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Visual attention and speeds of pedestrians, cyclists, and electric scooter riders when using shared road – a field eye tracker experiment

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ABSTRACT

Shared roads for pedestrians and bicycles are common in modern cities. Recently, such roads are frequently utilised also by riders of electric scooters, which, being a novel personal transport means, are not regulated uniformly. Analysis of visual attention of young people who travelled the same shared road as pedestrians, as bicyclists, and as electric scooter riders was done with a mobile eye tracker. The results demonstrate that the numbers of fixations per minute for people using these transport modes were similar, but their distribution was different. The road ahead was observed much more by riders (39–43% of all their fixations) than by pedestrians (25% of all their fixations). Pedestrians frequently looked at the sides (40% of their fixations), while riders did not. Observation of other pedestrian road users by test participants travelling on feet took 26% of their fixations; for riders, the number increased to 35–38%, which indicates visual search for potential hazards while riding. Average speeds of pedestrians were high, 5.9 km/h; bicycle riders travelled at 16.8 km/h and electric scooters were ridden at 16.5 km/h. Thus, based on visual attention of electric scooters riders and their velocity, their vehicles ought to be classified as a special variation of a bicycle for most of regulatory, practical, and road safety purposes.

1. Introduction

Cycling and walking are typical forms of local locomotion, especially common in the urban environment. Recently, portable electric scooters (ES) were developed and quickly gained popularity and generated previously unknown issues associated with safety (Ma et al., 2021). Their users compete with pedestrians and cyclists to occupy the same space (Lanza et al., 2022), which may create conflicts and cause accidents. Hence, appropriate space assignment and regulation may be necessary. The balance between the safety of pedestrians and ES riders is still being sought (Yang et al., 2020), while the legislation process lags behind the rapid emergence and popularity of this new micromobility transportation mode (Button et al., 2020; Gössling, 2020). The status of ES varies between countries, from being unregulated at all, having been treated as pedestrians (Poland), as bicycles (Austria or France) or bicycle-like vehicles with restrictions (Belgium or Portugal), as motorcycles (Japan), to a complete ban on public roads (the United Kingdom or Hungary) (Akter et al., 2021). New regulations are emerging: while this article was undergoing review, test riding of ES at public roads was permitted in the United Kingdom (Statutory Instruments, 2020), the use and speeds of ES were curtailed in Norway in an attempt to lower the accident rates (Modijefsky, 2021), and the status of ES in Poland was modified (Sejm, 2021). Currently in Poland, where the study reported herein took place, riders of ES are treated similarly to cyclists, albeit in many aspects separately from them; amongst the recent changes was imposition of the maximum speed at any road (20 km/h), the minimum age for riders (10 years), the necessity to obtain a bicycle rider card (a licence mandatory for minors riding a bicycle on public roads in Poland, issued after passing an exam from traffic rules, usually during elementary school education) for those younger than 18 years unless they possess a valid scooter licence, the sobriety obligation (maximum permitted blood alcohol level 0.2‰), the requirement to use a bicycle path if it is present, regulations related to riding at pedestrian pavement (permitted only when the road speed limit is over 30 km/h and the bicycle path is absent), parking (only parallel at pedestrian pavement near the kerb, but leaving not less than 1.5 m for pedestrians), the ban on

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riding with a passenger, and several other issues.

So far, the relative share of ES was not reported as significant in comparison with other transport modes; mostly young and educated people use them (Laa and Leth, 2020; Mitra and Hess, 2021). Based on surveys and observations, it has been revealed that ES do not compete with bicycles for users, but rather complement them amongst somewhat other social groups (Curl and Fitt, 2020). ES could be conveniently used for short-distance transportation within people-friendly cities (Gössling, 2020a); possibly they could slightly extend the dimensions of the '15-minute city' or be used for the 'last mile' transportation (Baek et al., 2021). Nonetheless, because of the rapid emergence of ES and their novelty, it is not possible to predict their share or usage within a few years.

Amongst the paucity of research work done on riders of ES, analysis performed in virtual reality revealed that, at shared path, for pedestrians the speed of riders below 15 km/h could be acceptable, while the riders considered speed below 10 km/h as too slow (Che et al., 2020). As somewhat surprising one might consider the outcome of a study, in which ES riders were revealed to be quite ignorant of the rules of the road and basic road user etiquette (Cambetis et al., 2020; Petzoldt et al., 2021). They were also reported to be likely to engage in risky riding, including failure to wear a helmet when required, riding with a passenger, etc. (Haworth and Schramm, 2019; Siebert et al., 2021). Safety issues for both riders and less protected road users – pedestrians – are being reported quite frequently because of relatively high accident rate, in which riders of ES are involved (Harmon et al., 2020; Moftakhar et al., 2020; Namiri et al., 2020). Indeed, articles related to injuries appear to be dominating the publications about ES.

Walking and cycling as transport modes were subjects of research that was published in a plethora of articles, including several where eye tracker was utilised; whereas their review is beyond the scope of this technical article, one ought to note that the majority of eye tracking research of pedestrians was concerned with navigation issues (Liao et al., 2018; Kiefer et al., 2017; von Stülpnagel, 2020). Research of bicycle riders included steering (Vansteenkiste et al., 2013, 2014), road quality perception by people of different ages (Vansteenkiste et al., 2014a; van Paridon et al., 2019), interactions between cyclists and pedestrians (Mantuano et al., 2017), and their gaze behaviour during crossing signalised intersections (Rupi and Krizek, 2019). Somewhat related work done with an eye tracker, albeit concentrating on urban space design solely from the perspective of cyclists, was recently published (Krizek et al., 2020; Chaloupka et al., 2020). Assessment of ES riders with an eye tracker in natural environment has not been published yet, except an article related to the road surface quality (Trefzger et al., 2021).

It was envisaged that information related to visual attention while using differing modes of transport would help in understanding how to accommodate the needs of all road users and assure road safety. Hence, recordings from a wearable eye tracker were utilised to assess the speeds, manoeuvres, observation of other road users and travel path by the same persons who travelled as pedestrians, bicyclists, and riders of ES at the same shared road within urban environment to assess whether there would be differences in their visual attention. Such knowledge ought to bring better understanding of their specific needs, which should be used to develop a sustainable policy to accommodate everybody's personal mobility choice, help in appropriate assignment of space, and impose limitations, if necessary, to protect the society. The results from eye tracker study provided herein are to enhance the knowledge base not only for scientists, but also for policymakers. To the best of our knowledge, this work is the first such assessment of ES riders with eye tracker in natural environment. Moreover, it is the primary comparison of the three modes of transport at the same shared road.

2. Methodology

2.1. Test participants

There were 12 test participants, all of them volunteers not compensated in any way for their efforts, selected amongst students attending Politechnika Krakowska. All of them claimed to be regular users of both bicycles and ES and have corrected or uncorrected 6/6 vision. Ethical and data security guidelines set by Palacký University Olomouc and by Politechnika Krakowska were followed at all times and appropriate consent was signed. The group comprised 7 males (age 22.7 $\pm$ 1.3 years) and 5 females (age 22.6 $\pm$ 3.3 years) – information about sex of the test participants is provided as customary, even though it was not used for any of the analyses described in this article.

All of the test participants were assessed as a group, without within-subject comparison. Whereas there would definitely be differences depending on the presence of other road users or other momentary circumstances, combining of all of the results appeared to be good and reasonably reliable representation of average conditions and behaviour in natural environment. Because the group included evaluation of each participant also as a pedestrian, it can be considered as having an internal control.

2.2. Travel equipment

The test participants were provided with their travel vehicles, which were a standard size universal bicycle (7 speeds, wheels diameter 66 cm; seat height adjusted individually by each test participant) and a typical ES (300 W engine) without any advanced features.

Each of the test participants was given verbal instructions (in Polish language, native to all of them) about the route to be taken and was asked to obey rules of the road and travel safely but move like usually. Because the test location was near the main campus of Politechnika Krakowska, it was an area really well-known by all of the test participants and as such no wayfinding was needed. After giving the instructions, they were free to travel. In some cases, for verification, possible support, and external observation, test assistants were following the participants during their task.

2.3. Eye tracker experiment

For many years, eye tracking has been utilised extensively in various research, including applications related to transport; as such describing it is not needed (Duchowski, 2017). Despite advances in technology of the equipment, the basic concepts include metrics associated with pupil movements of the test subject: gazes, saccades, fixations, and fixation durations. For this research, equipment based on video recording of combined pupil and corneal reflection, spectacles Tobii Pro Glasses 2 (Tobii AB; Danderyd, Sweden) were utilised. Because they weigh just 45 g, the test participants quickly become accustomed to them and it could be assumed that wearing the equipment would not affect their behaviour. The equipment's software records a continuous film facing forward at 1920 $\times$ 1080 pixels, with the field of view 90°, at 25 Hz, while simultaneously the eyeballs are illuminated with near-infrared light and their movements are recorded. For each test participant, the correct operation of the eye tracking spectacles was checked with Tobii Pro Glasses Controller.

The collected data was processed using Tobii Pro Lab software with the build-in algorithm, which assumed that single gaze lasted 0.02 s and when three or more gazes were within 0.5° from each other they formed a fixation. Saccades were not analysed and some of gazes were lost because of not fitting within these parameters. As the output, the software furnished a list of fixations and the number of gazes that formed them (i.e. a dwell time), together with a screenshot of the recording containing a ‘heat map’ showing the visual focus points. Very seldom, the visual output from the software was blank; such cases were excluded from analysis. This source of errors is acknowledged; however, it was considered irrelevant for the purpose of performed assessment. Any modifications of the algorithms to furnish additional data was never intended, which makes any discussion or specific questions about this topic futile.

For the analysis of fixations and their lengths, the visual field was divided into six zones (areas of interest): *horizon*, *sides* (including persons sitting at benches), *pedestrian* (moving or standing), *roadway* (road ahead), *transport vehicle* (bicycle or ES other than utilised by the test participants), and *other* (including elements of the ridden bicycle, watch, etc.). It is important to note that borders of the zones were defined based on functional elements, without strictly following dimensional division. Such approach is known and its usefulness was confirmed (Vansteenkiste et al., 2015; Valtakari et al., 2021). Examples of the zones and the heat maps showing the visual attention are presented and described in Figs. 1–8; because the images were taken from the actual recordings, their quality was not optimised through digital manipulation other than lightness and contrast enhancement. Assignment of the fixations to various zones was done manually, using a fixation-by-fixation method.

It was hypothesised that differences in the observation distances by users of different modes of transportation could be indicators of visual search for the path forward and possible hazards (von Stülpnagel, 2020). Hence, additional manual labour was done and for each of the fixations at a person, at the road ahead, and at other transport vehicle was measured the distance between the test participant and the target of observation. For this purpose, field measurements were taken to create a detailed map of the analysed stretch.

From the recordings was measured speed, by simply dividing the analysed distance per travel time, with disregard for minor variations caused by manoeuvring, defined herein as deviation from a straight course across the test stretch. Furthermore, counted was the number of other road users who were overtaken (i.e. those who moved slower), who overtook (i.e. those who moved faster than test participants), who were passed (i.e. those who moved in opposite direction), who were bypassed (i.e. those who were stationary), and who remained in front.

2.4. Travel route

The entire path, shown on map in Fig. 9, was approximately 1500 m long. The route was travelled by each of the test participants, always in the same direction, on the bicycle, on the ES, and as a pedestrian – the order of transport mode was random. Some of the test participants were evaluated on one day, while others at different occasions. The testing took total of 5 days in late summer and 4 days in early autumn, around noon (±2h), when the road surface was dry; occasional first fallen autumn leaves were present on the pavement. The traffic at the analysed stretch was subjectively judged as typical.

Fig. 1. Zone: *horizon*. Observation of area far ahead, without fixation on any specific object. Distance typically longer than 55 m.

Fig. 2. Zone: *roadway*. Observation of the road ahead, within distances of approximately 11.5–12.5 m.

Fig. 3. Zone: *sides*. Observation of lawn on the left side. The zone would also include observation of trees or elements of small infrastructure on sides of the shared road.

Fig. 4. Zone: *sides*. Observation of a person sitting on the right side. Note that if the person were standing or walking, the classification would change to observation of zone *pedestrian*.

For the analysis presented herein, a flat straight stretch of 50 m of the shared road was taken (marked with blue dots in Fig. 9); the short analysed distance was selected to avoid any interferences and distractions associated with side traffic, turns, sloping or uneven road, etc. The road is a park alley lined with benches on both sides, 6.0–6.5 m wide, with asphalt surface in good condition; there are no road markings, riding of bicycles is expressly permitted at a shared road level identified by the road sign shown in Fig. 10a (i.e. both pedestrians and bicyclists

Fig. 5. Zone: *pedestrian*. Observation of a person walking or standing, regardless of the person's movement direction or location.

Fig. 8. Zone: *transport vehicle*. Observation of a bicycle ridden by a person not being the test participant.

Fig. 6. Zone: *other areas*. Observation of an element of the bicycle ridden by test participant. The zone also includes gazes at watch, etc.

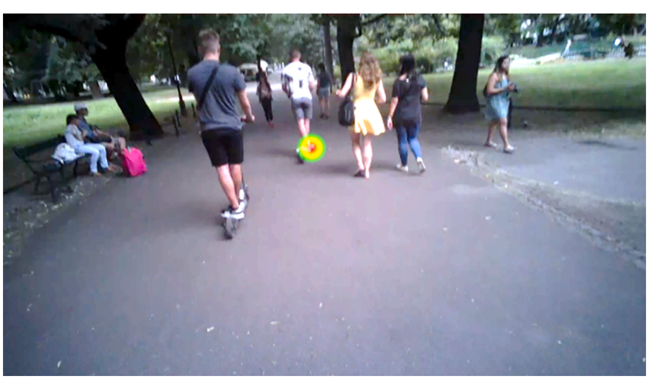

Fig. 7. Zone: *transport vehicle*. Observation of an ES ridden by a person not being the test participant.

may use the entire alley width in either directions, without specifying right- or left-hand drive). The road is frequented by pedestrians of different ages, both local residents and tourists, and also is used by riders of bicycles and ES. Because the analysed region was in approximately half of the travel path, all of the test participants were considered as fully accustomed to wearing the eye tracker and it could be assumed that they moved as they would usually.

The definition of shared road in Polish law is only indirect; it is resulting from the description of combined road signs (codes C13 and C16) as shown in Fig. 10a, differing from the same signs, but arranged like shown Fig. 10b or Fig. 10c that indicate separate travel paths. To the best of the authors' knowledge, there are no official road signs dedicated to ES in any European country.

3. Results

3.1. Speeds

All of the test participants moved quite fast, as shown in Fig. 11. Review of the raw data indicated randomness and the absence of 'fast' and 'slow' test participants: i.e. for example, a person who walked fast could be slow on bicycle and average on ES, and vice versa. The pace of pedestrians, on average 5.9 km/h, was much faster than measured recently during the task of wayfinding at train station in Kraków, where the mean speed was 4.3 km/h (Pashkevich et al., 2019, 2020). While this is could be puzzling and demand additional research, one should consider the absence of wayfinding, the straight road stretch without obstacles, and the fact that each of the test participants moved as a singleton completing an assigned task (Willis et al., 2004).

The differences in speed between pedestrians and cyclists or ES riders were statistically significant, confirmed by t-tests at 0.05 significance level: $t(11) = -9.855, p = <0.001$ and $t(11) = -11.811, p = <0.001$, respectively. No statistical significance was found between the speeds of cyclists and ES riders: $t(11) = -0.531, p = 0.607$.

The riders of both bicycles and ES travelled at speeds that can be considered hazardous, on average exceeding 16 km/h; the fastest riders were really dangerously fast, moving at >23 km/h. One must keep in mind that these speeds were within a shared space and not at separate dedicated roads; therefore, speed safe for the least protected road user should have been maintained. Manoeuvring at such speeds amongst pedestrians of all ages might lead to collisions and injuries (Maiti et al., 2020, Sikka et al., 2019).

One should observe here that within the recently imposed legislation in Poland (Sejm, 2021), a maximum speed for ES was set at 20 km/h at any type of road; however, at pedestrian pavement (and shared road, indicated by road sign shown in Fig. 10a, should be considered as one), riders of ES were obliged to move cautiously at speed similar to pedestrians and yield to them. Unfortunately, the statute is ambiguous and may be subject to undue interpretations; if taken verbatim, it may prevent an ES rider from overtaking a pedestrian, which would be absurd. Self-regulation of speeds of riders and pedestrian traffic density would be the ideal approach (Beitel et al., 2018), but this would demand high level of courteous behaviour; unfortunately, as demonstrated by the various aforementioned reports and evidenced by the concerns with safety – this is not realistic.

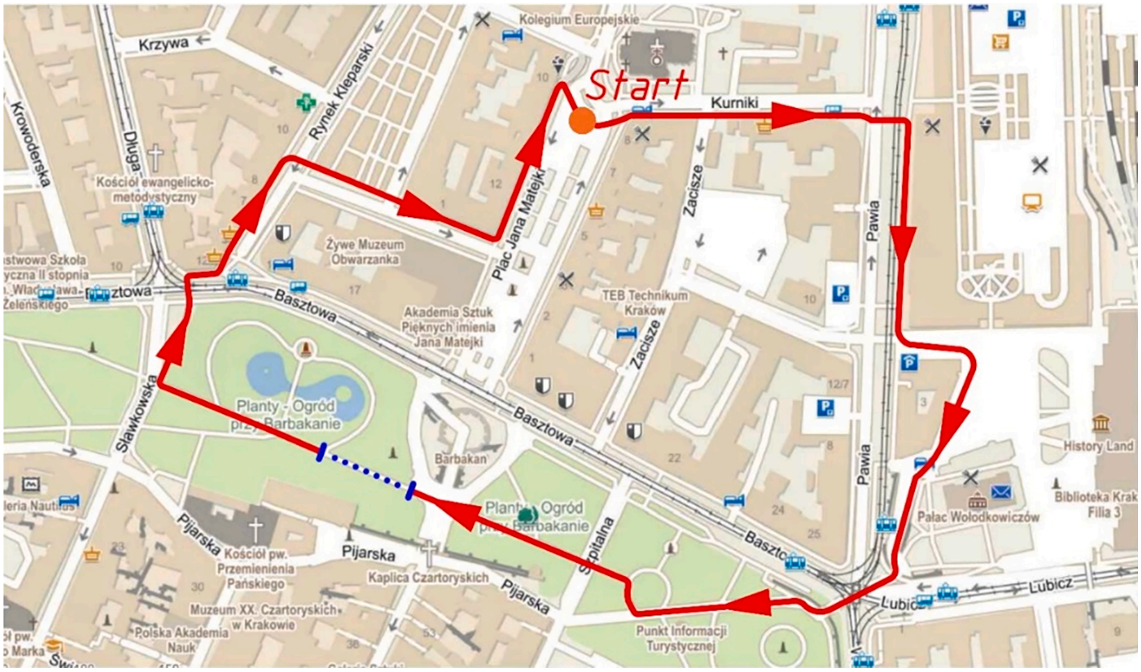

Fig. 9. Test route (red line) and test stretch for this analysis (blue dots). *Map source*: OpenStreetMap, public domain; route overlay by authors.

(a) (b) (c)

Fig. 10. Road signs C13/C16 in Poland: (a) Shared road, (b) Separate road with road for bicycles on the right, (c) Separate road with road for bicycles on the left.

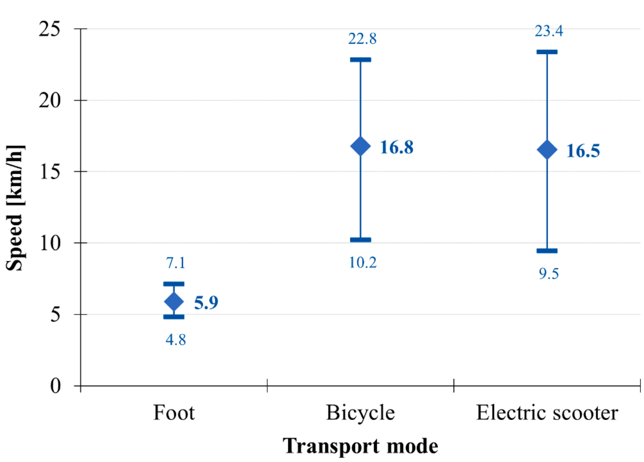

Fig. 11. Speeds (range and averages) at the analysed stretch.

3.2. Other road users

In Table 1 are listed the total numbers of other road users that the test participants encountered at the analysed stretch. The number of pedestrians overtaken by the riders of ES was very high, which was caused by one of the test participants encountering a large group of tourists; without that instance, the numbers would be similar. It is a natural drawback of naturalistic field studies.

When analysing riders' speeds and the numbers of overtaken and passed persons on the test stretch, their relationship within the scope of the study showed negative correlation: Pearson's correlation coefficients were $r(10) = -0.61, p = 0.036$ and $r(10) = -0.65, p = 0.023$ for ES riders and bicyclists, respectively. These results can be considered as an indication of self-regulatory behaviour (Beitel et al., 2018).

It was hypothesised that riders of the ES were more likely than bicyclists to manoeuvre between pedestrians. Some data and results of various calculations and searches for correlation are provided in Table 2. The number of manoeuvres was almost the same (26 and 25, respectively for cyclists and ES riders); however, recalculation of these numbers per overtaken road user revealed a meaningful difference (correspondingly 0.36 and 0.86), which might have indicated that indeed ES users were more likely to fit themselves between pedestrians.

Table 1
Encountered other road users (total numbers).

Travel mode of test participants	Overtaken by test participants		Overtook test participants		Passed other road users			By-passed	In front[a]
	Pedestrians	Bicyclists	Bicyclists	ES	Pedestrians	Bicyclists	ES	Pedestrians	Pedestrians
Foot	4	0	1	2	81	7	0	102	13[b]
Bicycle	19	2	0	0	68	13	0	63	5[b]
Electric scooter	44	1	0	0	74	1	1	70	19

[a]Persons who were walking in front of the test participants. [b]Including one rider of ES that was followed by a test participant. Two ES and one bicycle who overtook the test participants are included in another columns.

Table 2
Manoeuvres by the test participants while riding a bicycle and an electric scooter.

Travel mode of test participants	Total manoeuvres	Other manoeuvres[a]	Per test participant	Average per encountered person	Average per overtaken person	Average per passed person	Average per passed or overtaken person
Bicycle	26	14	2.17	0.29	0.36	0.38	0.33
Electric scooter	25	0	2.08	0.21	0.86	0.25	0.22

[a]Manoeuvres not associated directly with overtaken road users, initiated by the test participants mostly without apparent reason; they were excluded from the calculation of average manoeuvres per overtaken person.

Nonetheless, if one included the number of pedestrians who were either overtaken or passed, the opposite picture emergeed (0.33 versus 0.22, correspondingly). Pearson's correlation coefficients between the number of overtaken and passed pedestrians and the number of manoeuvres by cyclists and ES riders were respectively $r(10) = 0.40, p = 0.194$ and $r(10) = 0.81, p = 0.001$. These results are an indication that some of the manoeuvres by bicycle riders were not caused by the presence of other road users. Because often it was not possible to unequivocally assign a manoeuvre to the event of encountering a particular other road user, no positive conclusions could be drawn. This topic requires additional research.

Even though at such shared road it is permitted to travel in either side, only one cyclist and one ES rider used left side and correspondingly 3 and 1 rode in the middle of the road; the rest kept to the right. Due to small number of such instances, this interesting issue is not addressed any further.

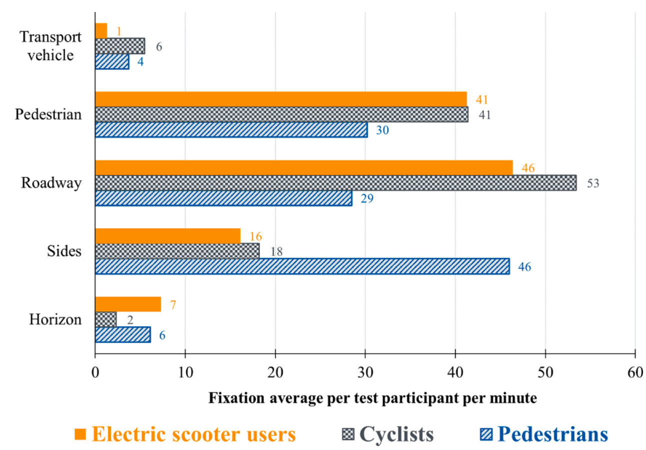

Fig. 12. Distribution of fixations.

3.3. Visual attention

Distribution of fixations, with the division into zones defined above, is provided as Table 3 (standard deviations given in parentheses) and

Table 3
Fixations distribution.

Transportation mode	Observation area	Total fixations (for all test participants)	Fixations percentage	Fixations average per test participant	Fixations average per test participant per minute	Average fixation duration [s]
Foot	Horizon	36	5.0%	3.0 (3.8)	6.1 (8.1)	0.50 (0.41)
	Sides	288	40.3%	24.0 (13.5)	46.0 (24.6)	0.34 (0.32)
	Roadway	180	25.2%	15.0 (9.1)	28.5 (15.9)	0.46 (0.40)
	Pedestrian	184	25.7%	15.3 (5.9)	30.2 (12.9)	0.45 (0.36)
	Transport vehicle	24	3.4%	2.0 (2.4)	3.7 (4.3)	0.64 (0.73)
	Other areas	3	0.4%	0.3 (0.9)	0.4 (1.5)	0.49 (0.60)
Bicycle	Horizon	5	1.9%	0.4 (0.8)	2.3 (4.4)	0.52 (0.37)
	Sides	38	14.6%	3.2 (3.4)	18.2 (20.4)	0.25 (0.40)
	Roadway	111	42.5%	9.3 (6.6)	53.4 (35.0)	0.39 (0.28)
	Pedestrian	91	34.9%	7.6 (4.3)	41.4 (23.2)	0.41 (0.32)
	Transport vehicle	15	5.7%	1.3 (2.2)	5.5 (9.9)	0.33 (0.28)
	Other areas	1	0.4%	0.1 (0.3)	0.4 (1.3)	0.10 (-)
Electric scooter	Horizon	17	6.8%	1.4 (1.8)	7.3 (8.4)	0.68 (0.82)
	Sides	38	15.3%	3.2 (3.4)	16.1 (17.0)	0.27 (0.22)
	Roadway	96	38.6%	8.0 (2.3)	46.4 (17.4)	0.40 (0.30)
	Pedestrian	94	37.8%	7.8 (4.4)	41.3 (17.8)	0.49 (0.39)
	Transport vehicle	4	1.6%	0.3 (0.9)	1.3 (3.2)	0.41 (0.30)
	Other areas	–	0.0%	–	–	–

visualised in Fig. 12. Because of the difference in speeds, the numbers of fixations per test participant is given in both the absolute values (the number of occurrences per the analysed 50 m stretch) and per minute. The total average number of fixations per minute was almost the same regardless of the travel mode, on average 116, but the ranges for individual tests were from 57 to 175. Large deviations in this type of naturalistic study have to be considered typical and can be attributed to the presence and actions of other road users.

Amongst the clearly measured differences, test participants travelling as pedestrians looked much more at the surroundings, directing at the zone *sides* approximately 40% of their fixations. Contrariwise, the riders observed the zones *road ahead* and *pedestrians* (76–77% of all their fixations), which can be treated as an indicator of increased visual search and scanning for potential hazards. This visual search for hazards appeared to be also reflected amongst pedestrians, in their much longer fixation times at the zone *transport vehicles* (0.64 s) than were measured in case of riders (0.33–0.41 s). Nonetheless, it ought to be cautioned that visual attention does not have to correspond to mental attention (Shinar, 2008). The finding that pedestrians attracted more visual attention from all test participants than transport vehicles appears to be a confirmation of a previously reported research (Trefzger et al., 2018); nonetheless, due to the low number of encountered other bicycles and ES (for all test participants only 28, as compared to encountered 526 pedestrians), no positive conclusions can be drawn. The simplest explanation for the increased observation of surroundings by test participants travelling as pedestrians is that, due to lower speeds, they had more time for enjoying their surroundings.

The statistical analysis is limited by the available data and should be seen as preliminary; only basic calculations were done to determine whether there were significant differences between the numbers of test participants' fixations at various zones when using dissimilar transport modes. For this purpose, two-way repeated analysis of variance (ANOVA) was performed to compare the main effect of the two independent variables (the used transport mode and the observed zone) and their interaction effect on the two dependent variables (the number of fixations per participant and the number of fixations per participant per minute). For the analysis, transport mode variable had three levels (pedestrians, cyclists, and ES riders) and the observed zone variable had four (*horizon*, *sides*, *roadway*, *pedestrian*, and *transport vehicle*); the zone *other areas* was excluded because of relatively low observations occurrences.

The results of ANOVA calculations are summarised in Table 4. All effects were statistically significant at 0.05 level, except transport mode factor in case of number of fixations per participant per minute. The main effect of observed zone factor indicated a significant difference between the number of fixations in the different observed zones. Taking into account that the main effect of transport mode was partly non-significant, the significance of the interaction effect must be pointed out. This effect can be observed in Fig. 12: the mode of transport “pedestrians” has quite a different pattern than the other two modes.

For a *post hoc* test were used pairwise t-tests with the Benjamini/Hochberg FDR correction to adjust *p*. Among the outcomes, the most notable one is that for all three modes of transport the number of fixations on zones *roadway* and *pedestrians* did not show a statistically significant difference: $p = 0.805$ for pedestrians, $p = 0.448$ for cyclists, and $p = 0.632$ for ES riders. Such situation could occur because of the presence of other road users: their relatively large number did not permit for route control through observation of only the roadway; to avoid collision and construct travel trajectory, observation of both the road ahead (zone *roadway*) and the other road users (zone *pedestrians*) was needed.

Any additional analysis or calculations, including advanced statistics, were not seen as necessary or reliable within the collected data and beyond the scope of this research. One must consider that the presence and behaviour of the encountered road users affected the outcome; hence, one would need to collect meaningfully more data to deconvolute the behavioural patterns of test participants and the external circumstances.

3.4. Fixations distances

Distribution of distances at which fixations occurred is summarised in Table 5 (standard deviations given in parentheses). They did not differ with statistical significance between the transport mode and zones, as is shown through ANOVA (the results are provided in Table 6). As such, similar observation may suggest similar behaviour (at least within the test participants); further investigation that was outside of the scope of this experiment may be warranted.

4. Discussion

The outcome from this study clearly demonstrated that, based on visual attention and speed during riding in shared space, ES ought to be placed amongst bicycles and subjected to the same restrictions and privileges. This agrees with the recent report of research, in which shoulder glances of ES and bicycle riders were observed (Pils et al., 2021). The results show evidence of dangerous riding, at speeds much too high for assurance of pedestrians' safety (Sikka et al., 2019). No highly aberrant behaviours, beside excessive speed, were recorded at the short test stretch; however, it should be added that none of the test participants, using any transport mode, followed all of the traffic rules throughout the entire 1500 m stretch: a total of 261 violations (both minor like stepping off marked pedestrian crossing and major like riding on pedestrian pavement outside a shared road or a failure to observe side traffic while crossing a road) were counted (50 while walking, 105 while cycling, and 106 while riding ES). Analysis of these violations – their locations, sources, and possible reasons – is another research topic. Similar number of violations by ES riders and bicyclists appear to be confirming that these personal modes of transportation are quite alike

Table 5
Observation distances (average distance to observed object [m] by travel mode).

Observation area	Pedestrians	Bicyclists	Electric scooter riders
Roadway	17.3 (7.0)	14.4 (2.9)	14.6 (4.2)
Pedestrian	15.2 (4.5)	18.2 (9.4)	15.5 (6.1)
Other transport vehicle	9.1 (3.2)	10.0 (3.8)	8.0 (4.2)

Table 4
Summary of ANOVA analyses related to fixations.[(a)]

Dependent variable	Source	df	F	p-uncorr	p-GG-corr	η_p^2	ε
Fixations per participant	Transport mode	2	82.125	<0.001	<0.001	0.882	0.914
	Observed zone	4	26.215	<0.001	<0.001	0.704	0.601
	Transport mode × observed zone	8	8.035	<0.001	0.0028	0.422	0.240
Fixations per participant per minute	Transport mode	2	0.272	0.764	0.704	0.024	0.756
	Observed zone	4	33.736	<0.001	<0.001	0.754	0.576
	Transport mode × observed zone	8	4.704	<0.001	0.0098	0.300	0.342

[(a)]df – degrees of freedom; F – F-value; p-uncorr – uncorrected p-value; p-GG-corr – Greenhouse-Geisser corrected p-value; η_p^2 – partial eta-square effect size; ε – Greenhouse-Geisser epsilon factor.

Table 6
ANOVA analysis of observation distances.[(a)]

Dependent variable	Source	df	F	p-uncorr	p-GG-corr	η_P^2	ε
Observation distance	Transport mode	2	0.345	0.712	0.690	0.030	0.901
	Observed zone	1	1.490	0.248	0.248	0.119	1.0
	Transport mode × observed zone	2	1.270	0.301	0.300	0.104	0.949

[(a)]df – degrees of freedom; F – F-value; p-uncorr – uncorrected p-value; p-GG-corr – Greenhouse-Geisser corrected p-value; η_P^2 – partial eta-square effect size; ε – Greenhouse-Geisser epsilon factor.

indeed. While considering speeds, it ought to be noted that at the time of data collection, the ES riders were in Poland legally considered pedestrians. While repeated experiment would be necessary to check whether the newly imposed law caused any changes in speeds or behaviour, it is very unlikely when judging by reports from other countries (Nikiforiadis et al., 2020) or by permanent extreme disobedience of speed limits recorded during our unrelated naturalistic driving study (Pashkevich et al., 2021).

Apportionment of large number of fixations by ES riders at pedestrians can be treated as an evidence for directing visual attention at areas perceived as a source of hazard (Schmidt and von Stülpnagel, 2018; von Stülpnagel and Krukar, 2018). One must note that even though the major groups of users of ES and bicycles may differ, for this study were selected students who used both of these modes of personal transportation on regular basis. Hence, while it is mostly the user and not the vehicle that create a hazard, this assessment provided an interesting insight as to the change of perspective with a change of the transport mode. Whereas explicit proposals for measures to improve road safety in this area are beyond the scope of this communication, education is seen as critical (SooHoo and SooHoo, 2020), even more important than regulation. Separating ES and bicycle traffic from pedestrians, while departing from the idea of shared space (Hamilton-Baillie, 2008), may be a feasible option – at least until education and culture prevail (Job, 2020).

The relatively small size of test group is typical for eye tracker field experiments and as such should not bring any concerns related to the validity of the study (Caine, 2016; Mantuano et al., 2017). Consistency of the outcome, evidenced by relatively low standard deviations for such experimental set-up, confirm soundness and universality of the test. The use of the same test participants as control group and randomisation of the order of testing them are seen as sufficient to avoid a hidden systemic bias.

The use of mobile eye tracker permitted for objective and impartial assessment of the visual attention, which is not possible when solely observation or surveys are utilised. Any doubts and inconsistencies in data could be checked through rewinding of the recordings and search for objective explanations; the absence of external factors affecting the visual attention would indicate individual traits. Unlike laboratory studies, this field experiment, in which the test participants were exposed to the plethora of distractions present in natural environment, gave the great advantage of departing from simulated environment that frequently lacks the reality. At the same time, this plethora of external factors during field data collection has the potential to change the outcome; in the case presented herein, a large tourist group encountered by just one person meaningfully impacted the results. However, such differences in external traffic load must be treated as natural variations and not negatively affecting the overall picture, but rather enhancing it; nonetheless, appropriate corrections and individual assessment was needed to identify the culprit of the outlaying data.

Amongst further research, it is proposed that perception differences between more or less frequent users of bicycles and ES should be analysed. In this preliminary study, older population, people from different cultures and foreigners were excluded, even though it is highly possible that their visual attention and road behaviour could be dissimilar, particularly if they were simultaneously involved in wayfinding. Perception of bicycle and ES riders by people who do not use these means of transportation (particularly by the elderly) appears to be worth a separate assessment. In addition, a comparison between riders of regular and electric bicycles might reveal yet unknown point of view, particularly when riding uphill. Various research needs associated with micromobility and including ES were recently reviewed (Boglietti et al., 2021).

5. Conclusions

While harmonised policy toward ES is not yet developed, this contribution to the pool of knowledge should permit for certain clarifications related to their safe use in a shared environment. A compromise ought to be found between the needs of various road users; with the growing micromobility, a space for ES should also be found, too. Whereas the approach of forbidding the use of ES on public roads on the ground of safety concerns could be comprehended, it simultaneously appears unwarranted and hindering development of novel modes of transportation; more balanced approach should bring the win–win situation for the society. Based on visual attention of riders and their speeds, ES ought to be treated as a special type of a bicycle. Only if necessary, appropriate limitations and regulations, not hindering or discouraging safe riders from micromobility, should be imposed.

CRediT authorship contribution statement

Anton Pashkevich: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Tomasz E. Burghardt:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Sabina Puławska-Obiedowska:** Project administration, Validation, Writing – review & editing. **Matúš Šucha:** Funding acquisition, Methodology, Supervision.

Declaration of Competing Interest

The authors declare no personal or business conflicts of interest.

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