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# Helmet non-use by users of bikeshare programs, electric bicycles, racing bicycles, and personal bicycles: An observational study in Taipei, Taiwan

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**ABSTRACT**

The bikeshare program in Taipei City and New Taipei City, called U-bike, was launched in August 2012 and has more than 7500 bicycles operating out of 769 stations. Research has suggested that bicycle helmet use is a means of reducing morbidity and mortality among bike users. Helmets, however, are not available for rent when a U-bike is rented. The current research conducted an observational study to examine the prevalence of helmet non-use by users of the bikeshare program, electric bicycles, racing bicycles, and personal bicycles in Taipei City and New Taipei City. Trained observers using compact video cameras collected helmet non-use data during various times of the day and on different days of the week. Observers collected data on cyclist attributes, bicycle types, and helmet use at several selected locations within Taipei City and New Taipei City. U-bike users were found to be the least likely to wear helmets. Other noteworthy findings include that violations such as phone use, red-light violations, and travelling at $\geq$25 km/h were associated with riding without a helmet. Male users of racing bikes tended not to wear helmets, while female users of other bicycle types were less likely to use a helmet. Carrying passengers by users of electric bikes and personal bikes was a determinant of helmet non-use. This paper concludes with a discussion and recommendations for future research.

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Bikeshare program; electric bicycle; helmet use; racing bike

## 1. Introduction

Public bikeshare programs are becoming popular worldwide. The main benefits of bikeshare programs include reductions in automobile use and traffic pollution/congestion, as well as the health benefits associated with increased physical activities (Pucher, Dill, & Handy, 2010). Typical successful bikeshare programs are in the US, where 15 bikeshare programs are active and more than 30 programs are under development. There are also bikeshare programs in other metropolitan areas such as Paris, Barcelona, Milan, London, and Mexico City (Midgley, 2011). With these programs, the public can rent bicycles for an hourly fee at kiosks at convenient locations throughout the city. The fee can be paid by tokens, coins, or bus/metro cards. The bikeshare program in Taipei City, called U-bike, was launched in August 2012 and has been extended to New Taipei City. Overall, there are a total of 7500 bicycles and 769 stations. Other active bikeshare programs in Taiwan include Taoyuan City, Hsinchu City, and Taichung City. Currently, there are more than 20,000 public bicycles available in Taiwan.

Research has suggested that bicycle helmet use is a means of reducing morbidity and mortality in bike users. The benefits have been well documented in several case-controlled studies that helmet use is associated with decreased rates of head injury and mortality in riders of all ages, with bicycle helmets decreasing the risk of head and brain injuries by 65% 88% (Amoros, Chiron, Martin, Thelot, & Laumon, 2012). Thompson, Rivara, and Thompson (2000) reported that nearly three-quarters of all bicyclist deaths and one-third of bicyclist injuries were related to head injuries. The most recent national accident statistics in Taiwan indicated that there were 130 bicyclist fatalities and 14,874 bicycle-related injuries in 2014. The main injured body part in these bicyclist deaths was the head (~61%), followed by injuries to the chest and extremities. Current efforts to increase helmet use for preventing head injuries in accidents include campaigns to increase awareness of the importance of helmet use, along with advocacy for helmet laws (Macpherson and Spinks, 2008). Q3 In Taiwan, helmet use is mandatory for motorcyclists but not for bike users, while several cities in the US have laws mandating the wearing of helmets (such as the District of Columbia).

Despite the importance of helmet use described above, most bikeshare programs do not provide the public with the opportunity to purchase or rent helmets when bicycles are rented, nor are there any requirements to wear a helmet while riding a rented bike. In the state of Minnesota, USA, where there is no mandatory helmet law, only 14% of the respondents reported

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ujst.
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wearing a helmet. Low helmet use was also reported by Fischer et al. (2012) in Washington, DC and Boston. Fischer et al. observed more than 3000 bikeshare cyclists and found that over half were unhelmeted, with significant differences depending on gender. Bikeshare users had a significantly lower helmet usage rate than those on personal bikes. Men were 1.6 times more likely to ride unhelmeted, and when controlling for sex, the time of week, and city, Fischer et al. reported a 4.4-fold greater likelihood of a bikeshare user without a helmet than a personal biker. Fischer et al. attributed this substantial difference in helmet use to the reality that helmets are not provided or easily accessible. A questionnaire survey study conducted in North America (Shaheen, Guzman, & Zhang, 2010) confirmed the results of Fischer et al., suggesting that 43% 62% of respondents reported *never* using a helmet when using bikeshare.

One of the documented reasons for not using helmets was that the trips were unplanned and therefore, a helmet was not brought along (Fischer et al., 2012). Indeed, the inconvenience associated with carrying a helmet appears to be a major barrier to their use. It seems clear that efforts should be made by governments to make helmets as accessible as possible. Unfortunately, for all bikeshare schemes in Taiwan, helmets are not provided at any rental kiosks, and relevant information on where the public can rent/purchase helmets nearby is not available.

The Taiwan Traffic Accident Report reveals a steady increase in the number of bicycle accidents, possibly because of the increasing popularity of bicycle use, such as bikesharing systems, in several cities. A government report (MOTC Traffic Statistics of Year, 2015*) indicates that the fatality rate among bicyclists is two times that of motorcyclists, mainly because of head injuries, which account for approximately 50% of all bicyclist fatalities. Although the government statistics are not necessarily specific to users of U-bike, it is not uncommon that U-bike users have lower helmet-use rates compared with other users of bicycle types. It is therefore argued in this study that U-bike users are especially vulnerable to head injuries.

When reviewed together, past studies, although few in number, provide an important picture of factors contributing to helmet use among users of bikeshare programs. However, the

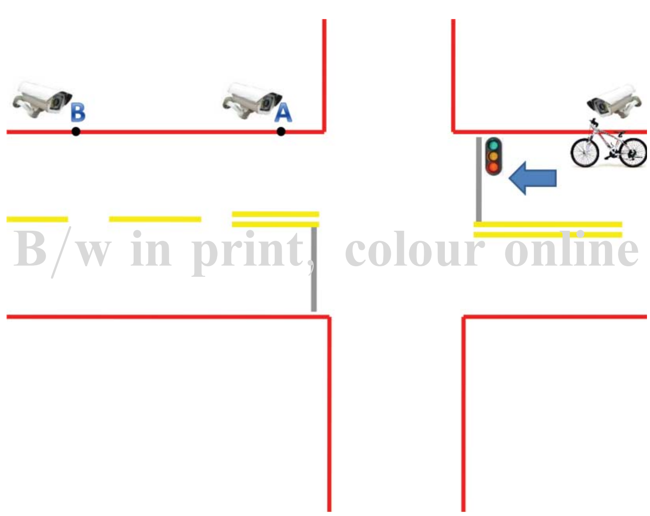


**Figure 1.** The layout of survey locations.

effects of other important variables, such as bicycle type, temporal factors, and the traffic-violation status, on helmet use have not yet been fully investigated. The main purpose of the current research was to investigate helmet non-use by users of U-bikes, electric bikes, racing bikes, and personal bikes. A better understanding of factors contributing to helmet non-use may provide traffic practitioners and policy makers with guidance in promoting helmet use.

In order to have a better understanding of the determinants of helmet use among the public using different kinds of bicycles, the research design, including how data were collected, selection of locations/participants, and the analytical approach are described in the following sections.

## 2. Methods

### 2.1. *Data source*

This was a prospective observational study of bicyclist helmet use in Taipei City and New Taipei City. Trained observers operating compact video cameras collected data at selected locations during various times and on different days of the week. This observational study lasted 1 year, from January 2016 to December 2016.

### 2.2. *Research design*

Factors associated with helmet non-use that we examined included rider attributes, time of the week, bicycle type (U-bike, electric bike, racing bike, or personal bike), weather factors, and the traffic-violation status (phone use, red-light violation (RLV), and speeding). Bikes provided by the bikeshare program have unique designs, markings, and configurations of taillights, which make them easy to distinguish from personal bicycles. Electric bikes can be identified by the batteries fitted to the bike, while racing bikes are unique with specially designed pedals.

Each trained observer was assigned to collect helmet non-use data from cyclists passing a selected location with a compact video camera. Bicyclists that were travelling on sidewalks were excluded; only those travelling on roadways were included. In order to observe whether the cyclists were running a red light, only those who encountered a red light were included as the subjects. Cyclists' speeds were measured by the time spent between two designated points (points A and B, as illustrated in Figure 1). Three video cameras were set up at each location, and they were well hidden to avoid being spotted by cyclists.

Those walking with their bikes and passengers were excluded from the current observation (only the cyclist himself/herself was observed). Helmet use was recorded as yes or no. For U-bike users, observation sites were chosen within sight of a bikeshare rental kiosk; while for electric bicycles, traditional markets were chosen since those were the focal points for these riders. For racing bikes, observations were conducted on sub-rural highways, where there are high volumes of racing bikes, and observational sites for personal bikes were in the vicinity of schools/universities. It is worth pointing out here that all bicycle types travelling through the designated locations were observed. For instance, all bicycle types were observed at a U-bike location.

Descriptive data analyses were conducted for the frequencies of riding unhelmeted by sex, type of bicycle, day of the week, and the traffic-violation status. Binary logistic regression models were used to estimate the likelihood of riding unhelmeted, after controlling for the type of bicycle, sex, day of the week, and the traffic-violation status.

### 2.3. 3 Time/period of the observation

The survey was conducted by well-trained research assistants throughout 2016 (from January to December 2016), in peak traffic hours (07:0009:00 and 17:0019:00) and off-peak hours (09:0116:59), and on weekdays/weekends to capture possible seasonal effects and temporal variations. It is worth mentioning that late evening/night/early morning observations were excluded from the current research because bicycling was not very popular during these periods (Pucher et al., 2010).

### 2.4. Selection of participants/locations

All two-wheeled users (U-bike, electric bike, racing bike, and personal bike) travelling through a selected intersection and encountering a red light were included as the subjects, providing a rich source of observations to facilitate statistical modelling of the determinants of helmet non-use.

The locations of observation sites were randomly selected. For instance, an exhaustive list of 614 primary and secondary schools are obtained from the Taipei City Council and New Taipei City Council. All of the 614 schools were given a number and a total of four schools were randomly selected using an online random number generator without priori constraint. It should be noted here that only four schools were selected due to limited funds on manpower (observers) and equipment (video cameras). The same random selection was applied to sites for U-bike, electric bike, and racing bike (four U-bike stations, four markets, and four sub-rural highways from a list of 769 U-bike stations, 91 markets, and 132 sub-rural highways).

## 3. Results

Tables 1 to 4 report the characteristics of users of various bicycle types and rates of helmet non-use. In total, data on 6567 cyclists were collected, of whom 762 were using racing bikes, 2861 were using personal bikes, 668 were using electric bikes, and 2276 were using U-bikes (see Tables 14). Users of U-bikes had the highest rates of riding unhelmeted (87.96%), followed by users of electric bikes (83.83%), users of personal bikes (74.48%), and users of racing bikes (12.6%).

A careful observation of Tables 1 to 4 shows that some consistent patterns appear regarding helmet non-use rates. Mobile phone use, RLVs, and the absence of any reflective lights were associated with an increased rate of helmet non-use. Bicyclists observed during off-peak hours, on weekdays, and during fine weather were less likely to wear helmets.

Several effects appear inconsistent across different types of bicycles. For example, male users of racing bikes were more likely to be unhelmeted, while female users of the other three bicycle types tended to ride unhelmeted. Riders of racing bikes and electric bikes had higher rates of travelling without a helmet in urban areas, although riding in rural settings was associated with an increased rate of non-use of helmets for users of

**Table 1.** Characteristics of users of racing bikes and helmet use in Taipei City.

| | *N* (%) | Helmet non-use, *n* (%) |
|---|---|---|
| Users of racing bikes | 762 | 96 (12.6) |
| Sex | | |
| Male | 518 (68.0) | 68 (13.1) |
| Female | 244 (32.0) | 28 (11.5) |
| Day of the week | | |
| Workday | 154 (20.2) | 57 (37) |
| Weekend | 608 (79.8) | 89 (14.6) |
| Time | | |
| 07:0008:59/17:0019:00 | 228 (29.9) | 51 (22.4) |
| 09:0016:59 | 534 (70.1) | 45 (8.4) |
| Location | | |
| Urban | 233 (30.6) | 67 (28.8) |
| Rural | 529 (69.4) | 29 (5.5) |
| Reflective aids | | |
| Yes | 631 (82.8) | 39 (6.2) |
| No | 131 (17.2) | 57 (43.5) |
| Weather | | |
| Fine | 463 (60.8) | 63 (13.6) |
| Raining | 299 (39.2) | 33 (11.0) |
| Phone use | | |
| Yes | 186 (24.4) | 69 (37.1) |
| No | 576 (75.6) | 27 (4.7) |
| Red-light violation | | |
| Yes | 261 (34.3) | 56 (21.5) |
| No | 501 (65.7) | 40 (8) |
| Speed (km/h) | | |
| <10 | 35 (4.6) | 29 (82.9) |
| 1019 | 436 (57.2) | 33 (7.6) |
| ≥25 | 291 (38.2) | 34 (11.7) |

**Table 2.** Characteristics of users of personal bikes and helmet use in Taipei City.

| | *N* (%) | Helmet non-use, *n* (%) |
|---|---|---|
| Users of personal bikes | 2861 | 2131 (74.48%) |
| Sex | | |
| Male | 1734 (60.6) | 1045 (60.3) |
| Female | 1127 (39.4) | 1086 (96.4) |
| Carrying a passenger | | |
| Yes | 918 (32.1) | 858 (93.5) |
| No | 1943 (67.9) | 1273 (65.5) |
| Day of the week | | |
| Workday | 1790 (62.6) | 1708 (95.4) |
| Weekend | 1071 (37.4) | 423 (39.5) |
| Time | | |
| 07:0008:59/17:0019:00 | 1798 (62.8) | 1123 (62.5) |
| 09:0016:59 | 1063 (37.2) | 1008 (94.8) |
| Location | | |
| Urban | 1946 (68) | 1271 (65.3) |
| Rural | 915 (32) | 860 (94.0) |
| Reflective aids | | |
| Yes | 1042 (36.4) | 462 (44.3) |
| None | 1819 (63.6) | 1669 (91.8) |
| Weather | | |
| Fine | 1824 (63.8) | 1409 (77.2) |
| Raining | 1037 (36.2) | 722 (69.6) |
| Phone use | | |
| Yes | 1609 (56.2) | 1407 (87.4) |
| No | 1252 (43.8) | 724 (57.8) |
| Red-light violation | | |
| Yes | 572 (20.0) | 557 (97.4) |
| No | 2289 (80.0) | 1574 (68.8) |
| Speed (km/h) | | |
| <10 | 1535 (53.7) | 1183 (77.1) |
| 1024 | 833 (29.1) | 537 (64.5) |
| ≥25 | 493 (17.2) | 411 (83.4) |

**Table 3.** Characteristics of users of electric bikes and helmet use in Taipei City.

| | *N* (%) | Helmet non-use, *n* (%) |
|---|---|---|
| Users of electric bikes | 668 | 560 (83.83) |
| Sex | | |
| Male | 253 (37.9) | 205 (81) |
| Female | 415 (62.1) | 355 (85.5) |
| Carrying a passenger | | |
| Yes | 205 (30.7) | 173 (84.4) |
| No | 463 (69.3) | 387 (83.6) |
| Day of the week | | |
| Workday | 462 (69.2) | 396 (85.7) |
| Weekend | 206 (30.8) | 164 (79.6) |
| Time | | |
| 07:0008:59/17:0019:00 | 296 (44.3) | 219 (74) |
| 09:0016:59 | 372 (55.7) | 341 (91.7) |
| Location | | |
| Urban | 478 (71.6) | 415 (86.8) |
| Rural | 190 (28.4) | 145 (76.3) |
| Reflective aids | | |
| Yes | 179 (26.8) | 124 (69.3) |
| None | 489 (73.2) | 436 (89.2) |
| Weather | | |
| Fine | 457 (68.4) | 393 (86) |
| Raining | 211 (31.6) | 167(79.1) |
| Phone use | | |
| Yes | 255 (38.2) | 178 (69.8) |
| No | 413 (61.8) | 382 (92.5) |
| Red-light violation | | |
| Yes | 167 (25) | 143 (85.6) |
| No | 501 (75) | 417 (83.2) |
| Speed (km/h) | | |
| $<10$ | 56 (8.4) | 27 (48.2) |
| 1024 | 250 (37.4) | 196 (78.4) |
| $\geq 25$ | 362 (54.2) | 337 (93.1) |

personal bikes and U-bikes. A higher travel speed appeared to result in a decreased non-helmet rate for users of racing bikes, but the other three groups of cyclists exhibited a higher non-helmet rate with an increase in their travel speed.

One overall logistic regression model and four individual logistic regression models were estimated, with odds ratios (ORs), 95% confidence intervals (CIs), and $p$ values being reported (Tables 5–9). The overall model includes bicycle type (U-bike, electric bike, personal bike, and racing bike) as one of the variables (see Table 5). Four individual models were employed to estimate factors contributing to helmet non-use among different bicycle types, and results are reported in Tables 6 to 9. Only one interaction effect was found statistically significant in the overall model, and no interaction effect was found in the four individual models.

**Table 4.** Characteristics of users of U-bikes and helmet use in Taipei City.

| | *N* (%) | Helmet non-use, *n* (%) |
|---|---|---|
| U-bike users | 2276 | 2002 (87.96) |
| Sex | | |
| Male | 1280 (56.2) | 1032 (80.6) |
| Female | 996 (43.8) | 970 (97.4) |
| Day of the week | | |
| Workday | 1519 (66.7) | 1291 (85) |
| Weekend | 757 (33.3) | 711 (93.9) |
| Time | | |
| 07:0008:59/17:0019:00 | 1346 (59.1) | 1031 (76.6) |
| 09:0016:59 | 930 (40.9) | 909 (97.7) |
| Location | | |
| Urban | 1409 (61.9) | 1149 (81.5) |
| Rural | 867 (38.1) | 853 (98.4) |
| Weather | | |
| Fine | 1330 (58.4) | 1296 (97.4) |
| Raining | 946 (41.6) | 706 (74.6) |
| Phone use | | |
| Yes | 856 (37.6) | 842 (98.4) |
| No | 1420 (62.4) | 1160 (81.7) |
| Red-light violation | | |
| Yes | 296 (13) | 239 (80.7) |
| No | 1980 (87) | 1763 (89) |
| Speed (km/h) | | |
| $<10$ | 1034 (45.4) | 849 (82.1) |
| 1024 | 819 (36) | 755 (92.2) |
| $\geq 25$ | 423 (18.6) | 398 (94.1) |

The overall model reports that U-bike users were 187% more likely to be riding unhelmeted, compared to racing bike users. Other determinants of riding unhelmeted include rural roadways, males, carrying a passenger, non-rush hours, absence of reflective aids, weekend, phone use, and RLV. One interaction effect "phone use and RLV" appears to a contributory factor to helmet non-use. The interaction variable reports that those using a phone and violating red light were 107% more likely to be riding unhelmeted.

Turning to the individual models (Tables 6–9), the effect of rural roadways appeared to be statistically significant in determining unhelmeted riding, with respective increased ORs of 1.384 and 1.467 for users of personal bikes and U-bikes. Male users of racing bikes were 23.7% more likely to be riding unhelmeted, while males exhibited decreased odds of riding unhelmeted with the other three bicycle types (ORs of 0.755 for personal bikes, 0.806 for electric bikes, and 0.770 for U-bikes). Consistent results regarding the time effect (off-peak hours) were found across the four bicycle types, with respective ORs of 1.570, 1.164, 1.253, and 1.143 for users of racing bikes, personal bikes, electric bikes, and U-bikes.

The passenger effect was examined for two bicycle types only. Racing bikes and U-bikes are not manufactured with

**Table 5.** Results of the logistic regression of unhelmeted cyclists (total bikes, $N = 6567$).

| | OR | Lower CI | Upper CI | *p* value |
|---|---|---|---|---|
| Bicycle type (ref.: racing bike) | | | | |
| U-bike users | 2.873 | 1.973 | 4.738 | $<0.01$ |
| Electric bike users | 1.907 | 1.242 | 2.984 | $<0.01$ |
| Personal bike users | 1.462 | 1.094 | 1.954 | $<0.01$ |
| Location | | | | |
| Rural | 1.313 | 1.046 | 1.641 | $<0.01$ |
| Sex | | | | |
| Male | 1.130 | 1.032 | 1.231 | 0.03 |
| Carrying a passenger | | | | |
| Yes | 1.231 | 1.073 | 1.419 | $<0.01$ |
| Time | | | | |
| 09:0016:59 | 1.229 | 1.049 | 1.466 | $<0.01$ |
| Day of the week | | | | |
| Weekend | 1.254 | 1.046 | 1.485 | 0.06 |
| Phone use | | | | |
| Yes | 1.760 | 1.267 | 2.444 | $<0.01$ |
| Red-light violation | | | | |
| Yes | 1.549 | 1.165 | 2.049 | $<0.01$ |
| Speed (km/h) | | | | |
| $\geq 25$ | 1.334 | 1.055 | 1.694 | $<0.01$ |
| Interaction: Phone use * RLV | 2.069 | 1.177 | 3.621 | $<0.01$ |

Summary statistics:
Restricted log-likelihood (constant only): −5863.5.
Log-likelihood at convergence: −3586.2.
$\sigma 2 = 0.388$.
OR: odds ratio; CI: confidence interval.

**Table 6.** Results of the logistic regression of unhelmeted cyclists (racing bikes, $N = 762$).

| | OR | Lower CI | Upper CI | *p* value |
|---|---|---|---|---|
| Location | | | | |
| Rural | 0.737 | 0.511 | 0.883 | 0.03 |
| Sex | | | | |
| Male | 1.237 | 1.11 | 1.539 | 0.08 |
| Time | | | | |
| 09:0016:59 | 1.570 | 1.284 | 1.886 | <0.01 |
| Reflective aids | | | | |
| None | 1.182 | 1.008 | 1.396 | <0.01 |
| Day of the week | | | | |
| Weekend | 1.207 | 1.113 | 1.782 | 0.02 |
| Phone use | | | | |
| Yes | 1.685 | 1.281 | 1.997 | <0.01 |
| Red-light violation | | | | |
| Yes | 1.967 | 1.509 | 2.357 | <0.01 |
| Speed (km/h) | | | | |
| ≥25 | 0.683 | 0.507 | 0.846 | 0.07 |

Summary statistics:
Restricted log-likelihood (constant only): −2116.7.
Log-likelihood at convergence: −1557.6.
$\sigma 2 = 0.264$.
OR: odds ratio; CI: confidence interval.

**Table 8.** Results of the logistic regression of unhelmeted cyclists (electric bikes, $N = 668$).

| | OR | Lower CI | Upper CI | *p* value |
|---|---|---|---|---|
| Sex | | | | |
| Male | 0.806 | 0.62 | 0.98 | 0.07 |
| Carrying a passenger | | | | |
| Yes | 1.222 | 1.086 | 1.469 | 0.02 |
| Time | | | | |
| 09:0016:59 | 1.253 | 1.11 | 1.599 | 0.06 |
| Reflective aids | | | | |
| None | 1.376 | 1.169 | 1.794 | <0.01 |
| Day of the week | | | | |
| Weekend | 1.084 | 0.887 | 1.297 | 0.138 |
| Phone use | | | | |
| Yes | 1.669 | 1.308 | 1.998 | <0.01 |
| Red-light violation | | | | |
| Yes | 2.117 | 1.497 | 2.687 | <0.01 |
| Speed (km/h) | | | | |
| ≥25 | 1.839 | 1.447 | 2.097 | 0.02 |

Summary statistics:
Restricted log-likelihood (constant only): −2329.7.
Log-likelihood at convergence: −1662.6.
$\sigma 2 = 0.286$.
OR: odds ratio; CI: confidence interval.

passenger seats, so the effect was not investigated for these two bicycle types. It should be noted that it is a violation for a cyclist to carry a passenger, although passenger seats are manufactured and sold. The passenger effect appeared to be statistically significant; when carrying a passenger, users of personal bikes and electric bikes were 40.3% and 20.2%, respectively, more likely not to be wearing a helmet.

The effects of the absence of reflective aids, cyclists' RLV, and using a mobile phone appeared to be significant determinants of riding unhelmeted for all four bicycle types. Take the phone-use effect as an example, the odds of riding unhelmeted were 1.685 for users of racing bikes, 1.519 for users of personal bikes, 1.669 for users of electric bikes, and 1.564 for users of U-bikes. The effect of reflective aids was not examined for U-bikes as all U-bikes are fitted with reflective aids, that is, taillights. In the event that reflective aids were not present, users of racing bikes, personal bikes, and electric bikes were 18.2%, 68.9%, and 37.6%, respectively, more likely to be travelling unhelmeted. All bicyclists observed to have RLV behavior were found to have increased odds of riding unhelmeted, with respective odds of 1.967, 1.781, 2.117, and 1.337 for racing bikes, personal bikes, electric bikes, and U-bikes.

The speed effect appeared to be inconsistent across the four bicycle types. With a speed of ≥25 km/h, users of racing bikes were 31.7% less likely to be unhelmeted. However, a speed of ≥25 km/h was found to be associated with increased odds of riding unhelmeted for the other three bicycle types, with respective odds of 1.216, 1.836, and 1.59 for personal bikes, electric bikes, and U-bikes.

**Table 7.** Results of the logistic regression of unhelmeted cyclists (personal bikes, $N = 2861$).

| | OR | Lower CI | Upper CI | *p* value |
|---|---|---|---|---|
| Location | | | | |
| Rural | 1.384 | 1.167 | 1.557 | 0.02 |
| Sex | | | | |
| Male | 0.755 | 0.573 | 0.869 | 0.06 |
| Carrying a passenger | | | | |
| Yes | 1.403 | 1.168 | 1.967 | <0.01 |
| Time | | | | |
| 09:0016:59 | 1.164 | 1.087 | 1.55 | 0.03 |
| Reflective aids | | | | |
| None | 1.689 | 1.385 | 1.993 | <0.01 |
| Day of the week | | | | |
| Weekend | 1.121 | 1.013 | 1.338 | 0.06 |
| Phone use | | | | |
| Yes | 1.519 | 1.375 | 1.867 | <0.01 |
| Red-light violation | | | | |
| Yes | 1.781 | 1.502 | 2.025 | <0.01 |
| Speed (km/h) | | | | |
| ≥25 | 1.216 | 1.097 | 1.693 | <0.01 |

Summary statistics:
Restricted log-likelihood (constant only): −4086.3.
Log-likelihood at convergence: −2752.2.
$\sigma 2 = 0.327$.
OR: odds ratio; CI: confidence interval.

**Table 9.** Results of the logistic regression of unhelmeted cyclists (U-bikes, $N = 2276$).

| | OR | Lower CI | Upper CI | *p* value |
|---|---|---|---|---|
| Sex | | | | |
| Male | 0.770 | 0.467 | 0.969 | <0.01 |
| Location | | | | |
| Rural | 1.467 | 1.118 | 1.827 | <0.01 |
| Time | | | | |
| 09:0016:59 | 1.143 | 1.087 | 1.339 | 0.09 |
| Day of the week | | | | |
| Weekend | 1.217 | 0.859 | 1.405 | 0.16 |
| Phone use | | | | |
| Yes | 1.564 | 1.278 | 1.896 | <0.01 |
| Red-light violation | | | | |
| Yes | 1.337 | 1.137 | 1.69 | <0.01 |
| Speed (km/h) | | | | |
| ≥25 | 1.59 | 1.197 | 1.806 | <0.01 |

Summary statistics:
Restricted log-likelihood (constant only): −3182.2.
Log-likelihood at convergence: −2095.1.
$\sigma 2 = 0.342$.
OR: odds ratio; CI: confidence interval.

## 4. Discussion and conclusions

The current research found that users of U-bikes had the highest rates of riding unhelmeted (87.96%). This was followed by users of electric bikes (83.83%), personal bikes (74.48%), and racing bikes (12.6%). Such findings are in line with those of past studies conducted in developed countries (e.g., Fischer et al., 2012), where lower helmet use was revealed for bikeshare users more than those for personal bikes. In Taiwan, it is difficult to establish a linkage between bicycle helmet use and bicycle accidents, because a detailed classification of bicycle types is not available in any official statistics/datasets. However, with the increasing popularity of bikeshare programs in several metropolitan areas, it is possible that a majority of bicycle accidents involve bikeshare users. In 2016, bicycle helmet use became compulsory for electric bicycle users but not for traditional bicycle users in Taiwan. A large-scale nationwide travel survey (Health Promotion Administration, HPA, 2012) reported that helmet use was relatively lower among bicyclists (6.8%) than among motorcyclists (82.2%). Because bikeshare program has become increasingly popular in recent years, the government should consider encouraging helmet use, and education efforts and campaigns should aim to increase riders' awareness of the benefits of helmet use.

Our result that users of electric bikes were the second most likely not to wear helmets deserves additional attention. Currently in Taiwan, by law, electric bikes can reach speeds of up to 25 km/h, and some electric bikes with modifications to the engine design can reach up to 40 km/h. Helmet use remains crucial for users of electric bikes, considering the high-speed impact in a crash when an electric bike is involved.

The result that racing-bike users have higher rates of helmet use is reasonable, as they may pay more attention to their safety equipment. The conjecture can be confirmed by the greater use of reflective aids found in the current research. Furthermore, with better designs of bicycles, users of racing bikes can travel faster and therefore, they are more likely to wear helmets. One noteworthy finding is that users of racing bikes had the highest RLV rates compared to all the other three bicycle groups. This result warrants further investigation.

Turning to factors contributing to helmet non-use among different bicycle types, several results merit further discussion here. Females were found to have a higher tendency not to wear helmets when using personal bikes, electric bikes, and U-bikes. Our results contradict those of Fischer et al. (2012) who reported that male bikeshare cyclists were more likely to be unhelmeted. However, we observed an obvious reduced likelihood of helmet use among male users of racing bikes.

Except for users of racing bikes who tended to wear a helmet in rural areas than in urban areas, users of the other three bicycle types appeared less likely to wear helmets on rural roadways. Our findings are consistent with those of studies examining motorcyclist helmet use in other developing countries such as studies in Malaysia (Kulanthayan, Umar, Hariza, & Nasir, 2000) and China (Yu, Ke, Ivers, Du, & Senserrick, 2011). Possible reasons include that cyclists perceive less risk in rural settings where there is less traffic. Nevertheless, crash impacts can be at higher speeds in such locations where traffic speeds tend to be higher and therefore, it is recommended that cyclists should always wear helmets in both urban and rural areas.

Our research contributes to the current literature by reporting that cyclists' RLV, phone use, and absence of reflectors were associated with an increased likelihood of riding unhelmeted among all users of the four bicycle types. RLVs and phone use are illegal behaviors and were found to be associated with helmet non-use for all four bicycle types. RLV by bicyclists was identified as the most frequent traffic-violation behavior in Taiwan (Pai & Jou, 2014) due to the fact that bicycles without number plates are less likely to be prosecuted for RLV behavior. Again, it seems evident here that bicyclists engaging in RLV behaviors and using a mobile phone may have a lower perception of safety, and as a result are less likely to ride with a helmet.

The absence of reflective aids on bicycles was found to be associated with helmet non-use among users of racing bikes, personal bikes, and electric bikes (all U-bikes are fitted with front and tail lights). It seems evident in the current research that there is a link between helmet non-use and the absence of reflective aids. This result is possibly because bicyclists using reflective aids are a group with higher safety perceptions and therefore are more likely to wear a helmet.

Use of all bicycle types at higher speeds ($\geq$25 km/h) appeared to result in a greater likelihood of helmet non-use. Although speeds were measured for a short distance (i.e., points A and B) and might not be representative of the entire trip, the result indicated the possibility that cyclists who ride at higher speeds may have lower safety perceptions, and their helmet use might therefore be lower. Speed enforcement is difficult for cyclists as they do not have number plates. Education efforts and safety campaigns might first educate the public about the importance of speed control, and subsequently encourage helmet use.

Similar to previous observational research, the current study has strengths as well as limitations. We observed numerous cyclists of various bicycle types in real-life environments and controlled for several influential variables, including phone use, speed, RLV, etc. Our study was limited due to it being a quasi-experimental study that was conducted on certain streets during certain hours of the day. As a result, the findings might not be representative of other locales and times.

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## Conflict of interest

The authors declare to have no conflict of interests.

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