impact of crashes. Incidents involving a motor vehicle increased cyclists' discomfort, in contrast solo crashes were considered unlucky or mishaps. Knowledge of crashes experienced by other cyclists tended to increase negative attitudes towards cycling, particularly among people who were not regular bike riders.

While cyclists do have a higher risk of being involved in a crash compared to vehicle drivers and passengers (Garrard et al. 2010), empirical evidence shows that fear of being involved in a crash is disproportionate to the actual level of risk to cyclists (Garrard et al. 2010, Johnson et al. 2010, Johnson et al. 2014). Washington et al (2012) reported that Queensland cyclists self-reported 0.5 injury crashes per year, which included on-road and off-road and falls. In two studies of Australian commuter cyclists in Melbourne (Johnson 2011) and the Australian Capital Territory (Johnson et al. 2014) helmet mounted video cameras were used to observe cyclist commuting trips. In almost 600 hours analysed (Melb: 127 hours; ACT: 466 hours) only 2 minor crashes were recorded, however, there were 7 near-collisions and 136 incidents. Studies from Washington et al and Johnson et al, demonstrate that actual crash involvement for cyclists is relatively low.

The broader culture towards cycling as articulated through the media and public policy which prioritises private vehicle use is considered to reinforce this fear (Horton et al. 2007). A comparative study conducted in Delft, the

Netherlands and Davis, USA examined attitudes and norms of cycling commuting (Heinen and Handy 2011). That study found that while there were similar positive attitudes towards the benefits of cycling, residents in the USA more often encountered negative reactions to cycling and this impacted the likelihood that they would cycle. Concerns about personal safety were also a concern for women in both cities.

Chataway et al (2014) in a comparative study of cyclists in Brisbane, Australia and Copenhagen, Denmark, suggested that ‘fear-based exclusion’ from cycling contributes to increasing tension on the roads and discourages wide-scale uptake of cycling. Lee et al (2015) interviewed non-cyclists who reported being influenced by severe incidents reported by the media about cycling which often, to be considered news worthy, are negative ‘If I were an experienced [cyclist], what I read in the paper wouldn’t so much influence me…But when you don’t have that experience, you tend to believe and base your reaction on what you read’ (Female, aged 50 years) (Lee et al. 2015: 20).

Indeed, research has reported that cyclists’ perceptions of safety increase with the frequency of cycling (Møller and Hels 2008, Lawson et al. 2013). Therefore it appears for some people the fear of cycling is a barrier that could be overcome by cycling, somewhat of a paradox for those people who are too fearful to take the first step.

This lack of support and exclusion of cycling at a cultural level is also a barrier to the benefits of safety in numbers, the theory proposed by Jacobsen, based on Smeed’s law, of a positive association between increased cycling participation and increased safety. At a community level, this theory purports that when more people cycle, drivers will have an increased expectation of cyclists and be more aware of them on the road. Drivers are also more likely to cycle and understand how to interact safely with cyclists. Further, people who are not cyclists themselves, and are not likely to be, will be more likely to know someone who is a cyclist and this will increase their awareness of other cyclists (Jacobsen 2003).

This theory was investigated by Johnson et al (2014) amongst Australian cyclists and drivers and found that people who were cyclists were more likely to report safe driving behaviours related to sharing the roads with cyclists than people who were not cyclists. In comparison, people who are not regular cyclists themselves were more likely to have negative attitudes about cyclists.

However, the actual number of people who need to cycle to achieve a safety in numbers benefit has not been quantified. Studies from the UK (Maycock et al. 2003) and Australia (Adelaide) (Bonham et al. 2006) report that when drivers infrequently encounter cyclists they have less appreciation of their behaviour and safety needs and that the frequency of the encounter is more important than the drivers’ experience of being a cyclist themselves. While an increase in the number of cyclists is likely to contribute to improvements in cyclists’ safety, the association is not causal. With a lack of meaningful exposure data (i.e. how many people are cycling, time cycling, trip frequency) it is not possible to determine where Australia is currently positioned on the continuum from too few cyclists to a sufficient number to achieve a safety in numbers effect.

While the perception of unsafety is not supported by the crash or injury data, people’s fears about cycling may be justified if we consider the non-collision events that cyclists do encounter.

2.4.2 Driver behaviour

Driver behaviour was also identified in the literature as being a contributing factor to cyclists’ feelings of safety (Joshi et al. 2001, Bauman et al. 2008, Johnson 2011). Research reported that cyclists’ discomfort was related to how drivers used the available infrastructure. Intersections including drivers turning and (appearing to) failing to look for cyclists were locations of discomfort. Roundabouts, roads with trucks and country roads with high speed zones, poor sight distances and unsealed shoulders are also locations where cyclists report feeling unsafe (Johnson 2011, Johnson and Le 2012). People who were less confident about riding were more likely to avoid peak travel times as they felt uncomfortable riding next to moving vehicular traffic, in particular alongside parallel parked cars.

A recent study from Israel, another emerging cycling country, by Kaplan and Prato (2013) analysed the online comments posted in relation to news stories that involved at least one cyclist and one driver. Their analysis highlights the animosity between cyclists and drivers and identified two primary stimuli: lack of bicycle infrastructure notably that bike lanes discontinue and lack of connectivity, and; confusion about whether cyclists were legally permitted to ride on the road. Reactions to sharing the road from both drivers and cyclists included fear and anxiety to more forceful emotions (e.g. anger, contempt). The most commonly self-reported behaviours of drivers included engaging in a verbal or physical argument with cyclists (e.g. yelling, honking horn). Aggression from drivers was correlated with cyclists’ fear and decisions to limit/stop cycling.

In a UK study, drivers considered on-road cyclists to be unpredictable, felt uncomfortable sharing the road with them and did so with an ‘impatient caution’ (Basford et al. 2002). While in Ireland, careless and reckless driving has been shown to negatively impact cyclists’ feelings of safety (Lawson et al. 2013) and in Australia, negative attitudes towards cyclists were associated with poor knowledge of road rules and lower tolerance of cyclists on the road (Rissel et al. 2002).

2.5 Discussion

From the review of the literature it was evident that there were many similarities between pedal cyclists and e-bike riders particularly in terms of people's attitudes towards cycling infrastructure and perceptions of safety. However, there are three characteristics of e-bike riders (as shown in Figure 1) which are particularly relevant when understanding this particular sub-group of users of bicycle facilities.

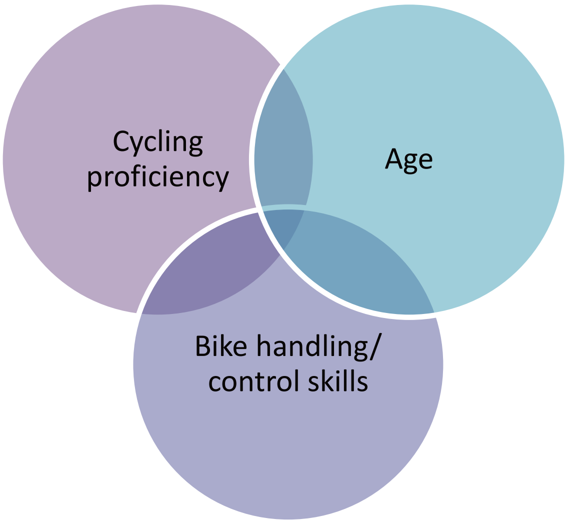


Figure 1 Key e-bike rider characteristics

As identified in the literature, many e-bike riders were not previously adult cyclists. This lack of experience may impact their level of cycling proficiency (i.e. level of comfort/confidence riding in complex situations e.g. alongside moving motor vehicles). Similarly, with limited/no cycling experience their bike handling/control skills may also be limited and this is further complicated by the specific requirements of riding an e-bike (e.g. heavy bike, additional interface e.g. power settings). Finally, the age of the e-bike rider is likely to be older than the average for pedal cyclists. While the e-bike enables older riders to continue to ride and maintain an independent travel option (Johnson and Rose 2015), older riders are likely to have greater physical frailties that impact the severity of injuries in the event of a crash. Further, complex traffic situations are reportedly difficult for some older cyclists to navigate (Vlakveld et al. 2014).

These e-bike rider characteristics need to be kept in mind when considering the interaction between e-bike riders and bicycling infrastructure. That interaction is considered in the following section which focussed on the relationships of e-bikes and current bicycle facility standards.

3

Review of current bicycle facility standards

The systematic review of the literature relating to e-bike safety reported in the previous chapter highlighted that, apart from China where vehicle standards are poorly enforced, there is little evidence that the e-bike itself presents any inherent differences from pedal cycles in terms of safety issues. However there are differences in the characteristics of the “typical e-bike rider” compared to “typical pedal cycle rider” which may have implications for safety outcomes. Those rider differences are relevant to any discussion about the implications of e-bikes for standards which govern the design of cycling facilities.

This section focuses on the standards for the design of on-road and off-road bicycle facilities with attention given to any design criteria which may need to be reviewed in the light of growing e-bike use. The review of design standards reported here considered both the relevant Austroads Guides as well as VicRoads publications. Austroads is the national organisation that provides guidance to engineers, planners and designers involved in implementing and retrofitting cycling infrastructure. In this study, Cycling Aspects of Austroads Guides (Levasseur 2014), the overarching document for cycling infrastructure design standards in Australia was reviewed. To complement the Austroads Guides, VicRoads has released a series of Cycle Notes (VicRoads, various dates) which provide bicycle design information for engineers and planners. Neither the Austroads Guides nor the VicRoads Cycle Notes make any specific mention of e-bikes.

The following Section (3.1) characterises the e-bike system to highlight the system elements which interact with the on and off-road infrastructure while Section 3.2 examines implications for bicycle facility design criteria.

3.1 The e-bike traffic system

The traffic system has long been characterised by distinguishing between infrastructure, road users and vehicles (Brash, 2003). Here that three-way characterisation is nuanced by distinguishing the elements of the e-bike system as being the e-bike rider, the e-bike and the infrastructure (Figure 2).

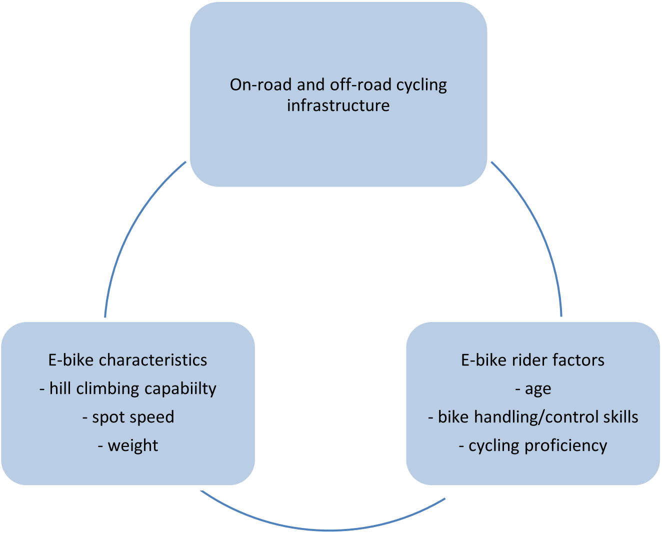


Figure 2 The e-bike system

As highlighted by the discussion in the previous section, three e-bike rider characteristics are of relevance: their age, their bike handling/control skills and their cycling proficiency. E-bike riders are more likely to be older than pedal cycle users. That can have implications for their reaction time and capacity to deal with complex traffic situations (Vlakveld 2015). E-bike riders may not be used to handling and controlling a bike which is not only heavier than a conventional bicycle but where the difference in weight distribution can impact the dynamics of the vehicle. For example, some e-bikes have a heavy hub motor in the front wheel and the dynamics of an e-bike with that design, particularly when the rider might be slightly overbalanced, could be expected to be very different from the dynamics of another e-bike were the motor is effectively enclosed round the crank and that additional weight is below the rider. A heavier e-bike may also require stronger grip on the brake handles to affect that same change in speed as on a conventional bike. Finally, there may be differences in the cycling proficiency of e-bike riders in terms of their competence for riding in traffic. They may reflect a lack of cycling experience or possibly riding experience which was gained when the rider was much younger.

In terms of riding an e-bike and how a rider interacts with the on-road and off-road infrastructure, two e-bike performance capabilities are potentially relevant: hill climbing capability and spot speed. Unlike a pedal cyclist for whom hill climbing capabilities are largely determined by physical fitness, e-bike riders have less regard for gradients. This greater hill climbing ability is likely to be a factor in route choice, as e-bike riders are less likely to avoid a hilly route. Spot speed, that is the speed an individual rider is likely or able to travel at a specific location, is likely to be higher among e-bike riders than pedal cyclists. This is distinct from the e-bike riders' average speed, or top speed, which when compared to fit pedal cyclists is likely to be comparable, or potentially slower. Both hill climbing capabilities and spot speed are behavioural differences which need to be taken into consideration when considering the cycling infrasructure requirements for e-bike riders compared to pedal cyclists.

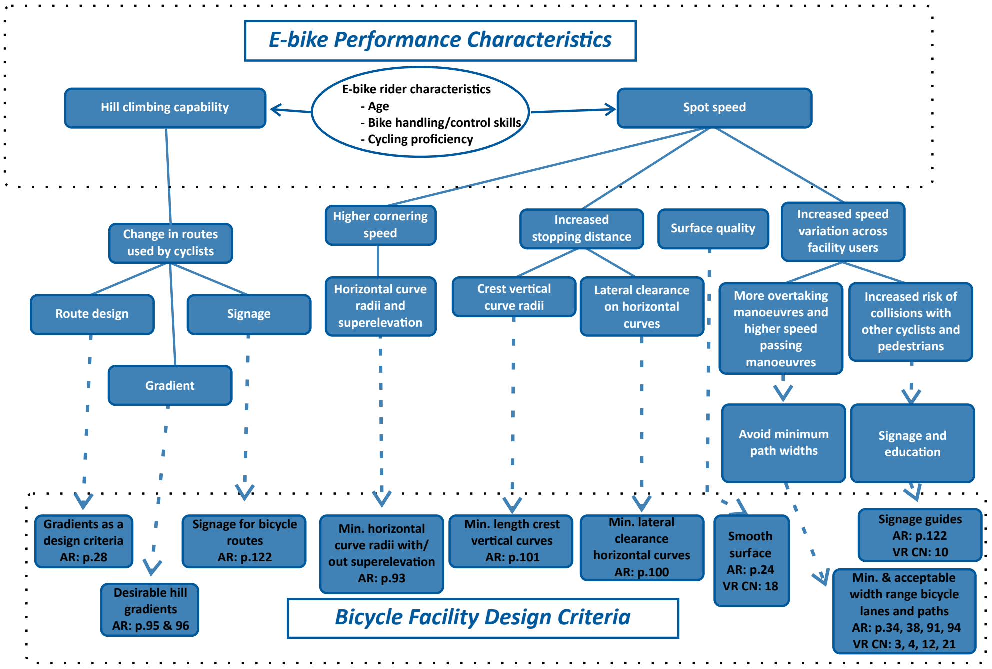
The two e-bike characteristics identified above have implications for bicycle facility design but they need to be tempered by the e-bike rider characteristics highlighted earlier. The next section draws the links between e-bike performance characteristics and bicycle facility design criteria.

3.2 E-bike and bicycle facility design criteria

The Austroads Guides emphasise a range of bicycle rider requirements (Levasseur 2014) which may need to be re-interpreted as follows when the performance characteristics of e-bikes (greater hill climbing capacity and higher spot speed than when on a conventional bicycle) are considered:

- **Space to Ride:** An e-bike rider can achieve a higher speed than when riding a conventional bicycle and therefore more passing and overtaking is likely. The level of service of the bicycle lane or path declines with increasing passing and overtaking manoeuvres. Minimum lane and path widths may need to be reconsidered
- **Smooth Surface:** Poor surface quality (e.g. loose gravel) can contribute to higher risk of losing control given that riders can travel at a higher speed than they would on a conventional bicycle and have to control a heavier e-bike with potentially different dynamics to a conventional bicycle
- **Speed Maintenance:** Greater capacity to maintain speeds on the flat as well as up gradients may result in more riders travelling at speeds close to or in excess of the speeds assumed in the geometric design of the facilities
- **Sight Lines:** Since riders can travel at a higher speed than they would on a conventional bicycle they may have inadequate sight distance to stop safely on crest vertical curves and on horizontal curves
- **Connectivity:** Greater hill climbing capacity may impact route choice and have implications for network connectivity and determination of which routes are signed for cyclists
- **Information:** Higher levels of overtaking and passing manoeuvres may require greater signage and potentially user education.

The reinterpretation of those rider requirements point to a number of implications for bicycle facility design. Figure 3 shows the linkages between e-bike performance characteristics and a range of bicycle facility design criteria. That Figure emphasises that e-bike rider characteristics need to be factored in when considering the hill climbing capacity and spot speed of e-bikes. Relevant sections of the Austroads Guides and VicRoads Cycle Notes which may require attention are highlighted in the lower portion of Figure 3.



Notes: AR = Austroads (2014) Cycling Aspects of Austroads Guides, Sydney.166pp.
VR CN = VicRoads Cycling Notes, published at various dates

Figure 3 Interaction between e-bike performance characteristics and bicycle facility design criteria

The greater hill climbing capacity of e-bikes means that they can enable cyclists to use routes that they would have previously avoided because of grades. Anecdotal evidence to that effect is reported in the literature (Dill and Rose, 2013). This has implications for route and design and potentially signage since this may change how cycle networks are designed or where routes are signed for cyclists.

The higher spot speed of e-bikes has potential implications for the geometric design of facilities. E-bike riders may be able to corner at higher speeds than conventional cyclists or at least higher speeds than they would be travelling if on a pedal cycle. Riders may find **horizontal curve radii** and **superelevation** are not well matched for their cornering speed and that could result in crashes. Advisory speed signs could have a role to play in this regard.

Higher spot speeds also have implications for stopping distances which are related to the design of **radii for crest vertical curves** and the **lateral clearance on horizontal curves**. Increased stopping distances may also arise for older e-bike riders as a result of slower reaction times and the need for need for stronger application of the brake handle to effect the same change in speed as on a pedal cycle.

Higher spot speeds, particularly when combined with the differences in dynamics of the bike and perhaps less well developed bike handling and control skills, could result in crashes on **surfaces of poor quality or condition**. This is potentially a higher risk on gravel paths.

The higher spot speeds will also result in greater variation in speeds across the users of bicycle and shared use facilities. This can result in not only more overtaking manoeuvres and high speed passing manoeuvres but also an increased risk of crashes with other road users.

Bike path level of service and capacity is measured in terms of the frequency of passing and overtaking manoeuvres (Hummer at al 2006). As the number of passing and overtaking manoeuvres increases, the level of service decreases for a given path width. Minimum path widths may therefore need to be avoided to provide not only an adequate level of service for riders but also to reduce the risks of collisions with other users. Signage and education of all users of shared facilities is also likely to be important in this context.

As noted earlier, any discussion of the relationship between e-bike performance characteristics and bicycle facility design criteria needs to recognise the important role of e-bike rider characteristics as a moderating factor. To date very little research has been directed at understanding the nature of any safety related events which may have been experienced by e-bike riders particularly in terms of the extent to which the e-bike or the infrastructure contributed to those events. The next chapter reports results from a survey of e-bike riders which examined their expectations of and experiences with a range of on and off-road cycling facilities.

4 Evaluation of expectations of on and off-road cycling facilities and practices

An online survey was conducted to investigate the experiences and expectations of e-bike users in on and off-road situations. The survey questions were developed following the literature review (Section 2) and the review of the Cycling Aspects of Austroads Guides (Section 3).

This section provides an overview of the development of the survey and participant recruitment followed by survey results.

4.1 Survey design

The general themes examined in the survey of e-bike riders were:

- self-reported cycling experience and skill
- e-bike ownership
- benefits and disadvantages of e-bike riding
- e-bike riding experience
- feelings of safety at locations with various cycling/no cycling infrastructure
- feelings of safety when interacting with motor vehicles.

Questions were also asked of people who were not currently e-bike owners but reported some previous e-bike riding experience and self-identified as potential e-bike riders. The main barriers to e-bike riding were explored along with the perceived benefits and barriers.

All respondents were asked questions covering socio-demographic variables and local environment characteristics which covered:

- demographic questions: age, gender, employment, education, income, household residents, home postcode
- licence status, access to a motor vehicle, frequency of driving
- attitudes about cyclist licensing and bicycle registration
- proximity of bike lanes/off-road paths to the respondents' home.

The questions included in the survey were developed following the review of the literature, the review of the Austroads cycling standards and consultation with RACV.

4.2 Inclusion criteria, recruitment and incentives

The survey targeted people living in Victoria, Australia, aged over 18 years of age and interested in responding to a survey about e-bikes. There were no additional inclusion criteria and people were welcomed to respond whether or not they owned or had ridden an e-bike. In addition, a prize draw involving three $200 Wish Gift cards was used as recruitment incentives.

Multiple recruitment strategies were used to maximise the number of survey respondents. The link to the online survey was provided via:

- RACV RoyalAuto magazine and enews email newsletter
- invitations to people who have previously been involved in cycling and e-bike surveys and indicated they are interested in participating in future research (n=~2,000). This recruitment pool includes (n=321) known e-bike riders who have participated in an ARC Linkage Project [1].
- Amy Gillett Foundation's online social network.

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[1] Linkage project title: A systemic model to underpin enhanced management of powered-two-wheelers as part of a safe, sustainable transport system (LP100200197)

4.3 Survey results

In total, 757 responses to the survey were received including 7 printed copies returned by post.

From the 757 respondents, a total of 677 completed the survey. The survey was branched and the majority of the questions were answered by people who owned or had regularly ridden an e-bike – categorised as e-bike riders. The e-bike rider status of the respondents is shown in Figure 4 below. Nearly three quarters of respondents (70%) were e-bike riders while about another quarter (27%) were potential e-bike riders. A very small number of respondents (less than 3% of the respondents) either did not ride or were not interested in e-bikes. While it is not possible to determine the representativeness of this sample to the entire Victorian e-bike rider population, the response rate is over three times that achieved in a 2012 e-bike survey conducted by the authors and offers new insights into e-bike riders and the issues arising with their use.

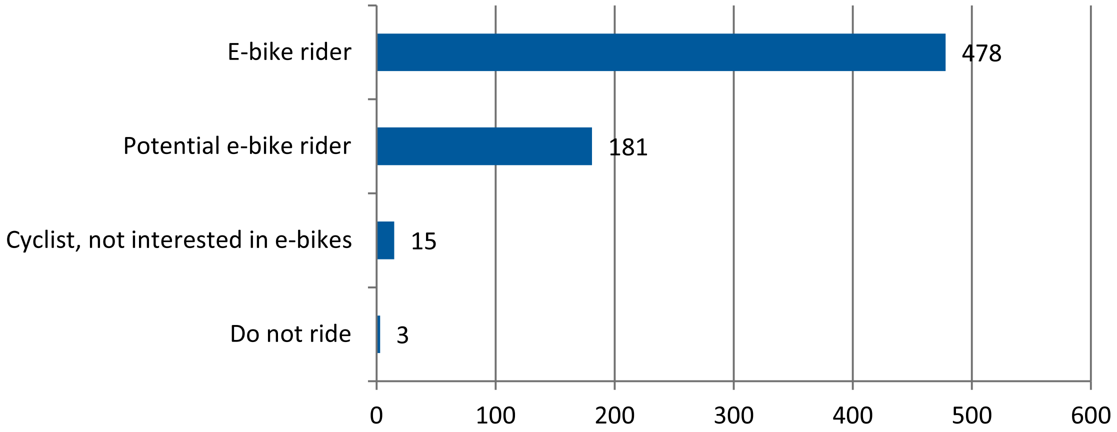


Figure 4 E-bike rider status of survey respondents (count)

Most of the results analysed in this report focus on the e-bike riders with a separate section dedicated to responses from the potential e-bike riders. The following section of survey results focused on the e-bike riders (n=478) and is followed by a separate section that focuses on the potential e-bike riders (n=181).

4.3.1 E-bike riders

Of the 478 respondents who were e-bike riders, just over half the respondents (n=276, 57.7%) were previous regular adult pedal cyclists, while 202 (42.2%) of respondents were not previous regular adult pedal cyclists. It was anticipated that e-bike riders who had previous cycling experience would have greater cycling experience and better bike handling skills than those people who were not previous adult cyclists. Further, this experience would impact the experiences of riding an e-bike. Here we differentiate between those respondents who were regular adult cyclists prior to purchasing their e-bike (rode daily, weekly, monthly) and those respondents who were not regular adult cyclists prior to their e-bike purchase (rode a few times a year, less than once a year, never).

Table 1 provides a summary of respondent characteristics cross-tabulated by previous cycling experience. When e-bike rider characteristics were statistically analysed using Chi-square tests to compare responses by previous cycling experience, five variables were statistically significantly different: gender, age, employment, income and number of children in household aged 17 years and under.

- *Gender:* the majority of all e-bike riders were male (73.9%). However, when analysed by previous riding experience, it is evident that more female e-bike riders were not previous pedal bike riders. Of the 122 female e-bike riders, 63.1% had not been adult cyclists
- *Age:* the majority of e-bike riders were aged over 50 years (66.9%, range: 18-86 years). Respondents who were previous adult cyclists were more likely to be younger (female: 48 years; male 54 years) than e-bike riders who were not previous adult cyclists (females: 55 years, male 58 years)
- *Employment:* Almost half of the respondents worked full time (44.6%) and almost a third were retired (30.8%). This was significantly different by previous cycling experience. A higher percentage of those who had not previously cycled were retired.
- *Income:* Income was also significantly different with a greater proportion of previous cyclists earning higher incomes than those people who were not regular cyclists. This is consistent with there being a higher proportion of retired persons in the group who were not previous cyclists.

- *Household composition – children aged 17 years and under:* Household composition was also significantly different with more people who were not previous cyclists having no children under 17 years living at home (86.9%) compared to previous cyclists (69.9%). It is probable that this difference is a function of the older age of the respondents who were not previous cyclists and the fact that they were retired.

The majority of all respondents were from Victoria (90.9%). Respondents from all locations have been included in these analyses unless specified.

Table 1 Socio-demographic characteristics of e-bike riders by previous cycling experience

	Previous cyclist		Not previous cyclist		All	
	N	%	N	%	N	%
Total	276	57.7	202	42.3	478	100
Gender**						
Female	45	16.4	77	38.3	122	25.7
Male	227	82.8	124	61.7	351	73.9
Other	2	0.7	0	0.0	2	
Age*						
18-39	46	16.7	23	11.4	69	14.4
40-49	62	22.5	27	13.4	89	18.6
50-59	66	23.9	54	26.7	120	25.1
60-69	62	22.5	62	30.7	124	25.9
70+	40	14.5	36	17.8	76	15.9
Employment**						
Working full time	145	53.9	62	31.8	207	44.6
Working part time/casual	37	13.8	45	23.1	82	17.7
Volunteer	6	2.2	2	1.0	8	1.7
Full time student	3	1.1	3	1.5	6	1.3
Not working	14	5.2	4	2.1	18	3.9
Retired	64	23.8	79	40.5	143	30.8
Education						
Primary school/partial secondary	11	4.1	7	3.6	18	3.9
Secondary	24	8.9	38	19.4	62	13.3
Technical school/TAFE	52	19.3	31	15.8	83	17.8
Graduate Diploma	46	17.1	29	14.8	75	16.1
University degree	89	33.1	60	30.6	149	32.0
Higher degree (Masters/Phd)	47	17.5	31	15.8	78	16.8
Income*						
< $20,000	14	5.8	12	6.7	26	6.2
$20,000 - $39,999	35	14.5	35	19.4	70	16.6
$40,000 - $74,999	49	20.2	57	31.7	106	25.1
$75,000 - $99,999	37	15.3	34	18.9	71	16.8
$100,000 - $149,999	61	25.2	28	15.6	89	21.1
Over $150,000	46	19.0	14	7.8	60	14.2

	N	%	N	%	N	%
Household						
Adults including self						
1	42	15.6	32	16.2	74	15.8
2	166	61.5	126	63.6	292	62.4
3	42	15.6	32	16.2	74	15.8
4	20	7.4	8	4.0	28	6.0
Children aged 17 years and under**						
0	186	69.9	172	86.9	358	77.2
1	34	12.8	12	6.1	46	9.9
2	33	12.4	6	3.0	39	8.4
3	9	3.4	6	3.0	15	3.2
4	4	1.5	2	1.0	6	1.3
Relationship status						
Single	54	20.9	43	22.2	97	21.5
Married/long term relationship	204	79.1	151	77.8	355	78.5

* statistically significant difference by previous cycling experience, $^{**}p<0.01$; $^{*}p<0.05$

The majority of all e-bike riders held a driver's licence (92.7%), regardless of their previous cycling experience. Details of driving licences, cycling training and membership are summarised by previous riding experience in Table 2. None of the differences between respondents who were previous cyclists and those who were not, were statistically significant.

Table 2 Licensing, training and membership details of e-bike riders by previous riding experience

	Previous cyclist		Not previous cyclist		All	
	N	%	N	%	N	%
Total	276	57.7	202	42.3	478	100
Licence status						
Car	257	93.1	186	92.1	443	92.7
Motorcycle	75	27.2	42	20.8	117	24.5
Heavy vehicle	48	17.4	25	12.4	73	15.3
None	6	2.2	9	4.5	15	3.1
Taken cycling training course						
Yes	33	12.1	23	11.6	56	11.9
No	239	87.9	175	88.4	414	88.1
Currently belong to cycling organisation						
Bicycle Network/Bicycle Victoria	73	27.2	26	13.3	99	21.3
Cycling Victoria	2	0.7	0	0	2	0.4
Cycling Victoria club	8	3.0	0	0	8	1.7
Audax Australia	2	0.7	0	0	2	0.4
Triathlon Victoria	2	0.7	0	0	2	0.4
Mountain Bike Australia	2	0.7	0	0	2	0.4
None	179	66.8	170	86.7	349	75.2
RACV member						
Yes	186	68.1	148	74.4	334	70.8
No	87	31.9	51	25.6	138	29.2

Licence status by e-bike ownership

Driving licences held by e-bike owners were examined to better understand the likelihood of e-bike riders also holding, or not holding, licences that would enable them to use motorised forms of transport. The majority of e-bike riders held a current driver's licence (92.7%) with almost a quarter also holding a licence to ride a motorcycle (24.5%) with some holding a heavy vehicle licence (15.3%). Of the e-bike riders, 15 did not hold any type of driving licence and this included both females (7) and males (8) and e-bike riders of all ages (18-39 years: 2; 40-49 years: 4; 50-59 years: 5; 60-69 years: 1; 70+: 3).

Motivation to first ride an e-bike

There were a wide range of motivations for people to first ride an e-bike. The full list of motivations and the percentage is listed in Table 3. In the online survey, the question about motivations for first riding an e-bike allowed the e-bike riders to provide multiple responses and the top three responses were to ride with less effort for health benefits (12.1%), to commute (11.8%) and to ride up hills (10.9%).

Table 3 Motivations for first riding an e-bike

	Count	Percentage
Less effort - health	54	12.1
Commute	53	11.8
Hills	49	10.9
Age	30	6.7
Curiosity	28	6.3
Friend/family	27	6.0
Holidays	27	6.0
Positive description (fun, pleasure, enjoyment)	27	6.0
Fitness	24	5.4
Car alternative	24	5.4
Less effort - not health	21	4.7
Tested at event (motoring show, sustainability festival)	16	3.6
Greater distance	14	3.1
Cost effective transport	12	2.7
Environment/sustainability	9	2.0
Faster, reduced travel time	7	1.6
Increased luggage capacity	6	1.3
To keep up with others	6	1.3
PT alternative, no PT available	5	1.1
Licence suspension	5	1.1
Other	4	0.8

Main benefits of riding an e-bike

When indicating the main benefits of riding an e-bike, respondents were able to provide multiple responses. Pre-coded responses listed six response options and respondents were able to provide additional comments in an open text box. The responses identified in Table 4 highlight the main benefits respondents associated with riding an e-bike, namely the ease of riding in hilly areas and over longer distances along with enjoyment and exercise. Fitness and the assistance the e-bike provides to enable riding after illness or injury were also highlighted by about one in two respondents.

Table 4 Main benefits of riding an e-bike

	Count	Percentage
Easier to ride in hilly areas	309	91.6
Enjoyment	274	81.3
Rider longer distances	267	79.2
Exercise	241	71.5
Fitness	184	56.6
Easier to ride after illness/injury	146	43.3

The open-ended responses provided an additional 48 responses to the main benefits of riding an e-bike which included (proportions of the 48 responses):

16.7%	replace car trips
14.6%	ride with less effort (health condition)
10.4%	ride in head winds; environmental benefits
8.3%	convenient; faster.

Three e-bike riders noted benefits of carrying luggage, cost effective transport and to ride with less effort (not health e.g. less sweaty) and safer. Two people noted commuting, positive description (e.g. fun) and health/fitness and one person mentioned to support the technology.

Feelings of safety riding an e-bike

Respondents were asked about how safe they felt riding their e-bike. The majority of respondents felt safe or very safe (83.6%) with the remaining respondents reporting they felt neither safe or unsafe (13.2%) and a small proportion who felt unsafe (3.2%).

To better understand feelings of safety on the e-bike, the responses to this question were cross-tabulated with previous cycling experience (Figure 5). People who were not previous cyclists reported feeling safer on an e-bike than on a pedal bike (4.1 out of 5) compared to e-bike riders who were previous cyclists (3.6 out of 5) however, the difference in perceived safety was not statistically significantly.

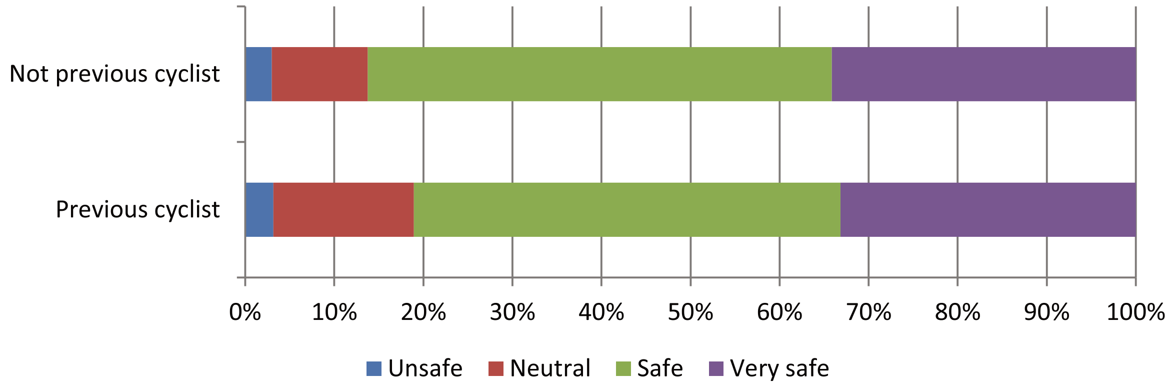


Figure 5 Feelings of safety riding an e-bike by previous riding experience

Riding behaviours

E-bike riders were asked a series of questions about specific behaviours when riding an e-bike and they were asked to compare those behaviours to riding a pedal bike to understand if there was a difference:

- when riding a pedal bike compared to an e-bike and
- between people who had been pedal bike riders prior to purchasing an e-bike compared to people who were not regular adult bike riders.

E-bike riders were asked to compare their behaviour on an e-bike compared to a pedal bike using a a 5-point Likert scale (strongly disagree, disagree, neither disagree nor agree, agree, strongly agree). These responses were averaged across the whole group resulting in a single value to represent the agreement of the group to each question. A higher number represents stronger agreement among the entire group (e.g. a response of 5 would represent all respondents answered ‘strongly agree’).

The average score from all respondents was calculated and analysed by the respondents’ previous cycling experience. As before, the analysis differentiates between those respondents who were regular adult cyclists prior to purchasing their e-bike (rode daily, weekly, monthly) and those respondents who were not regular adult cyclists prior to their e-bike purchase (rode a few times a year, less than once a year, never).

Table 5 presents the average group response to each question by riding experience. The order of agreement of responses was the same for all respondents regardless of their previous riding experience and none of the differences were statistically significant. All respondents strongly agreed that they accelerated faster and usually rode at a higher speed than they would compared to riding on a pedal bike. The least agreement was in relation to getting in front at traffic lights and respondents did not agree that it was harder to stop on an e-bike compared to a pedal bike.

Table 5 To what extent do you agree with the following statements when riding an e-bike compared to if you were riding a pedal bike (by previous riding experience)

	No.	Previous Cyclist	Not Previous Cyclist	Difference
I accelerate faster	351	3.6	3.6	0
I usually ride at a higher speed compared to riding a pedal cycle	353	3.2	3.1	0.1
I overtake more cyclists	353	3.1	2.9	0.2
I feel less safe on loose surfaces	350	2.7	2.8	-0.1
I want to get in front at traffic lights	349	2.3	2.1	0.2
I find it harder to stop	348	2	1.9	0.1

Response range: 1 strongly disagree; 2 disagree; 3 neither disagree nor agree; 4 agree; 5 strongly agree

Next e-bike riders were asked how often they undertook certain behaviours on an e-bike (21 behaviours) on a 5-point Likert scale (never, occasionally, about half the time, usually, always). The ranking of these behaviours are included in Table 6.

The behaviour e-bike riders reported most frequently undertaking was wearing a helmet. Regardless of previous cycling experience 95.4% of e-bike riders reporting always wearing a helmet. Other frequent behaviours included checking over their shoulder when overtaking other cyclists (always: 75.4%) and using bike lights at night (always: 74.6%). Most respondents reported that they did not use their mobile phone while riding an e-bike for sending/receiving calls or texts.

Two behaviours were statistically significantly different by previous cycling experienced. Despite a relatively high proportion of respondents who reported using bike lights, more previous cyclists reported always using lights (78.6%) compared to people who were not previous cyclists (70.1%). There was also a difference in the proportion of e-bike riders who reported never using bike lights at night (previous cyclist: 8.4%; not previous cyclist: 18.8%).

Given the risk to all cyclists of riding at night without lights, bike light use at night was cross-tabulated with cycling after dark. Of the people who reported not using lights at night (n=29), the majority (79.3%) also reported never riding after dark. Most e-bike riders who did ride after dark reported using bike lights.

The second behaviour statistically significantly different by previous cycling experience was riding through an intersection on amber knowing the traffic light may turn red. The majority of people who had not been previous cyclists reported never doing (77.1%) compared to only 62.3 percent of respondents who were previous cyclists.

Table 6 E-bike riding behaviours by previous cycling experience

	Previous Cyclist	Not Previous Cyclist	All
Wear a helmet	4.9	4.9	4.9
When riding on-road bike lane, check over shoulder	4.5	4.6	4.5
Use bike lights at night*	4.4	4.0	4.2
Indicate (hand signal) when turning right	4.0	3.8	3.9
Use a bell	3.6	3.6	3.6
Indicate (hand signal) when turning left	3.4	3.4	3.4
Ride on the road	3.4	3.2	3.3
Ride on off-road paths	3.2	3.4	3.3
Wear reflective or high visibility clothing	3.3	3.1	3.2
Cycle after dark	2.5	2.1	2.3
Ride on footpath alone	1.9	2.0	1.9
Ride on footpath with children	1.7	1.6	1.7
Ride past stop sign without coming to complete stop	1.7	1.5	1.6
Ride through intersection on amber knowing light may turn red*	1.5	1.2	1.4
Ride through intersection on red to turn left	1.2	1.2	1.2
Wear headphones	1.3	1.1	1.2
Ride through pedestrian crossing on red (on road)	1.2	1.1	1.1
Ride against flow of traffic	1.2	1.1	1.1
Use mobile phone to receive calls/texts when moving	1.1	1.0	1.1
Ride through intersection on red to ride straight through	1.0	1.0	1.0
Use mobile phone to make calls/send texts when moving	1.0	1.0	1.0

Response range: 1 strongly disagree; 2 disagree; 3 neither disagree nor agree; 4 agree; 5 strongly agree

* statistically significant difference by previous cycling experience, $p<0.05$

E-bike riders were also asked how often they undertook certain behaviours when riding a pedal bike (7 behaviours) on a 5-point Likert scale (never, occasionally, about half the time, usually, always). Responses are summarised in Table 7.

Comparing the self-reported behaviour of respondents on an e-bike to a pedal bike, all respondents were less likely to check over their shoulder when passing another cyclist when riding on-road on a pedal bike compared to an e-bike. All other behaviours were comparable regardless of whether the respondent was on an e-bike or a pedal bike. However, it is important to note that these are somewhat of an assumption by the *Not previous cyclist* group as their self-reported cycling was a few times a year or less and so they are reporting what they do on those rare occasions when they did ride a bicycle which may be subject to recall bias.

Note, as mentioned in Section 4.3.1, *Not Previous Cyclists* includes respondents who were infrequent adult cyclists prior to their e-bike purchase (rode a few times a year, less than once a year, never).

Table 7 Pedal bike riding behaviours by previous cycling experience

	Previous Cyclist	Not Previous Cyclist	All
When riding on-road bike lane, check over shoulder*	4.3	3.9	4.1
Ride past stop sign without coming to complete stop*	1.7	1.3	1.6
Ride through intersection on amber knowing light may turn red*	1.4	1.2	1.3
Ride through intersection on red to turn left	1.2	1.1	1.1
Ride through pedestrian crossing on red (on road)	1.2	1.0	1.1
Ride against flow of traffic	1.2	1.0	1.1
Ride through intersection on red to ride straight through	1.0	1.0	1.0

Response range: 1 strongly disagree; 2 disagree; 3 neither disagree nor agree; 4 agree; 5 strongly agree

* statistically significant difference by previous cycling experience, $p<0.05$

Scenarios

Respondents viewed a photograph and description of 10 locations with varied cycling infrastructure or no infrastructure and for each scenario indicated their perceptions of safety on a 5-point Likert scale (very unsafe: 1 to very safe: 5). The average score from all respondents was calculated and each scenario was ranked according to the score of how safe e-bike riders felt at the location. All 10 scenarios and their ranking are illustrated in Figure 6.

The fully separated bike lane, also known in Melbourne as the ‘Copenhagen lane’, was ranked the safest type of infrastructure by respondents with a score of 4.6 out of 5. The least safe scenario was the bike lane alongside parallel parking bays through a shopping strip, with a score of 2.47 out of 5. Each scenario was then cross-tabulated with the following data:

- previous cycling experience
- age
- gender
- feeling of safety when riding an e-bike.

Previous cycling experience

The scenarios were ranked in exactly the same order when analysed by the respondents’ previous cycling experience. Further, there was no statistically significant difference between those two groups (experienced and inexperienced cyclists).

Age

Although there were some exceptions, there was general agreement across the age groups with the order of scenarios from safest to least safe. There were some exceptions, notably the youngest age group (18-39) ranked local roads with no parked cars as the safest scenario followed by off-road paths then the fully separated bike lane – while all other age groups ranked the fully separated bike lane as safest.

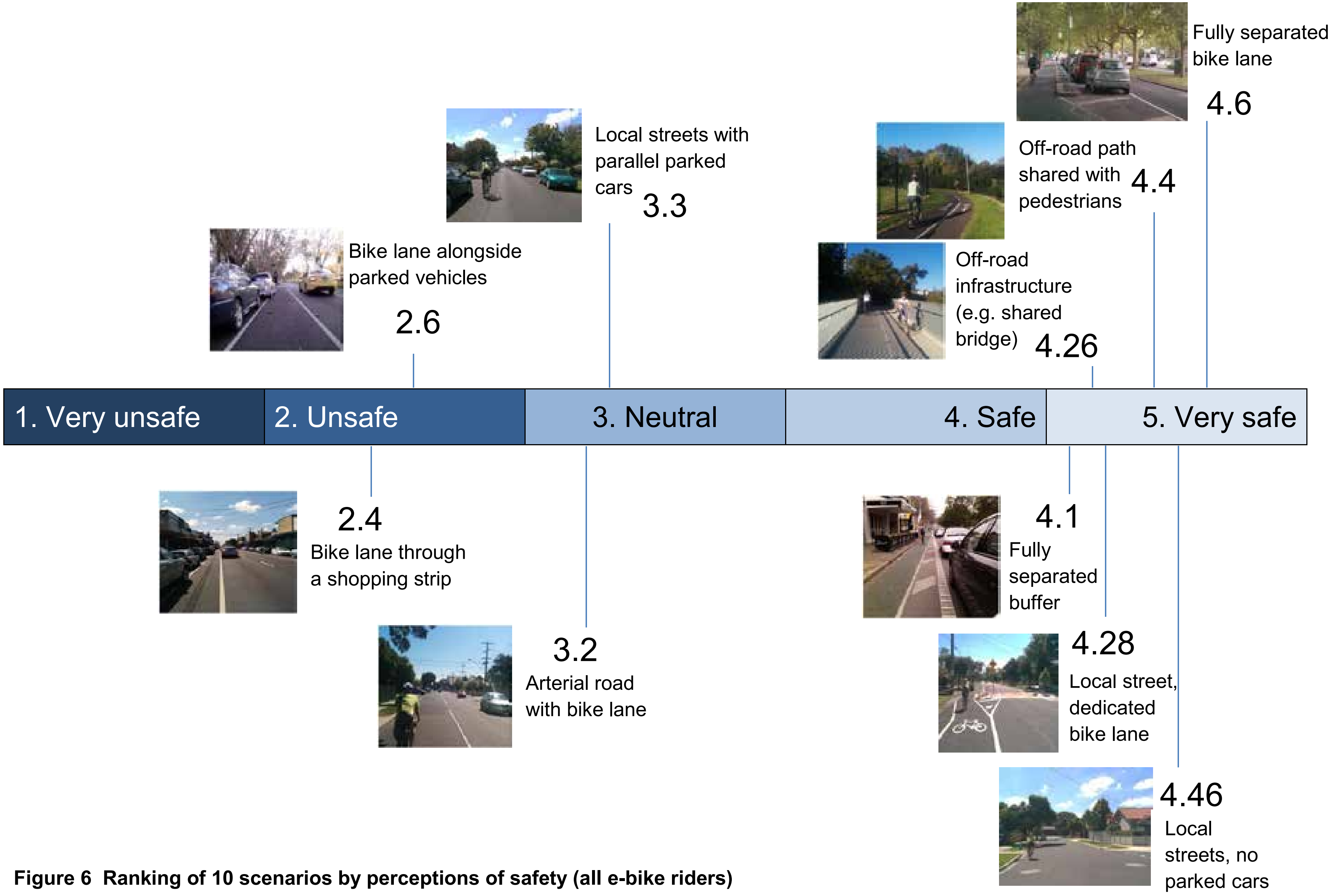


Figure 6 Ranking of 10 scenarios by perceptions of safety (all e-bike riders)

Table 8 Feelings of safety at 10 scenarios by age

Scenarios	18-39	40-49	50-59	60-69	70+	All
Fully separated bike lane	4.6	4.6	4.6	4.6	4.5	4.6
Local streets with no parked cars	4.9	4.4	4.5	4.3	4.2	4.46
Off-road path shared with pedestrians	4.7	4.3	4.3	4.3	4.3	4.40
Local street with dedicated bike lane	4.5	4.4	4.3	4.2	4.0	4.28
Off-road infrastructure (e.g. shared path on bridge)	4.5	4.3	4.2	4.2	3.9	4.26
Fully separated buffer	4.3	4.1	4.0	4.1	3.8	4.10
Local street with parallel parked cars	3.7	3.3	3.2	3.2	3.1	3.32
Arterial road with bike lane	3.5	3.4	3.2	3.1	3.2	3.29
Bike lane alongside parked vehicles	2.9	2.7	2.6	2.6	2.4	2.66
Bike lane through a shopping strip	2.5	2.5	2.5	2.4	2.3	2.47

Across the age groups, on average, the safety ranking decreased with the increasing age of the respondents (18-39 years: 4.01; 40-49 years: 3.8; 50-59 years: 3.74; 60-69 years: 3.7; 70+: 3.57).

Gender

Compared to all respondents, females reported the scenarios in the same order from safest to least safe. The males ranked some of the middle scenarios differently. The list of scenarios by gender is included in Table 9. The responses by males and females were tested statistically. One scenario was significantly different with males more likely to feel safe compared to females on arterial roads with a bike lane.

Table 9 Feelings of safety at 10 scenarios by gender

Scenarios	Female	Male	All
Fully separated bike lane	4.6	4.6	4.6
Local streets with no parked cars	4.5	4.4	4.46
Off-road path shared with pedestrians	4.2	4.4	4.40
Local street with dedicated bike lane	4.2	4.2	4.20
Off road Infrastructure (e.g. shared path on bridge)	4.1	4.3	4.26
Fully separated buffer	4.6	4.6	4.60
Local street with parallel parked cars	3.3	3.3	3.32
Arterial road with bike lane	2.9	3.4	3.29
Bike lane alongside parked vehicles	2.5	2.4	2.45
Bike lane through a shopping strip	2.3	2.5	2.47

Feeling of safety when riding an e-bike

The majority of respondents reported that they did feel safe or very safe when riding an e-bike (83.5%). The people who reported feeling safe/very safe also had the same ranking of scenarios as all respondents. Table 10 below shows the ranking of scenarios by feelings of safety. The category of *Did not feel safe* comprises respondents who replied to the question 'How safe do you feel when riding the e-bike?' with 'neutral' or 'unsafe' (n=59).

Table 10 Feelings of safety at 10 scenarios by feelings of safety on an e-bike

Scenarios	Feel safe on e-bike	Did not feel safe on e-bike	All
Fully separated bike lane	4.6	4.5	4.6
Local streets with no parked cars	4.5	4.2	4.46
Off-road path shared with pedestrians**	4.4	4.1	4.40
Local street with dedicated bike lane	4.3	4.0	4.28
Off-road infrastructure (e.g. shared path on bridge)**	4.3	3.8	4.26
Fully separated buffer	4.1	3.8	4.10
Local street with parallel parked cars**	3.4	2.8	3.32
Arterial road with bike lane	3.3	3.0	3.29
Bike lane alongside parked vehicles**	2.7	2.2	2.66
Bike lane through a shopping strip**	2.5	2.0	2.47

* statistically significant difference by previous cycling experience, **p<0.01; *p<0.05

There was only one scenario that differed in the rankings, with people who did not feel safe on their bike ranking local street with parallel parked cars lower than the people who did feel safe and all respondents. However, for half the scenarios, there were statistically significant differences in the rankings between those respondents who felt safe on their e-bike compared to the respondents who did not feel safe. Those who overall did not feel safe on their e-bike reported lower perceptions of safety for each of the scenarios.

E-bike rider type

Respondents self-reported their e-bike rider type by selecting one of the following five options:

- *Strong and fearless* – identify as a cyclist, cycle on all roadway conditions
- *Enthused and confident* – comfortable sharing the road with motor vehicles, prefer a bike lane
- *Enthused but not confident* – new/returning to riding
- *Interested but concerned* – don’t currently cycle at all but interested in riding, concerned about safety
- *No way, no how* – not interested in cycling at all, pedal or e-bike.

Here we augmented the four types developed by Dill (Dill and McNeil 2013) with the category *Enthused but not confident*, during the development of this study (first suggested by RACV). The e-bike rider type question was positioned at the front of the survey and was followed by a filtering question that meant that the groups *Interested but concerned* and *No way, no how*, were redirected and did not complete the questions about the 10 scenarios. The results for this section are only for the first three e-bike rider types which were: *Strong and fearless*, *Enthused and confident*, and, *Enthused but not confident*. As the other two categories, *Interested but concerned* and *No way, no how*, were grouped as *Not e-bike riders*.

Table 11 Feelings of safety at 10 scenarios by e-bike rider type

	Strong & fearless	Enthused & confident	Enthused, not confident	All
Fully separated bike lane	4.7	4.6	4.6	4.6
Local streets with no parked cars*	4.6	4.4	4.3	4.46
Off-road path shared with pedestrians	4.3	4.4	4.4	4.40
Local street with dedicated bike lane	4.5	4.2	4.1	4.28
Off-road infrastructure (e.g. shared path on bridge)	4.3	4.2	4.1	4.26
Fully separated buffer	4.3	4.1	3.8	4.10
Local street with parallel parked cars	3.7	3.3	2.9	3.32
Arterial road with bike lane*	3.8	3.3	2.9	3.29
Bike lane alongside parked vehicles*	2.9	2.7	2.2	2.66
Bike lane through a shopping strip	2.7	2.5	2.2	2.47

* statistically significant difference by previous cycling experience, $p<0.05$

In the main, the scenarios were ranked as per all responses. The exceptions were that the most confident e-bike riders ranked local streets with dedicated bike lane and arterial road with bike lane higher than all respondents and the *Enthused, not confident* group ranked off-road shared paths higher.

Locations e-bike riders avoid

Nearly three quarters of e-bike riders (73.5%) reported that there were road types/locations that they avoided when riding their e-bike. Drawing on responses to an open ended question, the specific road types/ locations described by respondents have been differentiated by their previous cycling experience and are shown in Table 12.

Over half of all e-bike riders, regardless of their previous cycling experience avoided major roads or roads with busy motorised traffic, including peak travel times.

The third most avoided location were roads that the respondent had named with 46 different roads named across Victoria, mostly in metropolitan Melbourne. Fifteen roads were mentioned by more than one respondent: Princes Highway was named by 5 respondents; Beach Road, Nepean Highway and Sydney Road were named by 3 respondents each and 2 respondents each named Middleborough Road, Bulleen Highway, Dandenong Road, Heidelberg Road, Geelong Road, King Street/Road, Main Road, Springvale Junction, St Kilda Junction and Warrigal Road. However, in the main, e-bike riders did not name the suburbs for these roads and this limits the insights provided as many of these roads stretch for many kilometres, often through numerous suburbs.

Previous cyclists named more specific roads than those respondents who had not been regular adult cyclists prior to purchasing their e-bike. The difference in responses by previous cycling experience was not statistically significant.

Table 12 Types of roads/locations avoided by e-bike riders by previous cycling experience

	Previous cyclist		Not previous cyclist		All	
	N	%	N	%	N	%
Major roads	69	23.1	52	27.2	121	24.7
Roads with busy traffic, peak travel times	78	26.1	49	25.7	127	25.9
Specifically named roads	45	15.1	24	12.6	69	14.1
Poor surfaces e.g. loose gravel, dirt	10	3.3	14	7.3	24	4.9
Speed, 60kph+	17	5.7	13	6.7	30	6.1
Narrow roads	20	6.7	8	4.2	28	5.7
Roads without bike lanes	10	3.3	6	3.1	16	3.3
Roundabouts	5	1.7	4	2.1	9	1.8
City - roads, traffic, drivers	5	1.7	4	2.1	9	1.8
Shopping areas inc. centres and strips	4	1.3	2	1.0	6	1.2
Main intersections	2	0.7	2	1.0	4	.8
Only ride off-road	9	3.0	2	1.0	11	2.2
Alongside parallel parked cars	5	1.7	2	1.0	7	1.4
Roads with trucks	2	0.7	2	1.0	4	.8
Steep hills	2	0.7	2	1.0	4	.8
Bridges	1	0.3	1	0.5	2	.4
Country roads - narrow, restricted sight lines	4	1.3	1	0.5	5	1.0
Tram tracks	6	2.0	1	0.5	7	1.4
Roads with other cyclists	0	0	1	0.5	1	.2
Unpaved roads	2	0.7	1	0.5	3	.6
Bus routes	1	0.3	0	0	1	.2
Off-road shared paths	1	0.3	0	0	1	.2
Roadworks	1	0.3	0	0	1	.2

To overcome shortcomings at the locations that people avoided, the most common suggestion was bike lanes and paths (63.1%), including separated bike lanes (29.7%), more bike lanes (25.1%), connected bike lanes (5.3%) and more off-road bike paths (3.0%). Other suggestions included better road design that was inclusive of bicycles (7.6%), road user hierarchy that encouraged use by specific road users and restricted use by others (4.4%) and permitting cyclists of all ages to ride on the footpath (3.0%).

Unsafe event

Half of all respondents (55.3%) had experienced an unsafe event on their e-bike. The factors that contributed to these events are listed in Table 13. The most commonly reported factor that contributed to the unsafe event was an interaction with a motor vehicle which accounted for almost half (45.8%) of the unsafe events and included events with car doors (8.4%).

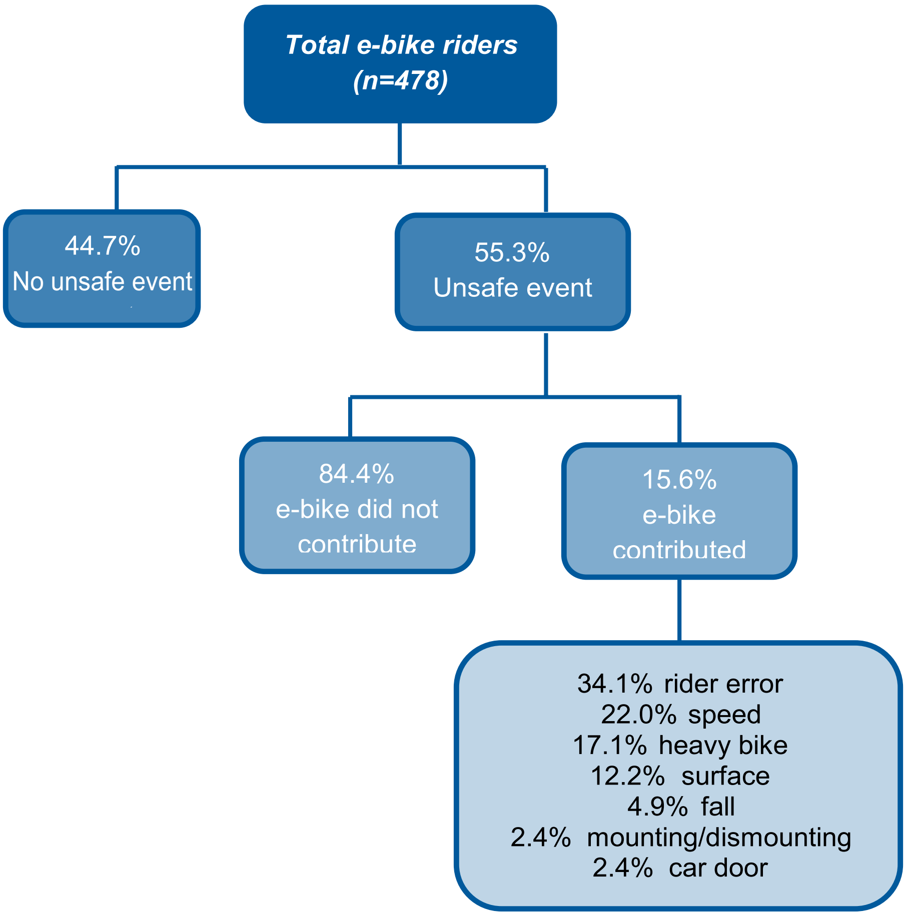
Rider error was the next most common factor and typically related to unintentional acceleration and loss of balance. Surface was also frequently reported as a contributing factor. Issues related to the surface included on-road and off-road, wet/slippery surfaces, gravel and potholes. Speed was reported by fewer than ten per cent of respondents. However, speed could be a factor in some of the other crash categories, in particular rider error and surface although it was not explicitly identified. Nine respondents reported they had fallen off their e-bike without elaboration and the heavy bike contributed to seven events. The presence of other cyclists, typically on bike paths, was identified as another factor contributing to unsafe events, and two of the respondents specifically identified pedal cyclists travelling at high speed on bike paths and the event occurring on a 'blind' corner. The respondents did not state the speed at which they were travelling. Pedestrians were also identified, in particular distracted pedestrians on bike paths. The factors grouped as *Other* were all responses with four or fewer responses and included dogs, distracted rider, tram tracks, mounting/dismounting and intoxicated.

Table 13 Factors that contributed to unsafe event

	Count	Percentage
Interaction with motor vehicle	67	37.4
(car door)	(15)	(8.4)
Rider error	23	12.8
Surface, wet, poor, gravel	21	11.7
Speed	15	8.4
Fell	9	5.0
Heavy bike	7	3.9
Other cyclists	6	3.4
Pedestrians	5	2.8
Other	11	6.1
Total	179	100.0

Figure 7 shows the number of unsafe events experienced by e-bike riders and details the factors in the events where the e-bike itself contributed. Of those people who had experienced an unsafe event, 15.6 per cent reported that the e-bike had contributed to the event. The top three reasons for these crashes, which comprised almost three quarters of the events, were due to rider error (34.1%), speed (22.0%) and the heavy bike (17.1%). Other factors that were attributed to the e-bike included surface being ridden on (12.2%), fall (4.9%), interaction with a motor vehicle (4.9%), mounting/dismounting (2.4%) and car door (2.4%). The contribution of the e-bike to the crash events were identified by the respondents, however, the role of the e-bike in these crashes is not clear.

Figure 7 Distribution of unsafe events experienced by e-bike riders



4.3.2 Potential e-bike riders

People were grouped into one of three categories: e-bike riders, potential e-bike riders and don't ride. The questions that identified the classification were early in the survey (Q6, Q7) and potential e-bike riders and don't ride groups skipped the main survey questions related to cycling behaviours and experiences.

The questions and responses that were used to identify potential e-bike riders were:

- How would you describe yourself as an e-bike rider?
  - o Interested but concerned – don't currently cycle at all but interested in riding, concerned about safety
- Have you ridden an e-bike?
  - o No, but I'm interested in trying/riding an e-bike.

In total, 181 respondents were identified as potential e-bike riders. Table 14 presents a summary of the key characteristics of the potential e-bike riders.

As for the e-bike riders (considered in the previous section), age and gender were statistically significantly different when analysed by previous cycling experience:

- Gender: the majority of all potential e-bike riders were male (71.7%). However, a greater proportion of female e-bike riders had no previous cycling experience. Compared to the e-bike riders (Table 1) considerably more potential e-bike riders responded, suggesting a sizable latent curiosity about cycling by e-bike among Victorian females and a high percentage of those were not previous cyclists.
- Age: the majority of potential e-bike riders were aged over 50 years (65.1%, range: 18-80 years). Respondents who are adult cyclists were more likely to be slightly younger (female: 51 years; male 52 years) than potential e-bike riders who were not previous adult cyclists (females: 56 years, male 56 years).

Table 14 Summary of key characteristics of potential e-bike riders by previous riding experience

	Previous cyclist		Not previous cyclist		All	
	N	%	N	%	N	%
	111	61.3	70	38.7	181	100
Gender*						
Female	17	15.3	32	46.4	49	27.2
Male	92	82.9	37	53.6	129	71.7
Other	2	1.8	0	0.0	2	1.1
Age*						
18-39	18	16.2	8	11.4	26	14.4
40-49	25	22.5	12	17.1	37	20.4
50-59	30	27.0	14	20.0	44	24.3
60-69	25	22.5	25	35.7	50	27.6
70+	13	11.7	11	15.7	24	13.3
Licence status						
Car	103	64.4	63	64.3	166	64.3
Motorcycle	31	19.4	16	16.3	47	18.2
Heavy vehicle	21	13.1	18	18.4	39	15.1
None	5	3.1	1	1.0	6	2.3
RACV member						
Yes	88	79.3	60	85.7	148	81.8
No	23	20.7	10	14.3	33	18.2

* statistically significant difference by previous cycling experience, $p<0.05$

The main barrier that stopped the majority of people (83.1%) riding was the cost to purchase an e-bike, including the majority of RACV members (95, 64.2%).

5 Discussion

A number of key issues emerge when the insights from the systematic literature review, the review of bicycle facility design guidelines and the survey results are synthesised. This section first examines the key issues associated with e-bike riders and then examines issues associated with infrastructure and safety.

E-bike riders

The results from the survey have reinforced the typical demographic characterisation of e-bike riders which is found in the literature. They are older riders, ranging in age from 18 to 86 years. The average age of survey respondents was mid-50s and the majority had some type of post-secondary education. While almost half worked full time, almost a third were retired. Unlike the typical image of cyclists in Australia, as being athletic and cycling for sport (O'Connor and Brown 2007, O'Connor and Brown 2010), e-bike riders were more likely to be riding for transport, to commute and replace some car trips. For many, the e-bike augmented their other transport modes, as nine out of 10 had a current driver's licence and the majority of respondents were members of RACV.

There are a range of barriers to cycling for many people, some of which are being overcome with an e-bike. The most frequently reported motivations for first riding an e-bike include riding with less effort to improve health, for long distance commutes to work, to overcome hilly terrain and age. It is unlikely that these issues will be or perhaps could be overcome to enable someone to ride a pedal bicycle. Typically in reports of cycling participation in Australia, females comprise less than a third of participants (Australian Bicycle Council and Austroads 2013). The survey conducted as part of this study produced a similar result with females comprising a quarter of all respondents. However, almost four in ten female e-bike riders had not been regular cyclists before purchasing or riding an e-bike. While women accounted for about a quarter (27%) of potential e-bike riders, nearly two thirds (65%) of them were not previous cyclists. This highlights that women who have not been previous cyclists are a potentially important sub-market for e-bikes. The ability of e-bikes to attract people who were not previous cyclists has not been highlighted in the literature to date. Those riders are likely to have a lower level of cycling proficiency and their bike handling skills may not be in tune with the faster, heavier e-bike that they are riding.

Not surprisingly given many e-bike riders were older and retired, they were on lower incomes. This is likely to mean that the higher cost of an e-bike, compared to a conventional bicycle which the rider might contemplate as an alternative, may be a barrier to the uptake of this mode by current non-users.

The experience profile of e-bike riders suggests that there is a need for education about the safe use of their e-bikes. Elderly riders may have more difficulty applying sufficient pressure on brake handles to produce the same decrease in speed as on a conventional bicycle. Riders need to be aware of the risk which can be associated with riding an e-bike at a higher speed than they would if riding a conventional bicycle, particularly in more complex traffic situations. Evidence from the literature and also from the survey, suggest that poor surface quality, particularly gravel, can be associated with a higher risk of losing control of the e-bike. If an unsafe event does arise, riders then need to respond appropriately on a heavier bike that may have different dynamic characteristics to a conventional bicycle. Given that e-bike riders are older, there is a risk of more severe injuries particularly when factoring in the heavier e-bike and travelling at a higher speed than they would on a conventional bike. Some form of education or awareness campaign could be beneficial for new and existing e-bike riders, particularly those who are older and lack previous cycling experience.

Infrastructure and Safety

Consistent with the literature, survey respondents have highlighted the importance of dedicated infrastructure in providing an environment in which they feel safe to cycle. While respondents indicated they felt very safe on facilities where they were separated from traffic, they felt unsafe in unprotected bicycle lanes. In addition, those e-bike riders who were not previously cyclists felt even less safe on unprotected bike lanes than their experienced counterparts.

Neither the literature review nor the survey responses highlighted any substantial safety issues associated with e-bike use. Australia is likely to be spared the poorer safety outcomes associated with e-bikes in China because of better enforcement of the maximum speed limit (25 kph) specified in the regulations. While about half the survey respondents had experienced an unsafe event when riding their e-bike, only one in nine of them felt the e-bike had contributed to the unsafe event. Consistent with results from previous surveys, the one conducted in this study identified poor path surface, spot speed, the heavier bike and rider error as contributing factors to unsafe events involving e-bikes. Those factors do have implications for designers of bicycle facilities.

Australian bicycle facility guidelines currently make no reference to e-bikes. Two particular features of e-bikes need greater consideration by bicycle facility designers: their greater hill climbing capacity and their higher spot speed relative to the speed the rider would be travelling at if riding a conventional bicycle. Particular features of bicycle facilities which may require closer attention from designers as more e-bikes are used on bicycle facilities include:

- recognition of the higher hill climbing capacity when bicycle routes are being designated
- care in the geometric design of facilities including the choice of horizontal and vertical curve radii and lateral clearances as well as widths for bicycle lanes and paths
- consideration of the risks associated with loose path surfaces when path materials are being chosen and path maintenance is being undertaken
- better management of increased interactions by users through signage and education.

6 Conclusion

This study is the first undertaken in Australia to examine the safety implications of e-bikes and in particular the implications of e-bikes for the design of bicycle facilities. It has drawn on a systematic review of the literature along with a review of relevant guides for the design of bicycle facilities. Those components of the study helped inform the development of a survey of e-bike riders and potential e-bike riders. Nearly 500 e-bike riders responded to that survey, along with nearly 200 potential e-bike riders.

The study has highlighted the importance of the older age profile, less riding experience and potentially lower cycling proficiency which characterises e-bike riders. Those e-bike rider characteristics, when combined with the greater hill climbing capacity and higher spot speed of e-bikes, have potential implications for bicycle facility design. Current bicycle facility design guidelines in Australia make no mention of e-bikes yet they have implications for designation of bicycle routes, choice of path surface materials and maintenance as well as for the geometric design of bicycle facilities.

Consistent with the literature, respondents to the survey conducted in this study have highlighted that while they feel very safe on facilities which provide separation from motor vehicles, they feel unsafe on unprotected bicycle lanes. While there is no evidence that e-bike riders are different to riders of conventional bicycles in that regard, it is appropriate to note, that e-bike riders who were not previously cyclists felt even less safe on unprotected facilities.

As e-bikes continue to grow as a proportion of the bicycle fleet there will be a need for on-going research to better understand how to maximise the potential of this mode to contribute to a safe, sustainable transport system. Given the characteristics of existing and potential e-bike riders, a priority would seem to be the development of education material or rider training programs designed to ensure that older riders of e-bikes develop understanding not only of their limitations but also how to safely control a heavier bicycle which will enable them to travel faster than if they were riding a conventional bicycle.

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