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Riding e-scooters day and night – observation of user characteristics, risky behavior, and rule violations

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Abstract. Crash statistics and hospital data show that injured e-scooter riders arrive at hospitals often at night and on weekends. Subsequently, the crash risk at night is higher compared to the daytime. A possible explanation might be increased rule violations, safety-critical behaviors, and changes in the user group at night compared to daytime. Therefore, we aimed to conduct an observational study analyzing the interrelationships of risky behaviors, rule violations, and user characteristics of e-scooter riders in two German cities. A total of 732 observations were analyzed with Chi-Squared tests and Generalized Estimating Equations. The results show increased rates of tandem riding at night compared to the daytime and increased rule violations of adolescents compared to older e-scooter riders regardless of the time of day. Rates of helmet use, wrong-way riding, headphone use, smartphone use, and luggage transport were comparable for daytime and night observations. The results suggest that educational campaigns should focus on tandem riding, especially targeting the user group of teenage riders. This study brings e-scooter riding at night into the light and emphasizes riders' nightly behaviors for policymakers and traffic safety.

Keywords: Micomobility, Traffic safety, Night riding.

1 Introduction

Riding e-scooters in Germany started in 2019, followed by a rush of shared e-scooters in the cities with a predominantly male and young user group (Haworth et al., 2021b; Haworth & Schramm, 2019; Huemer et al., 2022). Especially in the early stages, e-scooter riding at night was associated in the popular press with people being drunk, riding e-scooters in groups, and severe crashes (Noack, 2019; Tapper, 2019). Confirming these reports, crash statistics and hospital data show that injured e-scooter riders arrive at hospitals more often at night and on weekends compared to data on cyclists (Kleinertz et al., 2021; Stigson et al., 2021). In addition, Shah and Cherry (2022) showed a higher crash risk at night compared to daytime when putting the number of car-e-scooter crashes into perspective on the number of trips made.

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A possible explanation for increased crashes and injuries at night might be increased rule violations, safety-critical behaviors, and changes in the user group compared to daytime. To raise riders' awareness and reduce crash risk at night, policymakers and traffic safety specialists would benefit from findings about the changes from day to night regarding the behavior and characteristics of e-scooter riders. With this, they could address e-scooter riders at risk more specifically and aim to reduce critical behaviors that might occur more often at night than in the daytime.

Demographic characteristics, safety-critical behavior, and rule violations of e-scooter riders were the focus of international scientific research in recent years without particular differentiation between day and night. Evidence shows that e-scooter riders are primarily young and male (Curl & Fitt, 2020; Haworth et al., 2021b; Laa & Leth, 2020; Orozco-Fontalvo et al., 2022; Portland Bureau of Transportation, 2020; Siebert et al., 2021). With this, e-scooter riders might be more prone to risky riding than cyclists because they are inexperienced in riding and can be affected by a self-enhancement bias known for this age group (Harré et al., 2005; Sibley & Harré, 2009). By overestimating their abilities, young e-scooter riders might perform safety-critical behavior like tandem riding (two people on one e-scooter), riding against the direction of travel, and using the wrong infrastructure (i.e., footpaths, depending on national regulations). A first hint that safety-critical behavior is enhanced for younger e-scooter riders compared to older riders was shown by the observations of Huemer et al. (2022) for a sample consisting of e-scooter riders and cyclists. Still, a replication of this finding is missing.

For riding e-scooters at night, the rate of young people using e-scooters at night might be increased compared to the daytime if they head to bars, clubs, or pubs. In addition, these young users could be strongly affected by riding with their peers. Research on car drivers shows that adolescents' risky behavior increases with peers' being passengers (Leadbeater et al., 2008) and by having risky friends or peer pressure (Simons-Morton et al., 2012). Regarding e-scooter riding, the question arises whether adolescents travel primarily in groups with peers and whether this is associated with increased safety-critical behavior, especially at night.

An observational study could gather robust data on riding in groups and the safety-critical behaviors of e-scooter riders both day and night. Previous research used camera-based methods or human observers to study the demographic characteristics and rule violations of e-scooter riders (Arellano & Fang, 2019; Haworth et al., 2021a, 2021b; Haworth & Schramm, 2019; Huemer et al., 2022; Siebert et al., 2021). With camera-based methods, riding in groups cannot be captured well because of too-small image detail, especially when aiming to rate the togetherness of individuals at greater distances. In addition, at night, the image of camera-based observations loses sharpness and coloration, making the categorization of gender and age more difficult. A human observer, however, can study an e-scooter rider over an extended period and effortlessly recognize a person's social affiliation with others regardless of the time of day. Since there have been no previous studies on the nighttime use of e-scooters or riding in groups, this study aims to fill this gap through observations with human observers, also covering the behaviors of young e-scooter riders.

To sum up, we aimed to analyze the following research questions with an observational study:

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- Which safety-critical behavior of e-scooter riders can be observed at night compared to daytime?
- Are there differences in the demographic profile of e-scooter riders between day and night?
- Does the percentage of riding in groups increase at night compared to the daytime?
- Is riding in groups or age correlated with increased safety-critical behavior at night compared to daytime?

2 Methods

2.1 Observation plan and sites

To compare the user characteristics, risky behavior, and rule violations of e-scooter riders between day and night, we chose four sites in two German cities (Dresden and Berlin) that guaranteed high e-scooter usage during the daytime. In addition, these sites were located close to pubs, restaurants, and clubs, which enabled nighttime observations. Each site had two clearly defined observation areas (two sides of the road) with an expanse of around 70 m without junctions or intersections. An exception to this arrangement is site two because both a main street (with two observation areas), and a side street adjacent to it were observed there. Every observation area had one observer. The data collection was made in two weeks, in August and September 2020. The nighttime observations were conducted on Friday and Saturday evenings (9 pm to 0.30 am). We added the afternoon of the same day for daytime comparisons (2 pm to 6.30 pm) and another afternoon on a weekday (2 pm to 6.30 pm). Indicators for the chosen times were the evaluations of Tack et al. (2019) on the usage of rental e-scooters. Table 1 gives an overview of the observation plan.

Table 1. Observation plan for the four sites.

	Site 1	**Site 2**	**Site 3**	**Site 4**
City	Berlin	Berlin	Dresden	Dresden
Location	Warschauer Brücke	Unter den Linden	Albertplatz	Kulturpalast
Day (Tuesday / Wednesday) - observation times	Tuesday: 2 pm – 4 pm / 4.30 pm – 6.30 pm	Wednesday: 2 pm – 4 pm / 4.30 pm – 6.30 pm	Tuesday: 2 pm – 4 pm / 4.30 pm – 6.30 pm	Wednesday: 2 pm – 4 pm / 4.30 pm – 6.30 pm
Day (Friday / Saturday) – observation times	Friday: 2 pm – 4 pm / 4.30 pm – 6.30 pm	Saturday: 2 pm – 4 pm / 4.30 pm – 6.30 pm	Friday: 2 pm – 4 pm / 4.30 pm – 6.30 pm	Saturday: 2 pm – 4 pm / 4.30 pm – 6.30 pm
Evening / night (Friday / Saturday) – observation times	Friday: 9 pm – 11 pm / 11.30 pm – 0.30 am	Saturday: 9 – 11 pm	Friday: 9 pm – 11 pm / 11.30 pm – 0.30 am	Saturday: 9 – 11 pm

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2.2 Observation categories

The following variables were observed: age, gender, group size, vehicle type (rental, owner), tandem riding (two persons on one e-scooter), sidewalk riding, helmet use, used road infrastructure, riding against the direction of traffic, headphone use, handheld smartphone use as well as luggage on/at the e-scooter.

The following definitions were made:

- The category group size reflects the number of e-scooters within one group, i.e., the number of vehicles.
- A group is defined as a socially cohesive group of people.
- Within a group of two or more e-scooters, the person driving in front is observed for all other categories.
- For tandem riding, the person steering is observed for all other categories.
- Age categories were the following: children (<14 years), adolescents (14-20 years), young adults (20-40 years), middle-aged adults (41-65 years), and pensioners (>65 years)

Observers were trained in observational areas and categories before starting the official data collection. For observations, they used a tablet-based observation tool (Vollrath, 2019). Inter-rater reliability was excellent for observations of group size, helmet use, tandem riding, smartphone use, and gender (each $\kappa = 1.00$), almost perfect for headphone use and type of vehicle ($\kappa = 0.88$), substantial for luggage on/at the e-scooter ($\kappa = 0.75$), and moderate for age ($\kappa = 0.43$) (Landis & Koch, 1977).

2.3 Data analysis

We collected the data for all observed variables separated into two measures of daytime and one of nighttime. The total number of observations was N=732. The influence of the observation time on distributions of demographic characteristics, group size, and safety-critical behavior was tested using Pearson Chi-squared tests. We performed post hoc tests by comparing significance levels of adjusted standardized residuals with Bonferroni correction (Beasley and Schumacker 1995). The influence of age and group size on safety-critical behavior at night was tested for the variables wrong-way riding, sidewalk riding, and tandem riding with Generalized Estimating Equations with a binary logic link function. The predictors were observation time (day vs. night), observed group size (riding alone vs. riding in groups), age (adolescents vs. older), and their two-way interactions.

3 Results

First, we report the results on the differences between daytime and nighttime e-scooter riding on observed gender, age, group size, and vehicle type. Table 2 shows the descriptive numbers.

Table 2. Demographic characteristics of e-scooter riders, group size, and vehicle type depending on the time of observation (N=732). Exception of sample sizes due to impossible classification for vehicle type: n=182 for the day [Tuesday/Wednesday] and n=200 for evening /night.

Variable		Day Tuesday/Wednesday		Day Friday/Saturday		Night Friday / Saturday	
		n	%	n	%	n	%
gender	male	137	74.9	270	77.5	148	73.6
	female	46	25.1	78	22.5	53	26.4
age in years	children	5	2.7	4	1.2	1	0.5
	adolescents	37	20.2	48	13.8	41	20.6
	young adults	116	63.4	241	69.2	134	67.3
	middle-aged adults	25	13.7	55	15.9	23	11.6
	pensioners		-		-		-
group size	1 e-scooter	105	57.4	128	36.8	80	39.8
	≥ 2 e-scooter	78	42.6	220	63.2	121	60.2
vehicle	rental	167	91.8	330	94.8	196	98.0
	privately owned	15	8.2	18	5.2	4	2.0

Around three-quarters of all observed e-scooter riders were male, and one-quarter were female, regardless of the time of day, $\chi2$ (2) = 1.21, p = .559, *Cramer's V* = .040. The number of teenage e-scooter riders was slightly higher on Friday/Saturday nights than on the same days in the daytime, but without a statistically significant difference $\chi2$ (4) = 6.85, p = .144, *Cramer's V* = .069.

The observations of people riding e-scooters in groups with peers significantly changed when testing for the effect of observation time, χ^2 (4) = 29.41, $p < .001$, *Cramer's V* = .142. Post hoc tests showed that in the daytime in the middle of the week, the relative number of people riding alone was higher than expected ($p < .001$). In contrast, riding alone in the daytime of a Friday or Saturday day was lower than expected (p = .017). Riding in groups with peers was observed more often on Fridays/Saturdays (60% and 63%) than during the week (43%). An assumed increase in riding in groups at night hours cannot be confirmed.

The observation time significantly influenced how many rental or privately owned e-scooters were observed, $\chi2$ (2) = 7.73, p = .021, *Cramer's V* = .103. At night the percentage of rental e-scooters was higher than for daytime observations. With the rather small global effect, the post hoc tests with Bonferroni correction showed no significant differences (p = .128).

Next, the results on safety-critical behavior are reported. Table 3 shows the descriptive statistics of helmet use, wrong-way riding, sidewalk riding, tandem riding, headphone use, smartphone use, and luggage transport, depending on the observation time. As can be seen, the reported rates of safety-critical behaviors varied strongly. Overall, helmet and smartphone use were observed only in a few cases. For both, no influence of the observation time is given, helmet use: $\chi2$ (2) = 1.62, p = .446, *Cramer's V* = .047;

smartphone use: $\chi2$ (2) = 3.50, p = .173, *Cramer's V* = .069. Similarly, for the transport of luggage at/with the e-scooter, no influence of observation time on observed rates is given, $\chi2$ (2) = 4.43, p = .109, *Cramer's V* = .078.

For both wrong-way riding and sidewalk riding, we see similar patterns: The observed amounts are high in the daytime during the week, then become lower for the daytime of Friday/Saturday, and finally increase again for the night observations. Wrong-way riding was observed at night for every one in ten and sidewalk riding every three in ten. For both variables, a significant influence of observation time is given: wrong-way riding: $\chi2$ (2) = 7.50, p = .024, *Cramer's V* = .101; sidewalk riding: $\chi2$ (2) = 21.04, p < .001, *Cramer's V* = .170. For wrong-way riding with a relatively small global effect, the post hoc tests showed no significant differences. There are tendencies that observations of wrong-way riding were higher than expected in the daytime during the week (p = .104) and lower than expected in the daytime on Fridays/Saturdays (p = .088). For sidewalk riding, post hoc tests showed that sidewalk riding was higher than expected for daytime during the week (p = .010) and lower than expected for daytimes of Fridays/Saturdays (p < .001).

Tandem riding (two persons on one e-scooter) was increased for the nighttime observations compared to daytime observations regardless of the day of the week, with every one in ten observed e-scooter riders. An overall significant effect of observation time was found, χ^2 (2) = 10.40, p = .006, *Cramer's V* = .119. Post hoc tests showed that observations of tandem riding at night were significantly higher than expected (p = .002). These results indicate more rule violations of tandem riding for night observations.

Lastly, the percentage of headphone use was observed more often during the daytime in the week compared to Fridays/Saturdays regardless of daytime or night. The influence is significant, χ^2 (2) = 9.97, p = .007, *Cramer's V* = .117. Post hoc tests showed that the observed headphone use for daytime during the week was higher than expected (p = .015).

Table 3. Safety-critical behavior depending on the time of observation (N=732).

	Day – working days[1] (n=183)		Day - Friday/Saturday (n=348)		Night - Friday / Saturday (n=201)	
	n	%	n	%	n	%
helmet use	2	1.10	6	1.70	1	0.50
smartphone use	2	1.10	6	1.70	0	0.00
wrong-way riding	26	14.20	24	6.90	21	10.40
sidewalk riding	60	32.80	58	16.70	59	29.40
tandem riding	9	4.90	12	3.40	20	10.00
headphone use	26	14.20	27	7.80	11	5.50
luggage transport	17	9.30	26	7.50	8	4.00

[1] Except for Friday

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Table 4. Descriptive statistics of categories used for Generalized Estimating Equations, N=720 (without children).

Variable		n
Wrong-way riding	no	653
	yes	67
Sidewalk riding	no	550
	yes	170
Tandem riding	no	680
	yes	40
Observation time	night	198
	day	522
Group size	≥ 2 e-scooter	412
	1 e-scooter	308
Age	adolescents (15-20 years)	126
	older than 21 years	594

Table 5. Generalized estimating equation model results of predicting wrong-way riding, sidewalk riding, and tandem riding vs. showing no wrong-way riding*, no sidewalk riding*, and no tandem riding*. Bold highlighted results are significant at $\alpha < .05$. * Referenced category.

	Estimate	***SE***	**Wald**	***p***
Wrong-way riding				
Intercept	-2.26	0.22	107.14	<.001
night vs. day*	-0.33	0.36	0.82	.365
≥ 2 e-scooter vs. 1 e-scooter*	-0.47	0.41	1.33	.248
adolescent vs. older*	**1.33**	**0.54**	**6.07**	**.014**
night & ≥ 2 e-scooter vs. other combinations*	0.78	0.47	2.72	.099
night & adolescent vs. other combinations*	-0.41	0.52	0.63	.426
≥ 2 e-scooter & adolescent vs. other combinations*	-0.47	0.61	0.60	.441
QIC	*445.87*			
Sidewalk riding				
Intercept	-1.87	0.22	72.38	<.001
night vs. day*	0.13	0.34	0.14	.711
≥ 2 e-scooter vs. 1 e-scooter*	0.11	0.26	0.18	.674
adolescent vs. older*	0.80	0.51	2.46	.117
night & ≥ 2 e-scooter vs. other combinations*	0.18	0.46	0.16	.690
night & adolescent vs. other combinations*	0.22	0.44	0.26	.612
≥ 2 e-scooter & adolescent vs. other combinations*	-0.47	0.65	0.54	.464
QIC	*824.98*			
Tandem riding				
Intercept	-3.23	0.37	74.76	<.001
night vs. day*	**1.84**	**0.55**	**11.29**	**<.001**
≥ 2 e-scooter vs. 1 e-scooter*	-0.22	0.52	0.18	.668
adolescent vs. older*	**1.54**	**0.72**	**4.52**	**.034**
night & ≥ 2 e-scooter vs. other combinations*	**-3.08**	**1.22**	**6.35**	**.012**
night & adolescent vs. other combinations*	-0.70	0.82	0.73	.394
≥ 2 e-scooter & adolescent vs. other combinations*	-2.26	1.29	3.09	.079
QIC	*273.37*			

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To quantify the effects on wrong-way, sidewalk, and tandem riding, we tested the influence of age, group size, observation time, and their 2-way interactions with Generalized Estimating Equations. Table 4 shows the variables and levels being used in the model. Table 5 shows the results of the models. For *wrong-way riding*, we see a significant influence of age, indicating that adolescents ride more often against the direction of travel than older users of e-scooters, regardless of the time of day. There was no effect on wrong-way riding for group size, observation time, and two-way interactions. The model for *sidewalk riding* showed no significant influences at all, implying similar rates of users riding the e-scooter illegally on a sidewalk regardless of observation time, group size, and age. For *tandem riding*, several significant influences were found. Results show that tandem riding is increased for observations at night compared to daytime. One can also see a significant interaction between observation time and group size. It shows that tandem riding is less likely to occur when riding with two or more e-scooters at night than in other combinations. For a better understanding, Fig. 1 illustrates this interaction with descriptive numbers showing that the observed tandem riding rate is particularly enhanced for two people sharing one e-scooter at night. Finally, the model showed a significant influence of age on tandem riding. The result indicates that adolescents ride more often together on one e-scooter than older users do, regardless of the time of day.

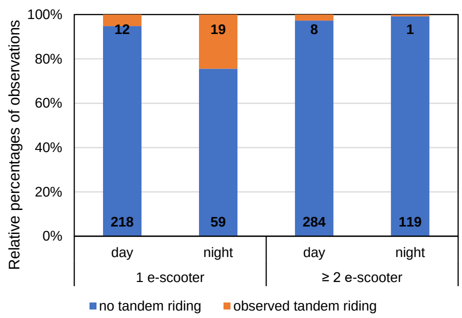

Fig. 1. Observed rates of tandem riding depending on observation time and group size.

4 Discussion

We conducted an observational study in two German cities to analyze possible differences between daytime and night for e-scooter riders concerning safety-critical behavior and the demographic profile of users.

Most interestingly, we found an increase in tandem riding at night compared to the daytime. Moreover, tandem riding at night was more likely to be shown for e-scooter riders using one e-scooter compared to those riding in groups with two or more e-scooters. This finding implies that tandem riding at night is a cause of concern, especially for pairs renting only one e-scooter. Reasons for increased tandem riding at night could be reduced availability of e-scooters, increased disinhibition by alcohol or drug abuse, shorter trips, peer dynamics, and pricing.

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It would be necessary to analyze in more detail what factors lead to renting only one e-scooter at night and sharing it with someone, for instance, with interviews in the nighttime. From a traffic safety perspective, some might say that tandem riding at night is a reason to prohibit the usage of e-scooters for specific hours. For instance, with the rental ban on shared e-scooter at night in Atlanta (after four deaths of e-scooter), Anderson et al. (2021) showed a reduction in e-scooter riders arriving at the hospital compared to times without the rental ban. However, tandem riding might also be reduced by less drastic traffic measures like price offers for pairs or promotional campaigns in the e-scooter apps. In addition, our results show that safety-critical behavior and rule violations for all other variables did not change when comparing day and night observations (helmet use, wrong-way riding, headphone use, smartphone use, and luggage transport). This implies that e-scooter riding at night is not automatically related to irregular behavior.

For adolescents (approx. 14-20 years old), we found an increased rate of wrong-way riding and tandem riding compared to older categorized e-scooter riders. With this, younger users appear to be more prone to these safety-critical behaviors, which is in line with the findings of Huemer et al. (2022). The result indicates that the self-enhancement bias, as observed in young car drivers (Harré et al., 2005; Sibley & Harré, 2009), might also be relevant in e-scooter riding. Inexperience with e-scooters and traffic rules, in general, could also contribute to the irregular behavior of young riders (Petzoldt et al., 2021). Indeed, more research is needed with the latest numbers to confirm these assumptions. No significant differences between day and night were found for the demographic profile of e-scooter riders. The observed distributions of gender and age correspond to previous findings for daytime observations (Haworth & Schramm, 2019; Huemer et al., 2022), with three-quarters being male and a main age range between 20 and 40 years.

A further relevant finding relates to the differences between both daytime observations. During the week, the rate of headphone use, wrong-way riding, sidewalk riding, and people riding with one e-scooter was higher than for precisely the same (day) times' observations on Fridays and Saturdays. Conversely, we observed lower group riding rates during the week than on Fridays and Saturdays. Bringing these results together might indicate a change in the trip purposes. For work days, e-scooters could be mainly used for commuting trips (using only one e-scooter, using headphones). In contrast, at weekends, people might use e-scooters for leisure activities with accompanying peers. This interpretation of data matches the observation of more privately-owned vehicles than shared ones during the week, which might also be commute-related. Such differences in trip purposes and maybe also user characteristics (except for age and gender) could also be a reason for increased crash rates of e-scooter riders on weekends. Further research should focus on rule violations in light of differentiations between rides of commuters and leisure activities, similar to Huemer (2018) with cyclists.

This research provided valuable results on safety-critical behaviors and demographic characteristics of e-scooter riders at night. However, some limitations must be acknowledged. A shortcoming of our observational study is the fact that the human observer could only categorize one person at the same time. This means that within a group of several people, the other ones might be under-represented in our data.

For this reason, we suggest further studies aiming to analyze riding in groups by combining human and video observation. With the help of time-synchronized video data, it would be possible to encode the other e-scooter riders. Another limitation is the small number of sites that were covered. We know that the locations used for observations can have their peculiarities, and data might be biased. For this reason, further research is needed to validate our findings.

5 Conclusion

The observational study being presented in this article analyzed safety-critical behavior, rule violations, and user characteristics of e-scooter riders during daytime and night. The results indicate a particular relevance of tandem riding at night and increased rule violations of adolescents regardless of the time of day. The results suggest that traffic safety education should focus on tandem riding, especially targeting the user group of teenage riders. With this study, we bring e-scooter riding at night into the light and emphasize rider's nightly behaviors for policymakers.

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