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Gender differences in bicycle infrastructure use and preferences: A disconnect between ideals and reality

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ABSTRACT

In low bicycling countries, bicycling participation is typically dominated by men. There are differences in the types of infrastructure women and men feel comfortable riding a bike in, where women report a preference for protected infrastructure that separates them from interactions with motor vehicle traffic. We know little, however, about differences in the types of infrastructure and roads women and men actually ride on, otherwise described as the difference in stated versus observed preference data. In this study, we quantified differences between women and men in the types of infrastructure they ride a bike in, and how this differs from their stated preferences. We conducted a prospective observational study of trips taken by adults made by bicycle in Greater Melbourne, Australia. We mapped the trips to road and bicycle infrastructure types using OpenStreetMap (OSM) data and stratified the results by gender. A total of 673 participants were included in the study (34% were women), who undertook 19,782 bike trips. There were statistically significant differences in infrastructure types used between women and men ($X^2 = 3743.5$, $p < 0.001$), where a larger proportion of trips taken by men were made on off-road paths (38% vs. 32%), and on arterial roads in mixed traffic (18% vs. 11%). A larger proportion of trips made by women were on local roads in either mixed traffic or painted bike lanes. For the 57% of women who reported feeling uncomfortable in mixed traffic, 46% of their trips were spent in mixed traffic environments. Further research that identifies the influence of a range of factors on women's bicycling travel behaviors, including trip purpose and conditions (e.g. if riding with children) is required to better understand how we implement infrastructure to enable more women to ride a bike.

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1. Introduction

Bike-riding has the potential to play a pivotal role in reduction of private vehicle emissions through modal shift, to significantly improve public mental and physical health, and to minimize existing transport and health inequities faced by under-represented groups, particularly women, older adults, and racialized people (Brand et al., 2021; Leyland et al., 2019; Ma & Ye, 2019; Oja et al., 2011). Despite benefits, bike-riding participation in many countries is low, and there are substantial inequities in who is able to access bike riding as a form of transport (Goel et al., 2022). In Australia, for example, twice as many men ride a bike than women (Goel et al., 2022). Women within these low participation areas are however, willing to ride (Pearson et al., 2022), and there are many countries where more women ride bikes than men (Haustein et al., 2020). A key difference between areas of low and high rates of participation by women is widespread provision of protected and connected infrastructure, where areas with greater provision of infrastructure have greater levels of women riding (Goel et al., 2022; Organization WH, 2023). This is consistent with previous research of barriers to bike riding, where more women report concerns about riding on the road alongside motor vehicle traffic (Pearson et al., 2023). While the importance of provision of protected and connected infrastructure is recognized as key to both increasing and diversifying bike riding participation, there are challenges in prioritizing what kinds of infrastructure should be implemented across cities to meet the needs of a diversity of population groups (Lemon et al., 2023; Robartes et al., 2021).

Our current understanding of what kind of infrastructure is needed to meet the needs of diverse populations, and particularly women, is reliant on evidence from stated preference surveys. Such evidence is the main and most popular source found across the literature that has been

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disaggregated by sex or gender, and involves participants detailing travel behavior and preferences, often within hypothetical scenarios. Previous research indicates notable differences in stated preferences of bicycling infrastructure between women and men who ride a bike, where women consistently report a greater preference for protected infrastructure that separates them from motor vehicle traffic (Aldred et al., 2017; Patterson et al., 2005). While this method of research is important for understanding individuals' perceptions and preferences for travel behavior, these surveys may not reveal the complexities of real-world travel behavior (Bricka et al., 2012), resulting in potential bias.

Stated preference data sources, including surveys and hypothetical scenarios that ask individuals how they think they would respond or feel within specific infrastructure scenarios are valuable, however are subject to potential social desirability bias and the influence of hegemonic gender norms (McLean & Hope, 2010; Minhas & Oksol, 2019). For example, men may underreport feelings of fear or discomfort in higher-stress bicycling infrastructure due to cultural expectations of stoicism and risk tolerance, while women may overstate their concerns, reflecting both internalized narratives of vulnerability and genuine experience. As a result, stated preferences may distort the complexity of the impact of gender on actual travel behavior. Revealed preference data through actual observed behavior offers genuine differences between women and men's behaviors, providing an additional perspective in the design of inclusive urban environments.

While there is a growing body of research on gender and bike riding, studies examining gender differences in actual trip characteristics using revealed preference data remain relatively limited. Specifically, they do not consider specific infrastructure types, and are of varying quality due to potential bias from reliance on utilizing crowdsourced GPS data sources (Heesch & Langdon, 2016; Pettit et al., 2016). For example, Strava data are limited by a lack of population representation shown by a demographic bias toward men and people aged between 25 and 44 years, and available only at an aggregate level (Boss et al., 2018; Lee & Sener, 2021). One study that used GPS data aimed to overcome the demographic bias of who cycles by oversampling women, however did not stratify results by gender (Broach et al., 2012). The body of research on actual trip characteristics has, nonetheless, demonstrated that women's bike trips tend to be shorter in distance, less likely to involve steep hills, more likely to involve trip-chaining (such as combining stops for errands, childcare, or household tasks), avoid complex intersections, and are more commonly undertaken during off-peak hours (Heinen et al., 2013; Misra & Watkins, 2018; Rupi et al., 2023). While these factors are critical in understanding the typical travel behavior of women when traveling by bike, they do not provide detail regarding the specific types of infrastructure used. Further, there may be differences between stated and revealed preference data. If infrastructure continues to be implemented without considering evidence of women's real-world travel behavior, it risks failing to adequately address their complex travel needs.

No research to date has compared how stated preferences (i.e. how people want to travel by bike) and revealed preferences (i.e. how people actually travel by bike) differ in the context of bike-riding. Comparing discrepancies between stated and revealed preferences for women and men can highlight other factors, beyond infrastructure preference, that may influence travel behavior. By stratifying by gender, differences in the types of infrastructure preferred and used by women and men can be determined, demonstrating if existing bicycle networks equitably satisfy the preferences of both groups.

Understanding gender differences in travel behavior and preferences is needed to be able to better design and plan equitable urban environments. In this research, we quantify the differences between women and men in the types of infrastructure they ride a bike in, and how this differs to their stated preferences.

2. Methods

2.1. Study design

This study was a prospective observational study of bicycle trips taken by adults in Greater Melbourne, Australia. We used the term "bicycle" within this study and throughout this paper as an inclusive term for all vehicles powered either in part or fully through pedaling, including bicycles, tricycles, recumbent bicycles, cargo bicycles, quadricycles, and electrically assisted cycles. We define trips as the movement or travel of a person between two activities for any purpose other than solely recreation (e.g. shopping, work, social, errands). In this paper we are contrasting the preferences and behaviors of women and men, however we recognize that gender is a continuum that extends beyond this. We present whole of population results in a separate paper, however due to small numbers of participants whom identified as non-binary and/or gender diverse ($n = 7$), this prevented us from exploring this group in further detail.

This project was approved by the Monash University Human Research Ethics Committee (Project ID: 29848).

2.2. Setting

Greater Melbourne is the largest city in Australia, and is the capital city of the state of Victoria (Australian Bureau of Statistics, 2021). Victoria has a population of 6.7 million, of which 67% reside in the Greater Melbourne area (Australian Bureau of Statistics, 2021). As per Victorian Integrated Survey of Travel and Activity (VISTA) data from 2018 to 2020, bike riding made up 2% of mode share, with 35% of bicycle trips made by females (Victorian Department of Transport & Planning, 2020).

2.3. Sampling and recruitment

We aimed to recruit a sample of people aged 18 years and over with representation based on age group, gender, urban area and interest in bike riding. To achieve this, we advertised a study flyer through print and online media across multiple stakeholder organization platforms, including Bicycle Network, WeRide Australia, VicHealth, Parents' Voice, the Amy Gillett Foundation, the Municipal Association of Victoria, Melbourne local Councils, local Bicycle User Groups (BUGs), and bike riding social media pages. The study flyer advised potential participants that they could be eligible to participate if they owned a bike and had ridden a bike within the past 12 months. The flyer also provided details regarding a prize draw to win an e-bike, one of 20 bike store vouchers, and one of 20 key stakeholder organization memberships if they completed the study data collection period. To confirm eligibility, participants completed a short online survey of their demographic and mobility information and were contacted by research staff following completion.

2.4. Data collection

Data collection was achieved through the use of a smartphone application that was paired with a Bluetooth beacon attached to participants' bicycles. Research staff posted eligible participants a Bluetooth beacon, ties to enable the beacon to be secured to their bike, and information regarding how to install the beacon and download an adjoining smartphone application, 'Ethica'. Ethica (now 'Avicenna') is an end-to-end platform that enables measurement of trips made by bike through GPS data without participants needing to manually begin and end trips on their smartphone. The Ethica app collected GPS data only when in proximity to the Bluetooth beacon installed on participants bikes and when movement was detected. Further details are provided within a previous paper (Bhowmick et al., 2025).

2.5. Survey design

Participants completed a short survey regarding their demographic information (age, gender, income, occupation, employment status, bike ownership and type of bike owned), mobility patterns (main mode of transport, frequency of trips by bike and purpose of bike trips) and comfort level in specific types of infrastructure scenarios. Comfort level was ascertained using questions derived from the Four Types of Cyclists tool, developed by Geller and refined by Dill & McNeil (Dill & McNeil, 2013; Geller, 2006). To enable use in an Australian context, alterations were made to survey questions to reflect kilometers per hour over miles per hour, and change from "striped bike lane" to "painted bike lane", to reflect terminology use. Alterations made were consistent with previous use of this survey in an Australian context (Pearson et al., 2022). Participants were categorized as either 'Strong and Fearless', 'Enthused and Confident', 'Interested but Concerned' or 'No Way No How' in relation to riding a bike, based on responses to the survey. Categorization of participants into one of the four groups depended on responses to questions regarding comfort level in specific infrastructure types, frequency of riding a bike, and interest in riding a bike. The process of categorization is detailed in Pearson *et al.* (Pearson et al., 2022). For the purpose of this study and based on the distributions of the categories, participants were classified into one of two groups: 1) 'Strong and Fearless' or 'Enthused and Confident'; and 2) 'Interested but Concerned'.

Questions used descriptions and graphics of a person riding a bike within the described infrastructure conditions. Participants were asked to select from a 4-point Likert scale for their level of perceived comfort in that scenario, ranging from 1="Very uncomfortable" to 4="Very comfortable". Results across similar infrastructure scenarios (e.g. painted bike lanes) were averaged to produce a mean, and this was used alongside frequency of and interest in bike riding to categorize individuals as one of the Four Types of Cyclist. Descriptions of each group are provided in Table 1.

2.6. Infrastructure preference data

Based on the responses to the questions regarding comfort level of participants in specific infrastructure types (from the 'Four Types of Cyclists' categorization), we captured the stated infrastructure preference of participants. There were seven questions that asked participants to rate their preference of infrastructure: one for protected bike lanes and off-road bike paths, three for painted bike lanes and three for mixed traffic situations (devoid of any bike infrastructure). Multiple questions regarding specific types of bike infrastructure (e.g. painted bike lane) presented each infrastructure type in combination with other road infrastructure characteristics (e.g. road type and road speed limit). Participants were asked to respond about their perceived comfort on a 4-point Likert scale: *very uncomfortable*, *uncomfortable*, *comfortable* and *very comfortable*. Responses to these questions were reclassified into a binary variable of 'uncomfortable' (including *very uncomfortable* and *uncomfortable*) and 'comfortable' (including *very comfortable* and *comfortable).* From this, we derived the proportion of participants who were *uncomfortable* riding a bike across each of the three infrastructure classes: 1) protected bike lanes and off-road paths (reflecting participants who responded 'uncomfortable'/'very uncomfortable' to the one question on protected bike lanes and off-road paths); 2) painted bike lanes (reflecting participants who responded 'uncomfortable'/'very uncomfortable' to all three painted bike lane questions); and 3) mixed traffic (reflecting participants who responded 'uncomfortable'/'very uncomfortable' to all three mixed traffic questions).

2.7. Road and path network

We used OpenStreetMap (https://www.openstreetmap.org) to extract information related to the underlying bikeable road network within our study area. We worked in conjunction with the Victorian Department of Transport and Planning and using existing studies to calibrate a bespoke classification system to suit local OpenStreetMap tagging practices. We used this for classification of road types, bicycling infrastructure and Bicycling Level of Traffic Stress

Table 1. Summary of each of the four types of cyclist.

Type of cyclist	Description as per Dill & McNeil	Use in this study
Strong & Fearless	"Very Comfortable" or "Comfortable" on nonresidential streets without bike lanes	Combined with Enthused & Confident group
Enthused & Confident	"Very Comfortable" or "Comfortable" on nonresidential streets with painted bike lanes	Combined with Strong & Fearless group
Interested but Concerned	"Very Uncomfortable" or "Uncomfortable" on nonresidential streets with or without bike lanes Not "Very Uncomfortable" on a path or trail separate from the street Does not "Strongly Disagree" with wanting to ride a bike more Does not meet above conditions, however has ridden a bike in the past 30 days	Included group
No Way No How	"Very Uncomfortable" or "Uncomfortable" on nonresidential streets with or without painted bike lanes "Very Uncomfortable" on a path or trail separate from the street "Strongly Disagree" with wanting to ride a bike more Unable to ride a bike due to injury or other medical condition	Excluded from study

(LTS). Leveraging these existing classifications, we developed a new combined road type and bicycling infrastructure to better understand the diversity of environments availed by people riding bikes. Details of each classification are outlined below.

Road type: Road segments and paths were classified based on functionality (OpenStreetMap, 2025). These included:

- Arterial roads: High-capacity roads which are principal connectors between major regions, commercial centers and inter-transport hubs. These roads typically have higher motor vehicle speeds.
- Collector roads: Roads that provide traffic movement between arterial and local roads, and act as feeders to local road systems.
- Local roads: Roads that primarily provide access to residential property. These roads comprise the majority of the network.
- Paths and crossings: All off-road paths (dedicated and shared bike paths) and road crossings.

Further detail regarding road type classifications are available at the Sustainable Mobility & Safety Research Group Github (Sustainable Mobility & Safety Research Group MU, 2024).

Bicycling infrastructure type: Bicycling infrastructure were classified within the Australian context based on local knowledge and existing studies. Classifications included:

- Dedicated bike path
- Shared bike path
- Pedestrian path/street with cycling allowed
- Protected bike lane
- Buffered bike lane (kerb-side/road-side/both-sides)
- Painted bike lane
- Advisory bike lane
- Peak hour painted bike lane
- Peak hour advisory bike lane
- Sharrow
- Shared zone
- Bus lane with cycling allowed
- Mixed traffic
- Bicyclist's dismount
- Pedestrian path/street with cycling not allowed

For the purposes of this study, we clustered these infrastructure types into 4 groups: off-road paths (including dedicated bike paths, shared bike paths and pedestrian path/street with cycling allowed); protected bike lanes; painted bike lanes (including buffered bike lanes); and mixed traffic environments (including advisory bike lanes, sharrows, shared zones, and bus lane with cycling allowed).

Further detail regarding bicycle infrastructure classifications are available at the Sustainable Mobility & Safety Research Group Github (Sustainable Mobility & Safety Research Group MU, 2023).

Combined road type and bicycling infrastructure classification: Our final classification includes a combination of road type and bicycling infrastructure, as defined above. Classifications were defined based on existing literature, and to suit local conditions. Classes included:

- Arterial Road – Mixed Traffic: Arterial roads devoid of any type of bicycling infrastructure, where riders directly interact with motor vehicles.
- Arterial Road – Painted Bike Lane: Arterial roads with an on-road painted bike lane that separates motor vehicle traffic from riders with a solid white, green or yellow painted line.
- Collector Road – Mixed Traffic: Collector roads devoid of any type of bicycling infrastructure, where riders directly interact with motor vehicles.
- Collector Road – Painted Bike Lane: Collector roads with an on-road painted bike lane that separates motor vehicle traffic from riders with a solid white, green or yellow painted line.
- Local Road – Mixed Traffic/Sharrow: Local roads that either have no bicycling infrastructure, or without a specific bicycle lane but with painted arrows and a bicycle symbol indicating it is a shared street.
- Local Road – Painted Bike Lane: Local roads with an on-road painted bike lane that separates motor vehicle traffic from riders with a solid white, green or yellow painted line.
- Protected Bike Lane: On-road bike lanes that are physically separated and thus protected from motorized traffic via a physical barrier.
- Off-road Bike Path: Either a shared user path (i.e. bicycles and pedestrians) or dedicated bike path that is completely separated from a road (i.e. does not share road space).
- Other: All other infrastructure types.

Bicycling Level of Traffic Stress (LTS): Bicycling LTS was derived using a combination of bicycling infrastructure, posted speed limits, motor vehicle volume, lane width and road type. Classifications were calibrated to suit local conditions. Classes included:

- LTS-1 (Low stress): Suitable for almost all people riding bikes, including children. LTS-1 involves off-road bike paths, protected (physically separated) bike lanes, and roads with minimal traffic and low speeds (typically below 30 km/h).
- LTS-2 (Moderate stress): Appropriate for most adults. Roads classified as LTS-2 have moderate traffic volumes and speeds (typically up to 40 km/h), often featuring dedicated bike lanes or wide shoulders. The interactions between cars and people riding bikes are low-stress but may still discourage less confident riders.
- LTS-3 (Higher stress): Suitable for experienced and confident riders. This classification includes busier streets with higher traffic volumes and speeds (typically above 40 km/h). Bicycling infrastructure may be present but often in the form of painted lanes.
- LTS-4 (High stress): Appropriate for highly experienced or confident riders, including those comfortable with high-speed traffic (often exceeding 50 km/h) and narrow lanes. These roads have little or no bicycle infrastructure.

Further detail regarding classifications of Bicycling LTS are available at the Sustainable Mobility & Safety Research Group Github (Sustainable Mobility & Safety Research Group MU, 2024).

2.8. GPS data collection and pre-processing

Our novel approach of collecting bike-riding GPS data from participants using the combination of a Bluetooth beacon and a smartphone app allowed us to collect data at a large-scale while mitigating challenges associated with continuous data collection, participant workload and user bias. Consequently, raw GPS data underwent standard pre-processing steps of noise filtering (Zheng, 2015), trajectory segmentation (Bhowmick et al., 2020; Lißner et al., 2020), and mode detection (Lißner & Huber, 2021) for being converted to individual bike trips (Bhowmick et al., 2025). Finally, the individual GPS trips were map-matched to the underlying bikeable road network to estimate associations with network-related data including road type, combined road and infrastructure type, and bicycling Level of Traffic Stress.

2.9. Comparing stated preferences and revealed preferences

To explore the disconnect between people's preferences and the environments in which they actually ride, we compared stated preference data with revealed preference data. Focusing specifically on participants who were classified as being uncomfortable in mixed traffic environments, we descriptively explored the proportion of their trips (based on trip distance) that were spent in mixed traffic environments (i.e. road environments without bicycling infrastructure).

2.10. Statistical analysis

We used the Chi-squared test of independence of variables in a contingency table to infer whether there were statistically significant differences in observed infrastructure preferences between men and women. We computed the aggregated total distance traveled by all men and women participants across all classes of three different types of infrastructure classifications, (a) road type, (b) combined road and bike infrastructure type, and (c) bicycling level of traffic stress type. Thus, we derived the three sets of distribution data for each type of infrastructure classification, each set containing a pair of distributions, one for men and one for women. Each pair of distributions were then compared using the Chi-squared test. While we used aggregated total distance in the Chi-squared test, we have provided proportions in the visualizations for ease of understanding.

3. Results

A sample of 903 participants completed the initial screening survey and were sent the required briefing study materials. Of this, 75% ($n = 673$) completed at least one bike trip. Of this sample, 666 participants identified as either women ($n = 221$; 33%) or men ($n = 445$; 67%), and were included in the following study results. A total of 19,782 bike trips across Greater Melbourne were collected from the sample.

3.1. Participant characteristics

Most participants were aged between 35 and 45 years (49%), identified as men (67%), and were categorized as Interested but Concerned (84%). Compared to the bike-riding population of Greater Melbourne, our study sample had a higher proportion of people who were aged between 45 and 64 years, and a lower proportion of people aged between 18 and 34 years. The majority of participants in our study sample were employed full-time (68%).

3.2. Travel behavior

Most participants reported that they used a car at least once per week but not daily (56.5%), and rode a bike at the same frequency (68.6%). Most participants owned a pedal bike only (88.6%). Approximately one third (33.9%) of trips by bike were made by women. Women took fewer trips per week compared to men (Mean = 3.7 vs. 4.8), rode for shorter distances on an average (Mean = 6.8 km vs. 10.6 km), and had a reduced trip duration (Mean = 26.9 min vs. 34.6 min). Further details of participant characteristics and mobility patterns are detailed in Table 2.

Table 2. Participant characteristics.

Characteristic	Women *n* (%) *n* = 221	Men *n* (%) *n* = 445	Total *n* (%)
Age			
18-24 years	4 (1.8)	12 (2.7)	17 (2.5)
25-34 years	48 (21.7)	70 (15.7)	120 (17.8)
35-44 years	68 (30.8)	111 (24.9)	180 (26.7)
45-54 years	44 (19.9)	106 (23.8)	152 (22.6)
55-64 years	38 (17.2)	94 (21.1)	133 (19.8)
65+ years	19 (8.6)	52 (11.7)	71 (10.6)
*Geller Typology Category**			
Strong and Fearless or Enthused and Confident	26 (11.9)	83 (18.7)	109 (16.2)
Interested but Concerned	193 (88.1)	362 (81.3)	562 (83.5)
Employment status			
Full-time	135 (61.1)	315 (70.8)	456 (67.8)
Part-time	50 (22.6)	49 (11.0)	99 (14.6)
Casual work	19 (8.6)	19 (4.3)	39 (6.1)
Unemployed or Not applicable	17 (7.7)	62 (13.9)	79 (11.7)
Frequency of car usage			
Daily	34 (15.4)	85 (19.1)	119 (17.7)
At least once a week but not daily	110 (49.8)	267 (60.0)	380 (56.5)
At least monthly but not weekly	35 (15.8)	52 (11.7)	90 (13.4)
Less than once per month	25 (11.3)	23 (5.2)	48 (7.1)
Never	17 (7.7)	18 (4.0)	36 (5.3)
Frequency of bike usage			
Daily	51 (23.1)	128 (28.8)	181 (26.9)
At least once a week but not daily	147 (66.5)	310 (69.7)	462 (68.6)
At least monthly but not weekly	21 (9.5)	5 (1.1)	26 (3.9)
Less than once per month	2 (0.9)	1 (0.2)	3 (0.4)
Type of bike(s) owned			
Pedal bike only	193 (87.3)	397 (89.2)	596 (88.6)
E-bike only	25 (11.3)	41 (9.2)	67 (9.9)
Both Pedal bike and E-bike	3 (1.4)	7 (1.6)	10 (1.5)

Note: Row totals may not be equal to sample size due to people who did not identify as a woman or man.
*Participants who were categorized as "No Way No How" were not eligible for participation in this study.

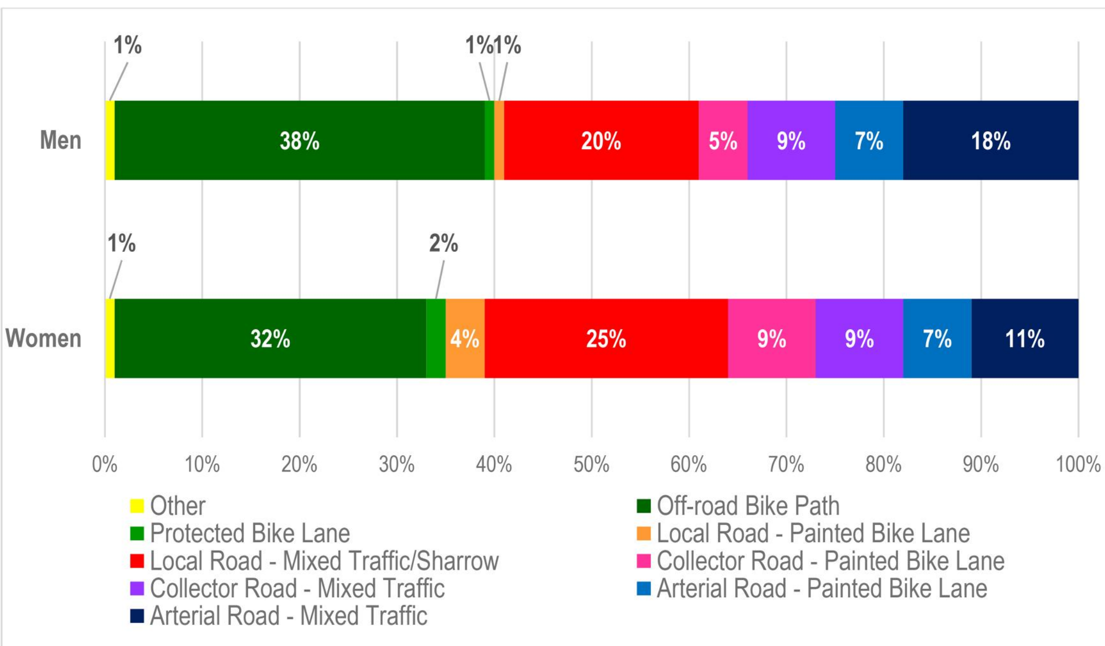

Figure 1. Proportion of total trip distance along road/bike infrastructure classifications, by gender.

3.3. Road and bike infrastructure use by gender

Significant differences were observed between women and men for the distribution of infrastructure used for bike trips (Figure 1). ($p < 0.001$). Off-road bike paths were the most commonly used infrastructure type by both women and men; however women rode less on this type of infrastructure than men. Of the total trip length covered by women, 32% of the distance was on off-road bike paths; the corresponding proportion was 38% for men. Similarly, women rode less on arterial roads in mixed traffic conditions than men (11% of total distance vs 18%). In contrast, women rode more on local roads (29% vs 21%), on collector roads with painted

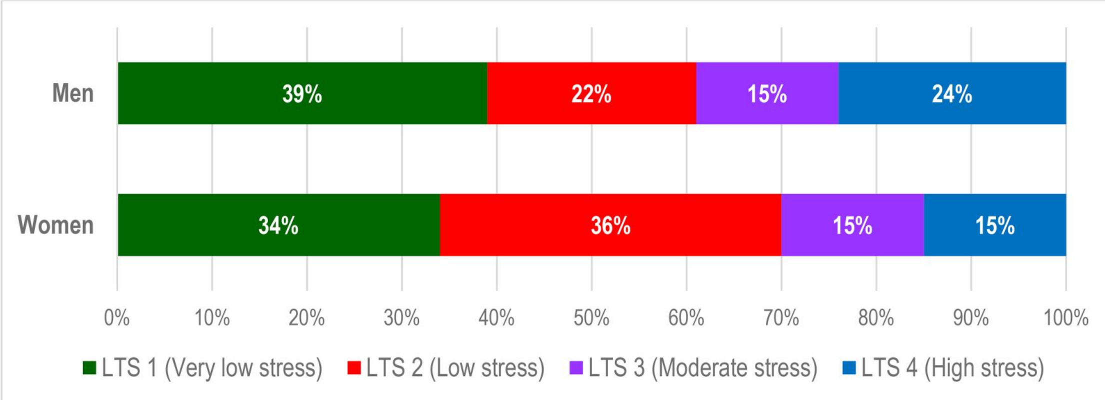

Figure 2. Proportion of total trip distance with traffic stress classifications, by gender.

bike lanes (9% vs 5%), and protected bike lanes (2% vs 1%) than men.

3.4. Level of traffic stress by gender

The difference in distribution of LTS proportions used was significant between women and men (Figure 2, x^2=3485.5, $p < 0.001$). Women's trips were mostly made on LTS-2 and LTS-1 classified street segments and paths, 36% and 34% respectively meaning they were in mostly low traffic stress streets and off-road paths. Similar to this, men's trips were mostly covered on LTS-1 classified segments (39%). However, women rode much less on LTS-4 road segments under high traffic stress situations than men (15% vs 24%).

3.5. Infrastructure preferences by gender

Figure 3 shows the proportion of women and men who self-reported that they were uncomfortable riding a bike along specific infrastructure types. Some participants reported feeling uncomfortable riding on off-road bike paths. The proportions were comparable across gender, where 16% of women and 13% of men stated that they felt 'uncomfortable' or 'very uncomfortable' in off-road bike paths. In contrast, 23% women stated feeling 'uncomfortable' or 'very uncomfortable' on painted bike lanes, while the same was stated by only 11% of men. Most participants, regardless of gender, stated that they felt 'uncomfortable' or 'very uncomfortable' in mixed traffic conditions. However, responses had notable differences by gender as more than half of the women (57%) stated this, while only one-third of the men felt the same (33%). These differences were statistically significant ($p < 0.001$).

3.6. Combined road and bike infrastructure use in people who were uncomfortable in mixed traffic

Figure 4 demonstrates the combined road and bike infrastructure use of people who reported feeling uncomfortable riding a bike in mixed traffic. Amongst those uncomfortable in mixed traffic, there were significant differences for the distribution of combined road and bike infrastructure proportions for trips made by bike between women and men (x^2=1474.8, $p < 0.001$). Nearly half of the distance of bike trips made by women who were uncomfortable in mixed traffic, were made in mixed traffic (46%). Of the total trip length covered by women, 34% were made on off-road bike paths, compared to 44% of trips made by men. Women rode more on local roads within mixed traffic (27%) compared to men (22%), and more on collector roads with painted bike lanes (8% vs 5%). There were negligible differences in other combined road and bike infrastructure types.

3.7. Level of traffic stress along routes, for people who were uncomfortable in mixed traffic

Amongst people reporting they were uncomfortable in mixed traffic, there were significant differences observed between women and men and the distribution of LTS for their bike trips($p < 0.001$). The majority of trips of women and men were taken on LTS-1 (very low stress) and LTS-2 (low stress) classified street segments and paths. However, a higher proportion of men's trips were taken on LTS-1 (very low stress) street segments and paths (45%) compared to women (37%). Men rode more on LTS-4 street segments, under high stress conditions (18%) compared to women (12%) (Figure 5).

4. Discussion

To the authors' knowledge, this is the first study to compare direct differences in stated and revealed preference data in active travel. This study used revealed-preference data from a GPS data collection method for bicyclists within Greater Melbourne, and explored the differences in types of infrastructure and road types traveled between women and men. Comparison of stated and revealed preference data revealed substantial differences in the environments people feel comfortable riding a bike in, and the kind of infrastructure they ride on in real world scenarios. We demonstrated that women who felt uncomfortable in mixed traffic (over half of the sample) spent almost half of their trips in mixed traffic. Further, there were significant differences between women and men in the distribution of distance along different infrastructure types, level of traffic stress used for bike trips. Trips made by women were more often on local roads,

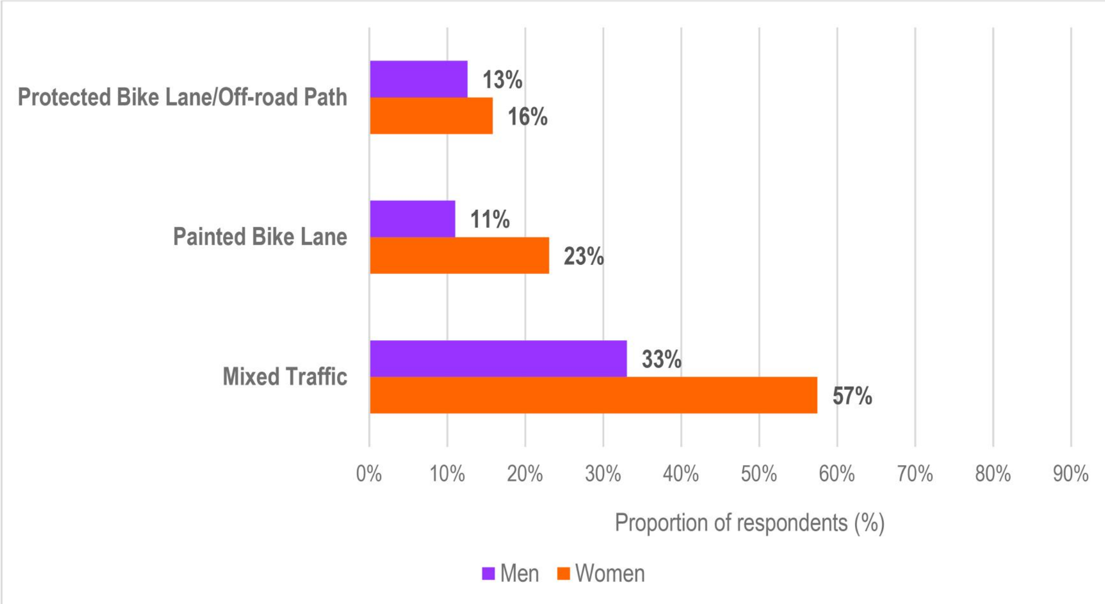

Figure 3. Proportion of respondents who reported they would be "uncomfortable" or "very uncomfortable" riding on infrastructure types, by gender.

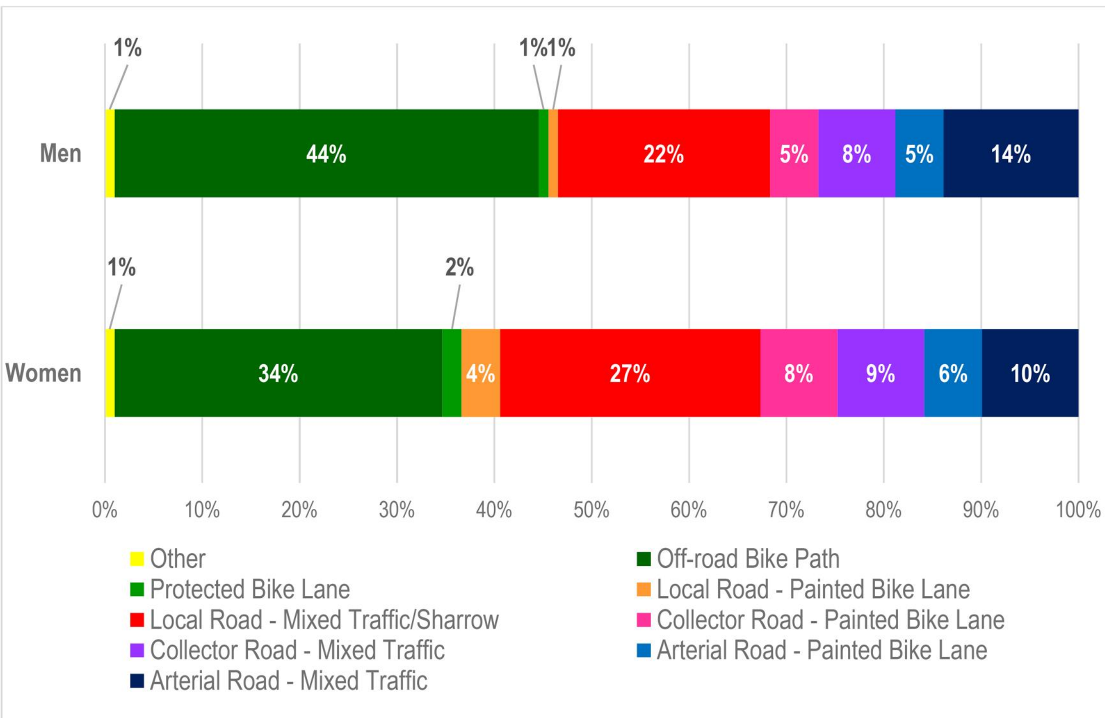

Figure 4. Proportion of total trip distance along road/bike infrastructure classifications for people who were uncomfortable in mixed traffic, by gender.

while more of the trips made by men were on paths, protected bike lanes and arterial roads with painted bike lanes. Men rode more on street segments classified as LTS 4 (high-stress) compared to women. The infrastructure types most used differed to preference data, where less women reported being comfortable in mixed-traffic and painted bike lanes.

A higher proportion of men's trips by bike in this study were on off-road paths and arterial roads, and more trips made by women were made on local roads. This is in direct contrast with stated preference findings within this and other research, where most women prefer to ride a bike on protected infrastructure, including off-road paths (Aldred et al., 2017). Within Greater Melbourne, where data were collected, a network of arterial roads service trips between major activity centers, and particularly radial trips between the outer suburbs and the central business district (CBD) (Australian Bureau of Statistics, 2021). The CBD is the core employment hub within Greater Melbourne, currently housing 458,400 jobs, and mostly serviced by individuals living outside of the CBD (Sustainable Mobility & Safety Research Group MU, 2023). This places substantial pressure on

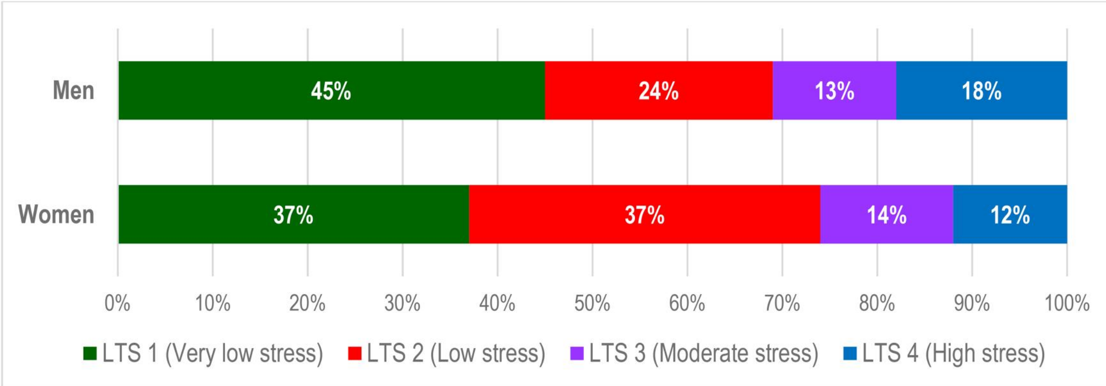

Figure 5. Proportion of people who were uncomfortable in mixed traffic.

arterial routes to facilitate daily commuter traffic (City of Melbourne, 2021). In response, the Victorian State Government introduced Strategic Cycling Corridors; a network of mostly separated bike infrastructure along arterial routes (Victorian Department of Transport and Planning. \(, 2020). There is the potential that while this has enabled a greater number of people to commute by bike, this may privilege those most likely to be taking direct, radial trips between their home and place of work in the CBD, which tend to be men (Zheng, 2015). Women are more likely to take inter-connected and multi-purpose trips for non-work-related purposes including maintenance purposes (e.g. going to the shops or attending a healthcare service), or to escort other members of their household (e.g. children) (Damant-Sirois & El-Geneidy, 2015; Gossen & Purvis, 2005; Krizek et al., 2005). In Australia, women also tend to work closer to their place of residence than men, favoring a greater need for travel in local areas (Australian Bureau of Statistics, 2021). This may in part explain why a greater proportion of trips taken by men in this study were on off-road paths and on arterial roads, and why a greater proportion of trips by women were made on local roads. Of concern is that while a greater proportion of trips taken by women are made on local roads, provision of infrastructure supportive of safe and inclusive riding, such as protected bike lanes, are implemented on arterial roads, with little intervention provided on local roads.

Few studies have used revealed-preference data to explore the gender differences in bicycle route preference with specific combinations of road and infrastructure type (Lusk et al., 2014; Misra & Watkins, 2018; Rupi et al., 2023). No studies have been conducted in Australia, where bicycling participation is low, and less women ride a bike than men (Victorian Department of Transport & Planning, 2020). Existing literature has identified significant differences between women and men in route choices. Rupi *et al.* used GPS traces of bicycle routes in Bologna, Italy, where they found that more women avoided complex route elements than men, including intersections without traffic lights, and left turns (i.e. crossing over another lane of traffic) (Rupi et al., 2023). Similarly, Lusk *et al.*, found that significantly less women used intersections with no traffic signals compared to men (Lusk et al., 2014). This suggests that women tend to favor routes with less interactions with motor vehicle traffic, potentially perceived as unsafe. Pearson *et al.* saw that most participants who identified as women preferred infrastructure that limited interaction with motor vehicle traffic, further supporting the findings of previous literature (Aldred et al., 2017; Pearson et al., 2023). However, revealed-preference data identified that the great majority of women's trips by bike were in mixed traffic. This suggests that while women have a greater preference for infrastructure that separates them from motor vehicle traffic interaction, existing networks of supportive infrastructure in Melbourne are not supportive of the routes women take by bike.

This study revealed a notable contradiction in the stated preferences and actual travel behavior of women who report discomfort riding in mixed traffic. Despite their stated discomfort, nearly half of the distance of their bike trips occurred in these conditions. In this study, we measured level of comfort within specific infrastructure types as a proxy for what route a person would choose, and GPS data to reveal actual route choice. There are a number of potential explanations behind observed differences. Revealed preference research is constrained to what infrastructure is available; in contrast, stated preference enables people to answer consider hypothetical environments, where any infrastructure is available. While these types of data are similar, they are not identical. This disconnection between them is also likely shaped by a number of other external influences, including the availability and quality of infrastructure, the influence of habit on route preferences, perceived social norms, and other complexities in decision making. Limited evidence exists to understand and quantify the difference between stated and revealed preference data in transport behavior where identical constructs are measured (Bhowmick et al., 2025). Given the results of this study, this reliance on stated preference data alone may lead to interventions implemented that do not adequately address the needs of populations. To specifically understand the difference between revealed and preference data, revealed preference data to quantify the difference between reported and actual comfort could include physiological measurement of people while riding a bike, using methods such as heart rate variability, and galvanic skin response (Lim et al., 2022).

This research found that women spend a large proportion of their trips by bike on local roads, within mixed traffic environments, despite most being uncomfortable in these scenarios. The classifications of road type and bicycling infrastructure in this study are crude, and do not consider the likely substantial heterogeneity within them. Differences in quality of lighting, visibility, slope, density, natural surveillance, land use and other factors would have a likely gendered impact on use (Misra & Watkins, 2018; Rupi et al., 2023), however this is not represented within existing classifications. For example, some mixed traffic environments may be within industrial areas with limited lighting, resulting in avoidance by women due to personal safety concerns. In contrast, some mixed traffic environments that are local roads may better support multi-purpose journeys, typically made by women (Heinen et al., 2013). Given these environments would both be categorized as mixed traffic, these important nuances are not well represented. Further research with more detailed spatial datasets of road and bicycling infrastructure networks may provide a better understanding of the impact of these factors.

This study considered level of discomfort in regard to risk of injury and stress from riding a bike within motor vehicle traffic, and considered only the infrastructure type and road type in analysis of route preference. In reality, there are a range of other complex factors that influence individuals' (particularly women's) route preferences, including trip purpose, who they are riding with, topography, time of day, and personal safety (i.e. risk of sexual harassment or assault) (Heinen et al., 2013; Misra & Watkins, 2018; Pearson et al., 2023; Rupi et al., 2023). For example, despite implementation of high-quality protected bike infrastructure (preferred by most women within this study) in an area in the United Kingdom, a decrease in the numbers of women riding a bike on this route was recorded (Jones, 2012). In qualitative research, women described that as this was now a traffic-free route, there was limited natural surveillance from passing cars and pedestrians, causing them to feel concerned for their personal safety. This is in direct contradiction to stated preference findings within this research, highlighting the nuances and complexity in decision making that people (and particularly women) navigate in reality. While the findings of this research provide high-level evidence of gender differences in bicycle infrastructure use, continued research to understand what the variety of factors are that influence bicycling travel behavior and decision making is needed.

This study provides the first revealed preference data in Australia of the differences in bike trip characteristics between women and men, highlighting differences in the types of infrastructure they avail when traveling by bike. Further, to the authors' knowledge, this was the first combined stated and revealed preference data set to show gender differences in bike-riding route-choices. Despite strengths, some limitations were present. OSM data were used to classify road types (i.e. highway class) and infrastructure types. OSM is a crowdsourced data platform where completeness is not guaranteed. There is potential that our bike infrastructure classifications could have relied on incomplete data, resulting in incorrect categorization. However, OSM data is relatively complete in Australia, and therefore the likelihood of misclassification is minor.

This study utilized a convenience sample. There is a potential that we did not adequately capture representation across the whole bike riding population, particularly considering people were required to have a smartphone and be able to read and understand study flyers posted in English. This potentially limits generalizability of study findings to new migrants. There is potential value in conducting a similar study targeted to new migrants, and particularly to new migrants using a bicycle for their employment (e.g. delivery riders). Further, we did not distinguish between trip purposes and conditions, meaning some trips within this study may have been taken for leisure purposes. Identification of trip purpose and condition (e.g. is the person riding with children) would be beneficial to future research in understanding how this influences route preferences. Comfort levels were originally reported on a 4-point Likert scale, and converted into categories. This may have impacted the granularity of the analysis.

5. Conclusions

To enhance ability to equitably plan infrastructure to support more people cycling, we analyzed GPS data for bicycle trips across Greater Melbourne, Australia, to understand differences in travel behavior of women and men. We identified differences in the use of infrastructure, where a larger proportion of bike trips made by men were on paths and arterial roads, and a larger proportion of women's bike trips were on local roads, and within painted infrastructure or mixed traffic. This was despite a stronger preference for protected infrastructure among women. It is important that planning of infrastructure supportive of bike riding, such as protected bike lanes, are not solely concentrated on arterial roads or focused on enabling commuter trips. To enable a greater number and diversity of people to ride a bike, provision of infrastructure on local roads to enable multi-purpose trips within neighborhoods is necessary. Further research should consider finer grained spatial datasets to elucidate the wider range of factors that may influence gender differences in bicycling route choice.

Disclosure statement

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