PRELIMINARY RESULTS FROM FIELD TESTING

Croatian Science Foundation

eSCURB: Electric scooters in urban environments: A study of safety, infrastructure, and mobility dynamics

A2.4 Visual attention of e-scooter riders

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Contents

Ethical Declaration and Authorship Statement

We declare that this report is the result of the collective authorship of the project team. We declare that the report and its research was carried out in accordance with the principles of research, professional, and academic ethics, as well as with the requirements of the project, its funders, and the funding scheme. The project activities and its results were implemented within the framework of, and in compliance with, the project objectives, conditions, and the applicable rules of the funding agencies.

In preparing the project, we ensured the accuracy, traceability, and credibility of the presented data, consistently cited the sources used, and observed applicable legal and ethical standards. Appropriate scientific and professional sources were used in preparing the project report, and these are listed in the respective bibliographies or source lists. In doing so, we consistently respected copyright and the principles of proper source citation.

Generative artificial intelligence was also used as a support tool, exclusively for the following purposes:

- searching for and reviewing general information, especially for comparing contents throughout sources and searching for statistical sources (tools: ChatGPT and Copilot);
- translating sources and texts from foreign languages and into foreign languages (primarily DeepL and Copilot);
- translating reports between Slovenian, Croatian, and English for reporting and inter-project communication purposes (primarily DeepL and Copilot);
- grammatical and stylistic proofreading of original texts created by the project team (tools: Grammarly and Copilot).

Generative artificial intelligence was not used for independently creating the substantive parts of the research or the project results, but solely as support in processing, understanding, and linguistically optimizing content, as well as for translation between the project languages.

Procedures

The testing was conducted on Wednesday, October 8, 2025, from 08:00 to 18:00 at the Safe Riding Training Ground in Ljubečna, Slovenia.

The Safe Riding Training Ground is a controlled learning environment designed to enhance understanding of driving limits, teach appropriate vehicle handling techniques, and develop driving skills under various weather conditions and road traffic situations. At the training ground, candidates for obtaining a driving licence at the initial stage of driver education undergo training, completing their first hours of practical instruction using different types of vehicles.

In addition to initial training, the facility also enables further improvement of driving skills for candidates who attend practice sessions with their own vehicles, accompanied by supervisors who already hold a valid driving licence for the relevant vehicle category. Furthermore, organised safe driving courses are conducted at the training ground, aimed at improving road safety and enhancing the ability to manage critical traffic situations.

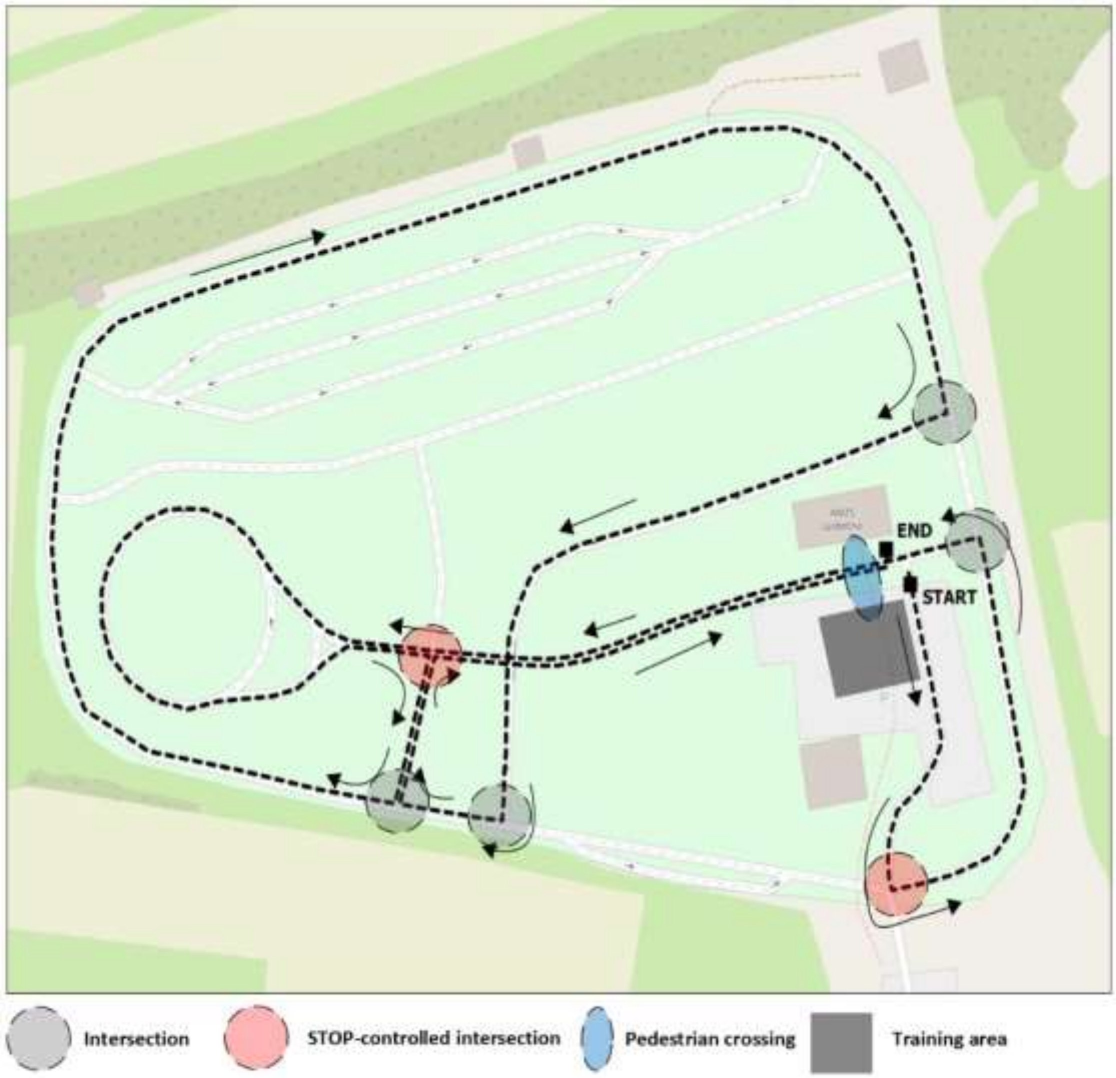
The training ground's infrastructure is designed to simulate various traffic scenarios, including driving through roundabouts, at intersections with priority roads, at intersections with roads of equal priority, over and under overpasses, and in adverse weather conditions. Such a design enables a comprehensive approach to traffic situations and contributes to participants' better preparedness for real-world road traffic conditions.

Description of the test route

Figure 1 presents the complete map of the Safe Riding Training Ground, including the entire route that all participants completed during the field testing. A designated training area was available to participants; this area was not used by any other users during field testing and was equipped with traffic cones arranged for slalom riding. The participants were able to use this area to familiarise themselves with riding the e-scooter.

The ride started and ended in front of the AMZS Ljubečna offices. In the following section, the route's characteristics are described in greater detail.

Figure 1: Map of the Safe Riding Training Ground with the field testing route for e-scooter riding.



The route proceeded as follows. The ride started at the measurement station and continued along a minor road to an intersection controlled by a STOP sign (Figure 2). At this intersection, the participants performed a left turn onto a major road. Subsequently, the route continued with a left onto a minor road from the major road (Figure 3).

Figure 2: Stop-controlled intersection

Figure 3: Intersection with a left turn

The route then continued past the pedestrian crossing located in front of the AMZS office (Figure 4), followed by a section where the participants rode under an overpass (Figure 5).

Figure 4: Pedestrian crossing

Figure 5: Through an underpass

The route then continued straight through an intersection controlled by a STOP sign (Figure 6). After this section, the route entered a roundabout, where participants completed one full round before exiting. Subsequently, the rider performed a right turn from a minor road onto a major road, followed by an additional right turn from a minor road onto a major road, as illustrated in Figure 7.

Figure 6: Stop-controlled intersection, followed by a roundabout

Figure 7: Intersection with right turn

This was followed by a longer ride along the major road, which did not include any specific traffic features or maneuvers (Figures 8 and 9).

Figure 8: Straight stretch of road – first part

Figure 9: Straight stretch of road – second part

This was followed by a right turn from the major road onto a minor road (Figure 10), crossing an overpass (Figure 11), a right turn from a minor road onto a major road, and subsequently two consecutive right turns from the major road onto a minor road.

Figure 10: Intersection with right turn

Figure 11: Crossing an overpass

The route concluded at the measurement station (Figure 12).

Figure 12: Final straight section

Experimental protocol

Participants arrived at the Ljubečna Safe Riding Training Ground , where they were first informed about the study procedure. Upon arrival, all participants signed an informed consent form (Appendix A) and completed a pre-ride questionnaire which was the same as the survey for the general public or e-scooter users that was utilized in WP 2 A2.1. Two versions of the pre-ride questionnaire were prepared: one for participants who identified themselves as e-scooter users, defined as individuals who had used an e-scooter at least once per week prior to the testing period, and one for participants who identified themselves as non-users of e-scooters.

Each participant was assigned a unique participant identification code, which was recorded by a member of the research team on the informed consent form. This identification code was subsequently used throughout the study to ensure that all required questionnaires were completed and collected for each participant. The same code was also stated at the beginning of each recording, enabling the integration of data from multiple sources—including video recordings, eye-tracking glasses, and mobile application data—during the data analysis phase.

The participant identification code was used solely to link data collected from different devices and measurement instruments. At no point was the code used to identify individual participants, and no personally identifiable information was associated with the recorded data, thereby ensuring participant anonymity throughout the study and during subsequent data analysis.

Participants were then equipped with the required measurement and safety equipment. This included Tobii Smart Glasses, a smartphone (LG G810 EEA) with the Strava application installed, which was placed in a trouser pocket, and a smartwatch (Huawei GT3 Pro 475) worn on the wrist. In addition, all participants were provided with a safety helmet and other necessary protective gear. Prior to the ride, the experimental route was explained to the participants using a map of the training ground.

Figure 13: Map of the training ground, used for learning participants

If desired, participants were given the opportunity to complete a short practice loop on the e-scooter model ECO SPEED 10x within the designated training area, allowing them to familiarise themselves with the vehicle before the main experiment.

Following the preparation phase, participants completed the entire predefined experimental route. During the ride, the researcher followed the participants along the route to record the surrounding traffic environment. At the same time, this allowed the researcher to provide directional guidance when participants became uncertain about the route.

After returning to the measurement station, participants completed a post-ride questionnaire assessing their overall riding experience.

A total of 35 participants completed the experimental procedure and were included in the final dataset. Although slightly more potential participants initially arrived at the training ground, some individuals decided not to proceed with the full experimental protocol after completing the initial e-scooter practice. These participants reported that they did not feel sufficiently comfortable or confident riding the e-scooter to safely complete the entire route. Consequently, only participants who felt confident enough to perform the full ride were included in the study.

Of the 35 participants included in the study, 10 identified themselves as regular e-scooter users, while 25 identified themselves as non-e-scooter users. Among the non-user group, several participants reported riding an e-scooter for the first time during the familiarisation ride conducted at the test field.

Test Vehicle: ECO SPEED 10X

The experiment was conducted using the electric scooter model ECO SPEED 10X (Figure 14), which belongs to the higher-performance category of electric scooters. The scooter has a maximum assisted speed of 25 km/h, in accordance with applicable regulations, and an estimated operating range of up to 50 km under standard conditions. (Big Bang, n.d.)

To ensure uninterrupted testing throughout the data collection period, two identical scooters were available and used alternately.

The ECO SPEED 10X is powered by two electric motors, one mounted on each wheel, each with a nominal power output of 1000 W, for a combined nominal power of 2000 W and a peak power output of up to 3200 W. The scooter is equipped with a 52 V, 18 Ah battery, which supports extended riding durations and stable power delivery during the experimental rides. (Big Bang, n.d.)

The scooter features a compact aluminium frame and is fitted with 10-inch pneumatic tyres, contributing to ride stability across different surface conditions. Braking is provided by hydraulic disc brakes (NUTT) with 140 mm discs, ensuring reliable deceleration and control. In addition, the scooter is equipped with front and rear suspension, which improves ride comfort and reduces the impact of surface irregularities.(Big Bang, n.d.)

Due to its dual-motor configuration and overall technical characteristics, the ECO SPEED 10X is suitable for longer routes and for riding on sections with varying gradients. These features made the scooter appropriate for the predefined experimental route and ensured consistent riding conditions for all participants. (Big Bang, n.d.)

Figure 14: Test Vehicle: ECO SPEED 10X

Source: Big Bang, n.d.

Riding parameters analysis

This study presents the analysis of e-scooter rides recorded using a smartphone, smartwatch, and Tobii Pro Lab smart glasses. GPS-based measurements from the Strava application indicated that most speeds remained below the 25 km/h factory limit of the e-scooter, with occasional peaks (phone: 38.8 km/h, watch: 52.0 km/h) attributed to short-term GPS inaccuracies. Instantaneous accelerations and ride smoothness exhibited extreme values due to signal fluctuations. Average accelerations (phone: ±2.82 m/s^2, watch: ±0.88 m/s^2) and average ride smoothness (phone: ±2.59 m/s^3, watch: ±0.53 m/s^3) reflected realistic riding behaviour.

Sensor Logger data collected from the smartphone demonstrated lower data quality, with approximately 70% of measurements invalid due to sensor noise, device orientation, and pocket placement. Despite this, general acceleration trends were observable. Tobii Pro Lab glasses provided additional insights into head motion and participant attention through stable accelerometer readings and pupil diameter measurements. Overall, the combined analysis of different devices and measurement techniques allowed for a coherent and meaningful assessment of e-scooter dynamics.

Recording of Participant Rides Using the Strava Application

The testing was conducted on Wednesday, October 8, 2025, from 08:00 to 18:00 at the Safe Riding Training Ground in Ljubečna, Slovenia. During the tests, participant rides were recorded using multiple devices and applications: the Strava app (on an LM G810 EEA XX mobile phone carried in a trouser pocket and a Huawei GT3 Pro 475 smartwatch worn on the wrist), the Sensor Logger app (on an LM G810 EEA XX mobile phone carried in a trouser pocket), and Tobii Pro Lab smart glasses. The participant and the accompanying person, who rode behind the participant, started recording the ride before or at the beginning of the trip and stopped recording upon arrival at the destination. On average, the difference between the recorded start times of the smartwatch and the mobile phone was 21 seconds, while the difference at the end of recording was one second.

Measurements collected with the Strava application were imported into ArcGIS Pro using .gpx files. In ArcGIS Pro, the data were converted into point layers using the *GPX to Features* tool. A separate point layer was created for each participant's ride. Within this tool, the Strava export file was used as the *Input GPX File*. The *Output Feature Class* was set as a point layer (the *Output Type* was kept as *points* to enable further analysis), and layers were named *Ride_FirstName_LastName_DeviceType* to facilitate later editing, as data were imported from both the phone and the smartwatch.

This was followed by a visual inspection of the created layers, representing digital twins of the participants' rides. From each ride, points representing prolonged stationary periods before the start of the ride (e.g., equipment setup, waiting for the start, route familiarization) or movements not belonging to the planned route (e.g., familiarization with the e-scooter, riding to the vehicle with equipment) were manually removed. This ensured that only points corresponding to the actual ride along the planned route remained. The validity of the remaining points was verified using participant video recordings. Each participant was recorded by a camera during the ride along the route (operated by the accompanying person riding behind the participant), and smart glasses were used to record the participant's field of view during the ride.

This approach made it possible to determine why some participants remained longer in specific locations—for example, stopping at a STOP sign and waiting for traffic to clear—or whether they deviated from the route (eight participants deviated from the route due to taking an incorrect direction). Based on ride duration, data from the Sensor Logger application and Tobii Pro Lab smart glasses were also filtered. Extracting the actual participant rides enables comparison of data collected using different techniques and technologies. For reference, the Strava application records location at one-second intervals. The number of recorded measurements therefore depends on the duration of the participant's ride—the faster the participant, the fewer measurements are recorded. Consequently, the distance travelled between two consecutive measurements increases.

To calculate acceleration from the collected data in ArcGIS Pro, an ArcPy script was used. The script was based on the principle that acceleration represents the change in velocity. If the velocity in a given interval is higher than in the previous one, acceleration occurs; if it is lower, deceleration occurs. Velocity calculation requires both distance and time. Since the Strava application records location at one-second intervals, the time component is fixed, leaving the metric distance between points as the remaining required parameter.

Acceleration is the change in velocity over time:

$$a_n = \frac{v_n - v_{n-1}}{\Delta t}$$

Since $\Delta t = 1$, it follows that:

$$a_n = v_n - v_{n-1}$$

Interpretation:

- if $a_n > 0$: acceleration
- if $a_n < 0$: deceleration (braking)
- if $a_n \approx 0$: constant speed

To calculate the distance between points as a metric distance, the ride point layers must be in a metric coordinate reference system. The coordinate system was therefore transformed using the *Project* tool. For Slovenia, the *Slovenia 1996 Slovene National Grid* projected coordinate system was used (the European *ETRS 1989* system could also have been applied). In addition, elevation data recorded by the Strava application were included in the script, as changes in altitude influence acceleration. To support the calculations, additional fields were created: distance, speed, acceleration, previous x-coordinate, and previous y-coordinate (all of type *Double*). The script describes the motion of the e-scooter during the ride and is based on the analysis of consecutive GPS points. The fields *dist_horiz_m* and *dist_3d_m* represent the distance between individual measurements—the former considering only the horizontal plane, and the latter also accounting for elevation changes, thus better reflecting actual movement in space. Speed is calculated from these distances. The field *speed_3d_raw_mps* represents raw GPS-derived speed, which may include small fluctuations due to signal noise, while *speed_3d_smooth_mps* represents a smoothed, more realistic speed. This value is then converted to kilometres per hour in the field *speed_3d_kmh*, which is most used when comparing with the actual e-scooter speed.

Changes in speed between consecutive points yield acceleration (*accel_3d_mps2*), where positive values indicate acceleration and negative values indicate deceleration. These values are further categorized in the field *accel_class*. The field *Time_s* represents cumulative ride time in seconds, while *Dist_rel_m* represents cumulative distance from the start of the ride, enabling visualization of results as a function of time or distance. The field *ORIG_FID* links records to the original GPX entries, and *Run* identifies individual rides. The field *Jerk_mps3* represents ride smoothness, defined as the change in acceleration between consecutive points, and expresses how abrupt changes in speed were. In GPS-based measurements, high ride smoothness values are typically a consequence of signal noise rather than actual sudden motion. The script processing time was approximately 30 minutes on a desktop computer with an 11th Gen Intel® Core™ i5-11400 processor @ 2.60 GHz and 16.0 GB of RAM.

Recording Participant Rides Using the Sensor Logger Application

Data collected with the Sensor Logger mobile application were analysed in MS Excel. The objective was to identify periods of acceleration and deceleration based on measurements of the device's linear acceleration. The analysis used the variables *totalAcceleration_x*, *totalAcceleration_y*, and *totalAcceleration_z*, which represent the device's linear acceleration along the three spatial axes. These values are calculated as the difference between the acceleration measured by the accelerometer and gravitational acceleration and therefore represent pure linear acceleration without the influence of gravity. Due to sensor noise or disturbances, acceleration values may occasionally reach unrealistic magnitudes. Such anomalies were replaced with zero values, as they do not represent actual motion. This prevents inaccurate measurements from influencing the final acceleration calculations or causing false detections of motion changes.

For each timestamp, the overall acceleration magnitude was calculated as the Euclidean norm of the acceleration components along the individual axes:

$$a_{\text{norm}} = \sqrt{x^2 + y^2 + z^2}$$

The resulting value represents the total intensity of acceleration regardless of the direction of movement. Since acceleration reflects changes in velocity, differences in acceleration magnitude between two consecutive time points can be used to identify motion phases. The change is expressed as:

$$\Delta a_t = a_{\text{norm},t} - a_{\text{norm},t-1}$$

A positive change indicates increasing speed, corresponding to acceleration, while a negative change indicates decreasing speed, corresponding to deceleration. When the change is small or close to zero, the device or participant is maintaining approximately uniform motion. In this way, motion phases over time can be identified: increasing acceleration values correspond to acceleration, decreasing values to braking, and stable values to uniform motion. This method relies exclusively on changes in linear acceleration measured by the device sensors. The data processing procedure for Sensor Logger measurements begins with importing the data files, extracting the timestamp and measured acceleration values. The data are then temporally aligned by converting the records into a uniform time series, where each row represents a specific measurement moment.

Recording Participant Rides Using Tobii Pro Glasses 3

The Tobii Pro glasses record data with microsecond resolution. To obtain a one-second interval, the values in the *Recording timestamp* column were divided by one million. Average measurement values for each one-second interval were then calculated using a pivot table (partial sums). The data were subsequently filtered again to include only the periods corresponding to the participant's actual ride. Acceleration was calculated using the same approach as for the Sensor Logger application, based on the *Accelerometer X*, *Accelerometer Y*, and *Accelerometer Z* variables. Changes in acceleration were determined as the difference between two consecutive calculated acceleration values.

In addition to motion data, the smart glasses also enable monitoring of participant attention through pupil diameter measurements. The variables *Pupil diameter left*, *Pupil diameter right*, and *Pupil diameter filtered* were included in the analysis. Average values for each time interval were calculated using a pivot table, and only data corresponding to the actual riding period were considered.

Results

Commentary on Strava Measurements

Measurements collected using the mobile phone and the smartwatch differ, which can be attributed to their placement during the ride. The smartwatch was worn on the wrist, where it generally has a clearer view of the sky and therefore a more stable and accurate GPS signal. In contrast, the phone was carried in a trouser pocket, where the GPS signal is partially obstructed, resulting in greater variability. Higher acceleration and ride smoothness values observed during e-scooter rides are primarily a consequence of GPS signal fluctuations rather than actual riding dynamics. The smartwatch tends to record higher extreme values due to a less smoothed, raw GPS signal, while the phone applies more smoothing and therefore shows fewer extremes. Consequently, average values are the most realistic and comparable, whereas maximum values mainly reflect temporary variations in GPS signal quality.

Regarding average speed over time, most recorded values remain below the factory speed limit of the e-scooter (25 km/h). For the phone, speeds exceeding this limit were recorded in 326 out of 10,158 measurements (3.21%), while for the smartwatch this occurred in 134 out of 8,907 measurements (1.5%). These proportions of falsely elevated speeds are fully consistent with the measurement setup. The smartwatch benefits from a more stable GPS signal on the wrist, resulting in fewer spikes, whereas the phone's position in a trouser pocket represents one of the most challenging conditions for GPS reception, leading to a slightly higher proportion of inaccuracies. Despite these less favourable conditions, the 3.21% share of elevated speeds recorded by the phone remains relatively low. Overall, the results indicate that both the smartwatch and the phone provided sufficiently stable measurements, and the observed differences are logical and consistent with device placement and GPS reception quality. A summary of the Strava measurement results is presented in Table 1.

Table 1. Summary of measurement results collected using the Strava application

	Watch		Phone	
Number of measurements	10.158		8.907	
Maximum route length (s)	560		557	
Category	Maximum value	Minimum value	Maximum value	Minimum value
Speed (km/h) over time	51,98111413	0	38,78512886	0

Average speed (km/h) over time	24,30337014	0	26,78669854	0
Average speed (km/h) over time per ride	51,98111413	0	38,78512886	0
Acceleration (m/s²) over time	13,222303	-12,93009421	7,28214439	-6,49141334
Average acceleration (m/s²) over time	0,88039906	-0,67752815	2,82278864	-1,97722283
Average acceleration (m/s²) over time per ride	13,222303	-12,93009421	7,28214439	-6,49141334
Ride smoothness (m/s³) over time	12,29616544	-13,24866594	7,8738598	-7,40637954
Average ride smoothness (m/s³) over time	0,52763887	-0,4723835	2,59082722	-2,98725577
Average ride smoothness (m/s³) per ride	12,29616544	-13,24866594	7,8738598	-7,40637954

Commentary on Sensor Logger Measurements

The analysis of data collected with the Sensor Logger application revealed a high proportion of invalid or unusable measurements. During the calculation of acceleration, 25.80% of values were zero, indicating that the sensor did not provide a valid measurement at those moments. Analysis showed that actual measured values in these cases were either extremely large (on the order of 10^{15}) or extremely small (on the order of 10^{-15}), suggesting sensor or logging errors. For the calculation of ride smoothness, the proportion of invalid values was slightly lower but still high – 21.08% of all measurements. A summary of Sensor Logger measurements is shown in Table 2.

Table 2. Summary of Measurements Collected with the Sensor Logger Application

	Acceleration	Ride smoothness
Number of calculated values	8.032	8.032
Number of zero values	2.072	1.693

For acceleration calculations, only data where at least one of the sensors (x, y, or z axis) provided a valid reading were used. Nevertheless, the analysis shows that on average 70% of primary measurements were invalid, so calculations were possible only on a subset of the data. Such a high error rate reflects the known limitations of mobile phone accelerometers – they are highly sensitive to interference, imperfect synchronization, and occasional measurement interruptions.

Table 3. Analysis of Measurements Collected with the Sensor Logger Application

Participant	Number of intervals	Number of intervals with zero value	Proportion of intervals with zero value
ž1	981	339	0,35
m5	756	375	0,50
tsunami	876	872	1,00
Tijama21	999	636	0,64
ž2	1.677	1.063	0,63
ž3	927	503	0,54
ž6	708	644	0,91
321	1.179	861	0,73
m6	693	679	0,98
1969	684	480	0,70
2406	993	491	0,49
2811	759	508	0,67
KICRA	861	714	0,83
dostojevski	708	479	0,68
123	669	550	0,82
m21	699	473	0,68
m30	747	463	0,62
m20	765	712	0,93
ž11	756	516	0,68
ž12	1.050	679	0,65
ž13	774	354	0,46
1112	807	625	0,77
m55	858	638	0,74
ž42	1.290	960	0,74
m50	864	422	0,49
m46	768	753	0,98
m78	1.248	726	0,58

The high proportion of invalid measurements in the Sensor Logger application is mainly due to the limitations of phone sensors and the way the app collects data. Smartphone accelerometers operate at high frequency but are exposed to various disturbances, such as micro-vibrations, movements of the phone in the pocket, changes in orientation, gravity effects, and digital signal processing errors. When the sensor fails to measure acceleration correctly due to these disturbances, extremely high or low values can occur, reflecting temporary errors in reading or computation. These errors are not a result of incorrect data processing but are an expected phenomenon when using mobile accelerometers in dynamic environments. Since the phone is not a specialized measurement instrument, the quality of measurements fluctuates considerably, which is reflected in the high proportion of unusable data.

Comparison of Measurement Techniques and Technologies

Table 4 presents a comparison of three measurement devices (phone, smartwatch, and smart glasses) and the three applications used with them. For the phone, two different applications were used, Strava and Sensor Logger, allowing for a direct comparison. In the Strava application, speed is not measured directly but calculated based on GPS data collected by the app. Therefore, acceleration had to be calculated by exporting the data to ArcGIS Pro, where a script reconstructs speed and acceleration using geolocation and timestamps. In this process, noise is relatively low – 3.21% for the phone and 1.5% for the watch – indicating that Strava provides stable data, which can be further smoothed in ArcGIS Pro.

In contrast, Sensor Logger records raw sensor data, meaning it measures direct changes in acceleration in real time without additional calculations or smoothing. Consequently, these measurements are the rawest and contain the highest noise levels – between 21% and 26%. This difference is expected, as the accelerometer captures all micro-movements, vibrations, shocks, and changes in the phone's position in the pocket, which strongly affect the signal.

Table 4. Comparison of Measurement Techniques and Technologies

Measurement Device	Application	Required Software	Data for Acceleration Calculation	Measurement Noise
LM G810 EEA XX	Strava	ArcGIS Pro	Secondary Data (ArcPy)	3,21 %
LM G810 EEA XX	Sensor Logger	MS Excel	Primary Data	21,08 % or 25,80 %
Huawei GT3 Pro 475	Strava	ArcGIS Pro	Secondary Data (ArcPy)	1,5 %
Tobii Pro Glasses 3		MS Excel	Primary Data	**Presented in Table 5*

Strava Measurements (Phone)

The participant's maximum speed was 38.785 km/h. Since the e-scooter is factory-limited to 25 km/h, this value can be interpreted as a GPS measurement error, which is entirely common when using a phone. During the measurement, the phone was stored in the trouser pocket, where the signal is partially obstructed, so individual position readings may deviate from the actual location. Such deviations are usually short-lived and occur due to signal loss, reflections, or GPS position corrections between two consecutive points. Because the e-scooter reaches its maximum speed within a few seconds, a small error in position can create an apparently higher travel speed, even though the actual speed does not exceed the limit. Most recorded speeds remain below 25 km/h, confirming that the extreme values are the result of measurement errors and that the data shown in Figure 1 are reasonable.

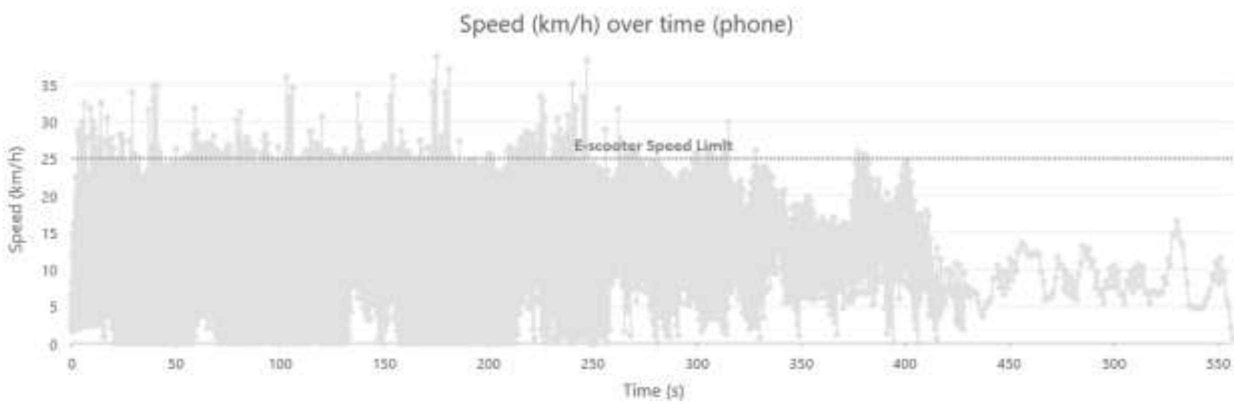


Figure 15. Speed (km/h) over time (phone)

Most of the average speeds over time are also below 25 km/h, except for a single measurement at 26.78669854 km/h. Since this value is only slightly above the e-scooter's factory speed limit, it can be attributed to a brief GPS error. Average speeds are generally less sensitive to such deviations, so it is expected that errors occur only sporadically. The values shown in Figure 2 are consistent with the actual behaviour of the e-scooter.

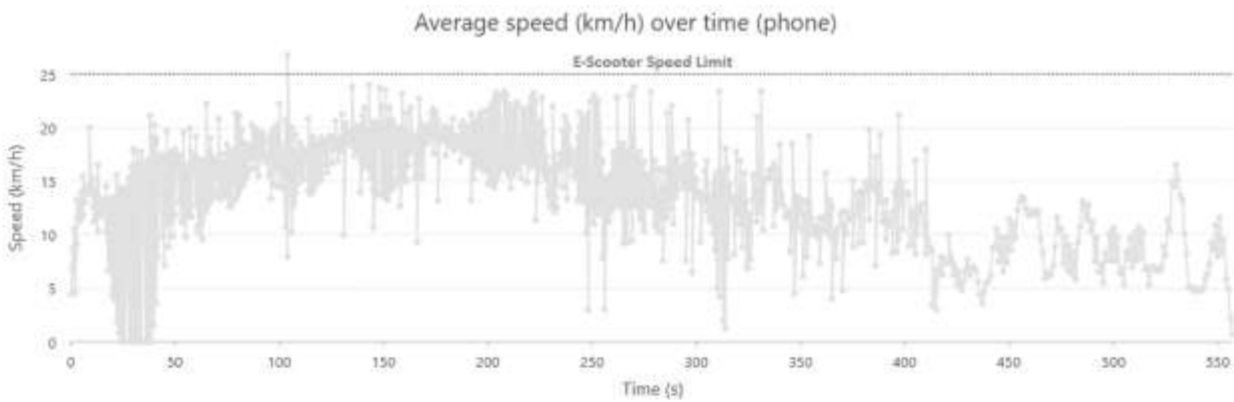


Figure 16. Average speed (km/h) over time (phone)

Measured acceleration values over time ranged between 7.28214439 m/s² and -6.49141334 m/s², but most readings fell between -2 and 2 m/s², which is entirely realistic for e-scooter riding. Extremely high values outside this range most likely do not reflect actual motion but result from less accurate GPS positions, which become especially evident in acceleration calculations, as these are based on speed differences between consecutive points. Some of the expressed values could also correspond to sudden acceleration or braking, depending on the participant's experience, but the extreme values exceed the e-scooter's real physical capabilities. Nevertheless, the values shown in Figure 3 are still meaningful given the method of measurement.

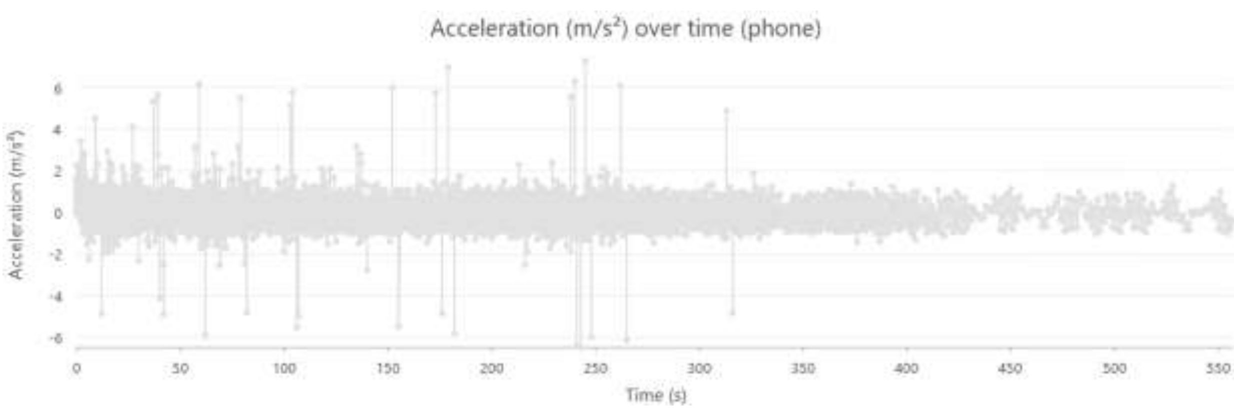


Figure 17. Acceleration (m/s²) over time (phone)

For the average acceleration over time, the extremes are considerably lower: a maximum of 2.82278864 m/s² and a minimum of -1.97722283 m/s². Since averaging filters out most short-term measurement noise, these values are closer to expected ranges. Actual e-scooter acceleration typically ranges around 1.0 to 1.8 m/s², which means the obtained results may be slightly skewed by measurement deviations but are still entirely plausible. Figure 4 therefore presents a more realistic representation of the ride compared to the raw instantaneous values.

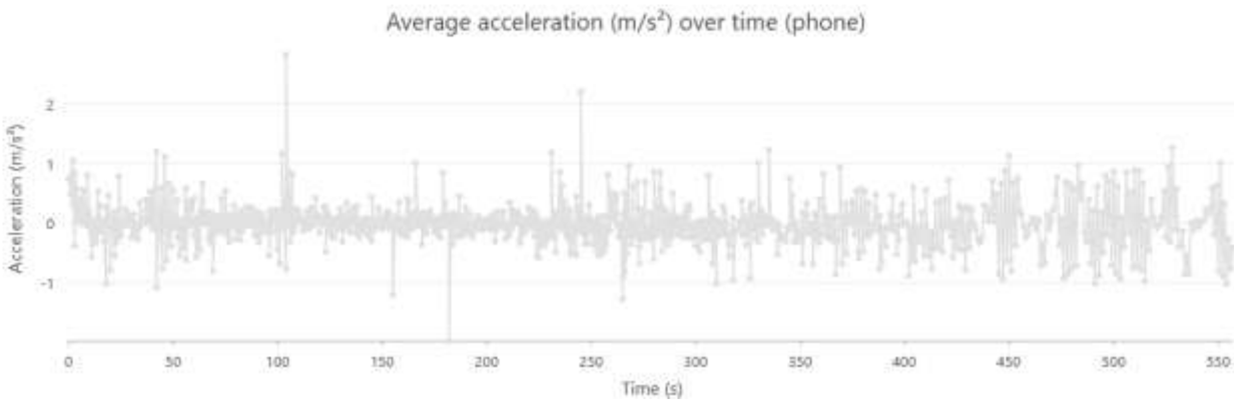


Figure 18. Average acceleration (m/s²) over time (phone)

The maximum average ride smoothness over time, representing the change in acceleration, showed a peak value of 7.8738598 m/s³ and a minimum of -7.40637954 m/s³. Even here, most values lie between -2 and 2 m/s³. Since ride smoothness is mathematically very sensitive to small errors in speed and acceleration, the high values are largely due to GPS fluctuations rather than actual sudden movements of the e-scooter. The average ride smoothness is therefore much more realistic, with a maximum of 2.59082722 m/s³ and a minimum of -2.98725577 m/s³, and most values remain within the range of -1 to 1 m/s³. The results shown in Figures 5 and 6 are reasonable and expected given the measurement method.

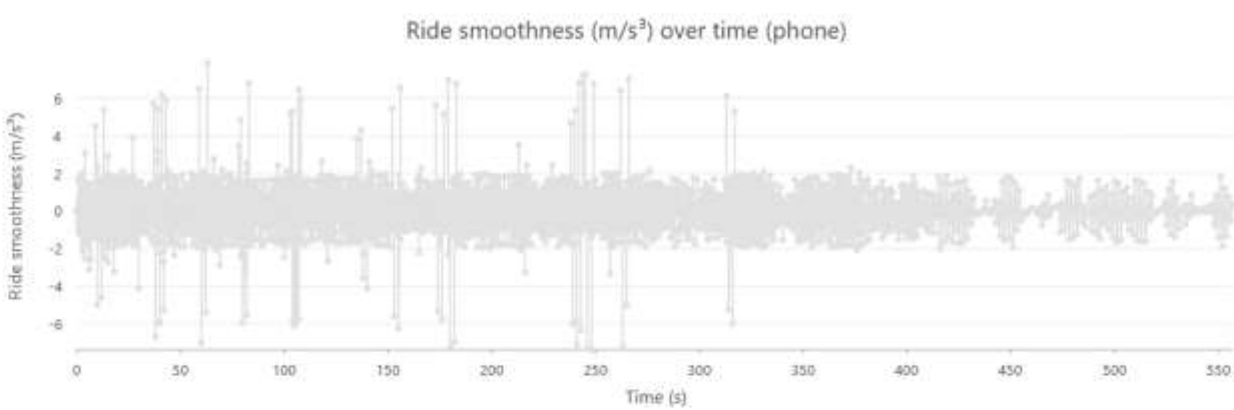


Figure 19. Ride smoothness (m/s³) over time (phone)

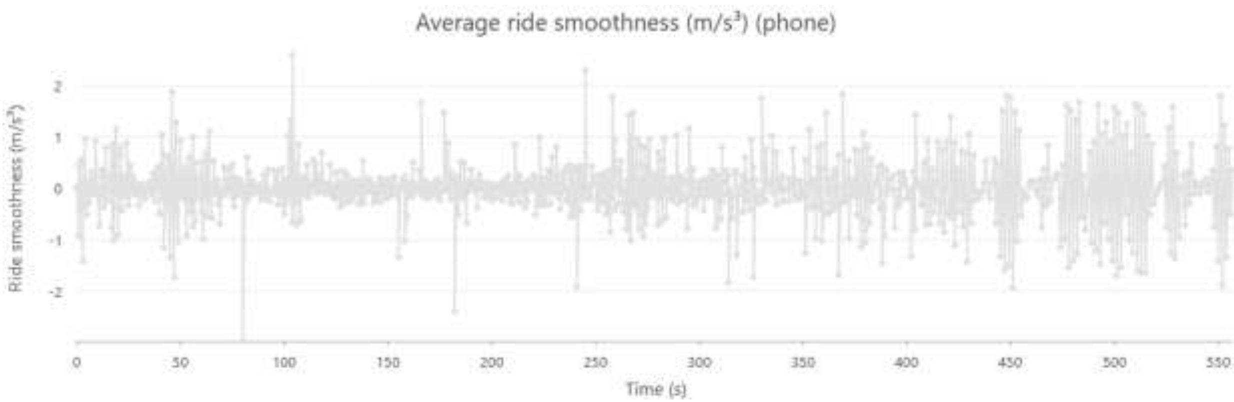


Figure 20. Average ride smoothness (m/s³) (phone)

Results of Strava Measurements (watch)

The maximum recorded speed of a participant was 51.98111413 km/h. Most measured speeds, however, remain below 25 km/h, which is expected given that the e-scooter has a factory-set maximum speed. Since this peak represents only a single point in the time series, it can be interpreted as a measurement deviation, most likely caused by acceleration between two consecutive measurements. During rapid speed changes, the measuring device (in this case, the smartwatch) can incorrectly estimate the distance travelled over a short time interval, so this deviation should be considered a measurement error. The values shown can be regarded as reasonable.

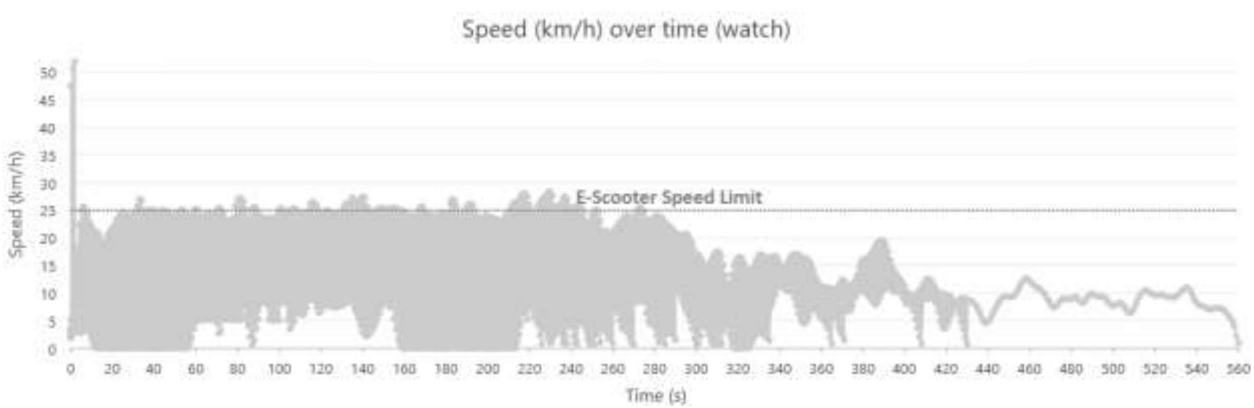


Figure 21. Speed (km/h) over time (watch)

The average speed over time remains below 25 km/h, which also confirms the e-scooter's factory speed limit. The highest average speed is 24.30337014 km/h, which aligns with expectations and shows that averaging effectively reduces the impact of measurement deviations in individual points. The values shown in Figure 8 can thus be considered reasonable.

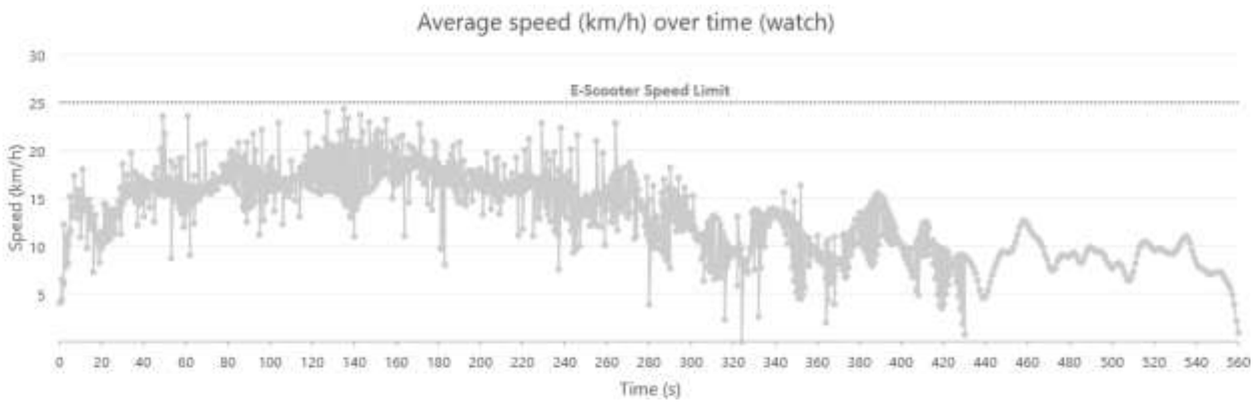


Figure 22. Average speed (km/h) over time (watch)

The maximum recorded acceleration is 13.222303 m/s², and the maximum deceleration is -12.93009421 m/s². These are isolated measurements and do not represent a general pattern. Most values lie between -2 m/s² and 2 m/s², which is entirely realistic for normal e-scooter riding. Significantly higher individual values can be attributed to rapid speed changes or measurement noise. The values shown in Figure 9 can therefore be considered reasonable.

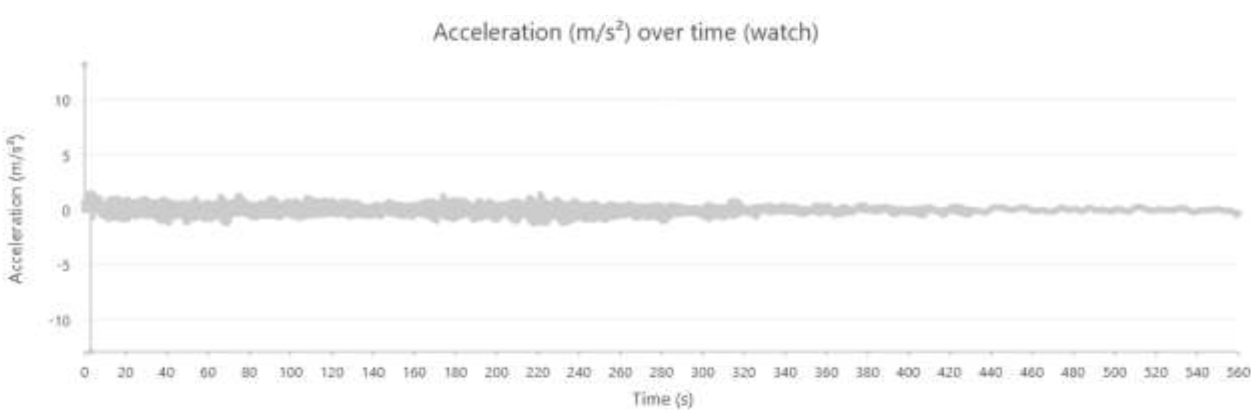


Figure 23. Acceleration (m/s²) over time (watch)

The maximum average acceleration is 0.88039906 m/s², and the maximum average deceleration is -0.67752815 m/s². Most values lie between -0.2 m/s² and 0.2 m/s², which is entirely expected for averaged data and indicates a stable and smooth ride. The values shown in Figure 10 can therefore be considered reasonable.

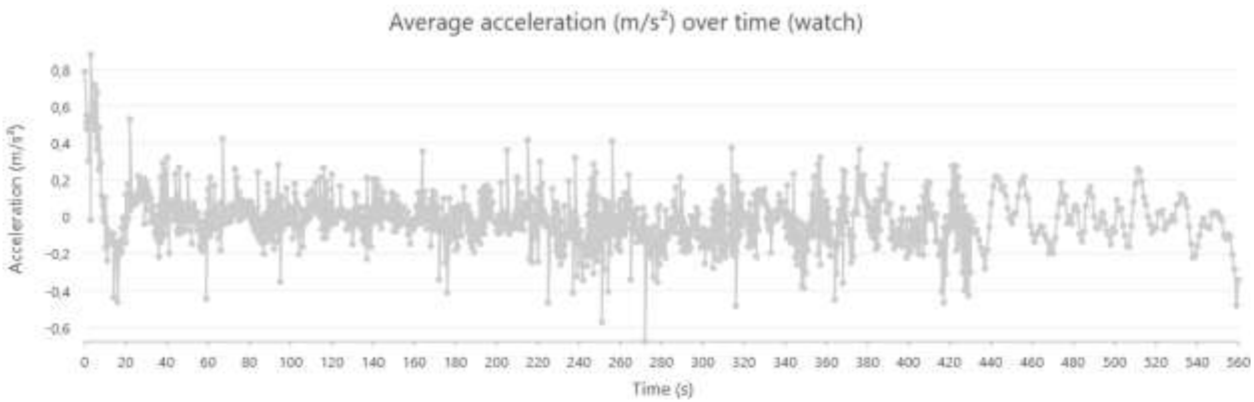


Figure 24. Average acceleration (m/s²) over time (watch)

The maximum ride smoothness over time is 12.29616544 m/s³, and the minimum is -13.24866594 m/s³, with these extreme values originating from just two measurement sets. Most of the data ranges between -2 m/s³ and 2 m/s³, indicating that the extremes are likely isolated measurement deviations. The values shown in Figure 11 can therefore be considered reasonable.

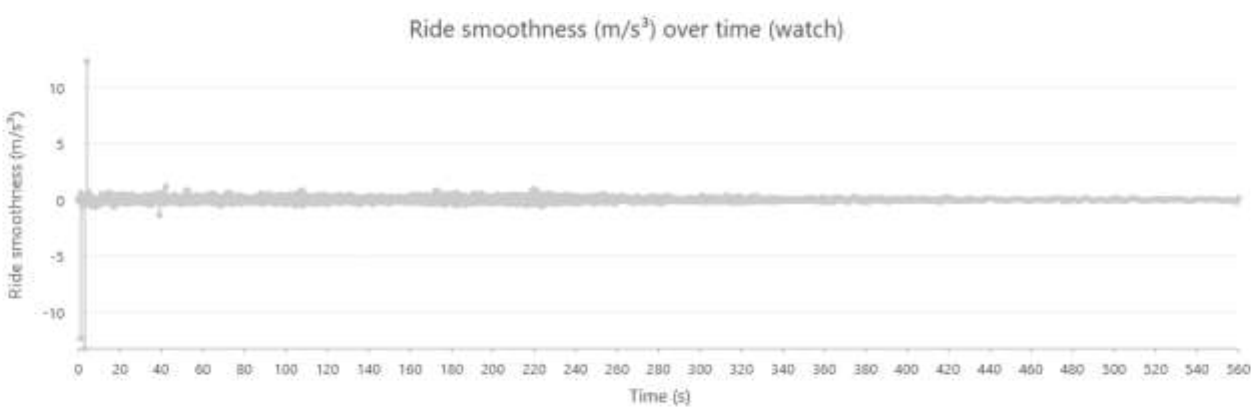


Figure 25. Ride smoothness (m/s³) over time (watch)

The maximum average ride smoothness is 0.52763887 m/s³, and the minimum is -0.4723835 m/s³. Most values lie within the range of -0.1 m/s³ to 0.1 m/s³, which is consistent with expected average changes in acceleration. The values shown in Figure 12 can therefore be considered reasonable.

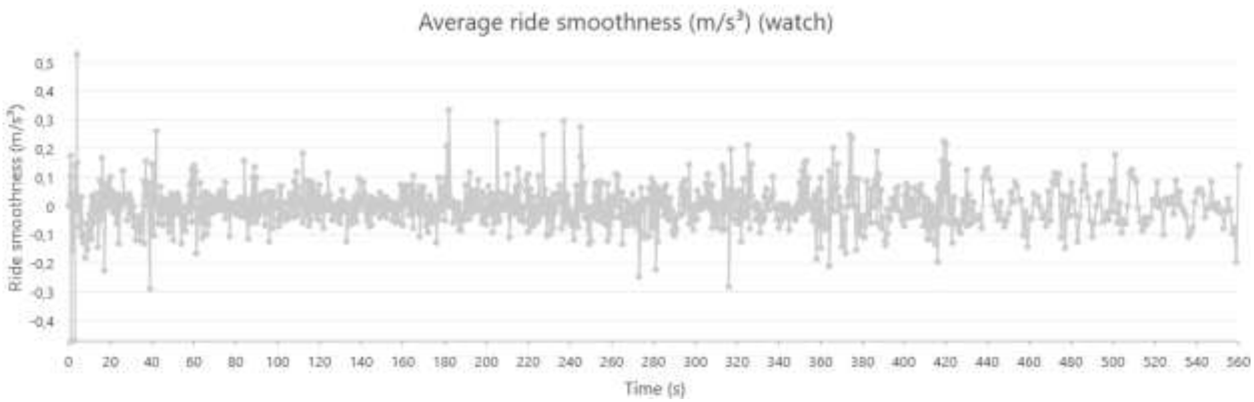


Figure 26. Average ride smoothness (m/s³) (watch)

Measurements collected with the phone and the smartwatch are meaningful and consistent with the expected behaviour of the e-scooter as well as with the limitations of the measurement devices. For both devices, most recorded speeds remain below 25 km/h, which corresponds to the factory speed limit of the e-scooter. Occasional speed peaks (39 km/h for the phone and 52 km/h for the watch) are rare and most likely result from measurement deviations during rapid changes in motion, when a single acceleration between two measurements can create an apparently higher speed. Similarly, acceleration and ride smoothness show occasional spikes, while average values remain stable and realistic. The phone generally shows slightly higher average acceleration and ride smoothness, as expected, due to its movement in the trouser pocket along with the user's body. The watch, fixed on the wrist, usually exhibits a smaller range of values but can still detect strong changes if the wrist moves abruptly. Considering the nature of the measurements, device placement, and riding conditions, the data from both devices align well with the actual ride and can be considered complete, meaningful, and useful for analysing e-scooter dynamics.

Sensor Logger Measurement Results (Phone)

The results collected with the Sensor Logger application indicate a significantly low data quality, mainly due to the phone being placed in the trouser pocket. Irregular sensor behaviour and occasional measurement dropouts resulted in an average of about 70% of values being invalid, which required replacing these values with 0. At no point were measurements available across all three axes simultaneously, so acceleration norms were calculated based on partially missing data. In Figures 13 and 14, this appears as curves without a clear structure reflecting the actual riding dynamics. Maximum recorded acceleration values (1.386470348 m/s²) and ride smoothness values (ranging from -1.284975823 m/s³ to 1.386470348 m/s³) are low and primarily reflect vibrations, movement of the phone in the pocket, and orientation noise, rather than actual e-scooter acceleration. Thus, Figures 13 and 14 mainly show sensor disturbances, fluctuations, and random movements, while the actual ride is not clearly detectable.

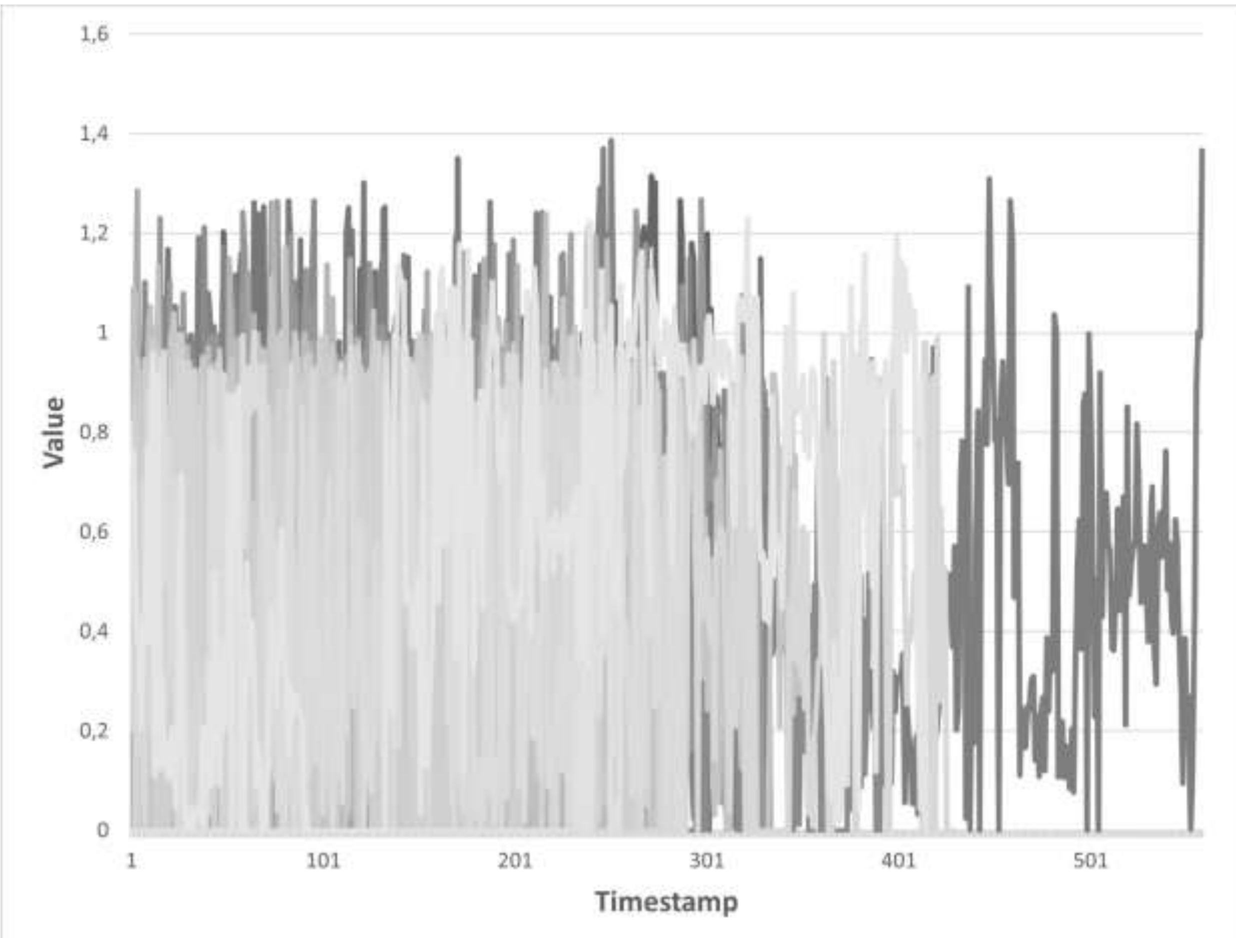


Figure 27. Acceleration (Sensor Logger)

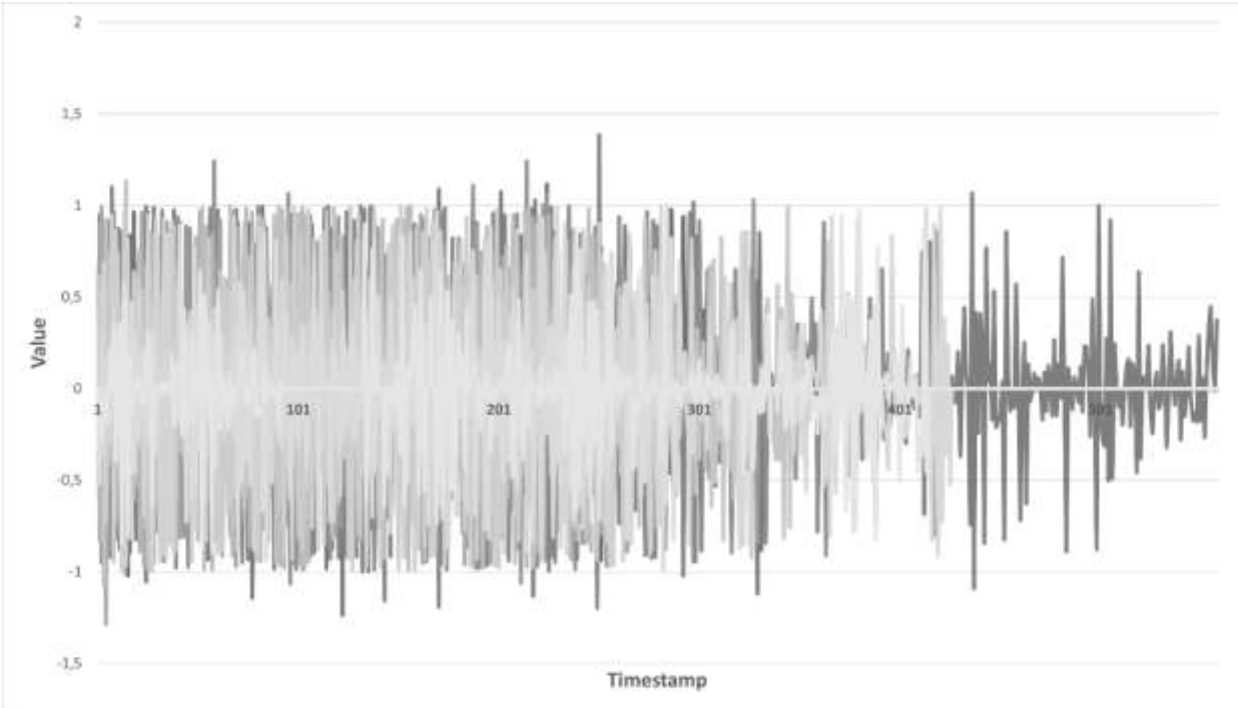


Figure 28. Ride smoothness (Sensor Logger)

Tobii Pro Glasses 3 Measurement Commentary

Table 5 shows the number of measurements per participant for the accelerometer and the pupil diameter of the left and right eyes. For the eye-tracking data, valid and invalid measurements are shown separately, along with the proportion of valid measurements and the difference in valid measurement rates between the left and right eyes. The total number of measurements varies considerably between participants. Accelerometer samples range from a few thousand to over 70,000, which is reflected in the differing total numbers of eye-tracking measurements. This indicates variability in the duration or structure of recordings among participants.

The proportion of valid pupil diameter measurements also varies significantly between participants. For the left eye, valid measurement rates range approximately from 0.09 to 0.74, while for the right eye they range from about 0.02 to 0.72. For most participants, the proportion of valid measurements is below 0.60, with some participants showing considerably lower values, resulting in a high number of invalid samples. Comparing the left and right eyes, some participants show similar valid measurement rates for both eyes, while others exhibit more pronounced differences. The difference in valid measurement proportion (left eye minus right eye) ranges approximately from −0.13 to +0.23. Positive values indicate a higher proportion of valid measurements for the left eye, negative values indicate a higher proportion for the right eye.

The results presented in Tables 6 to 40 are largely consistent and reasonable. Average acceleration values for all participants are very close to the gravitational acceleration, indicating stable sensor operation, proper calibration, and a relatively steady head position during riding, despite vibrations and minor head movements. Low to moderate standard deviations of acceleration reflect the natural dynamics of riding on surfaces of varying smoothness, while maximum and minimum acceleration values fall within expected ranges for this type of motion. Average ride smoothness over time for all participants is near zero, as expected, since short-term positive and negative changes in acceleration caused by accelerating, braking, and overcoming small obstacles tend to cancel out over time. The ranges and standard deviations of ride smoothness indicate the presence of brief dynamic events but without extreme deviations, suggesting relatively controlled riding and the absence of unnatural movements or data capture errors.

Pupil diameter measurements exhibit higher variability among participants, which is expected due to individual physiological differences, changes in lighting conditions, levels of cognitive load, and visual demands while riding an e-scooter. Larger ranges and higher standard deviations for some participants may result from a more dynamic riding style, more frequent gaze shifts, or less optimal eye-tracking conditions, but in a real-world context, this does not necessarily indicate deviations or errors. Differences between the left and right eyes are generally small and physiologically expected, with occasional larger differences possibly arising from perceptual asymmetries, head position, or tracking quality. Filtered pupil diameter signals typically show lower variability and fewer extreme values compared to unfiltered data, confirming the effectiveness of the applied signal processing procedures and increasing the reliability of the results' interpretation.

Table 5. Analysis of measurements collected with Tobii Pro Lab smart glasses

Participant	Accelerometer	Pupil diameter left				Pupil diameter right				Difference between left and right eye (left - right)
		Valid	Invalid	Total	Share of valid measurements	Valid	Invalid	Total	Share of valid measurements	Share of valid measurements (left eye – right eye)
123	37010	1831	13500	15331	0,12	315	15016	15331	0,02	0,10
321	39488	9726	6642	16368	0,59	8355	8013	16368	0,51	0,08
1112	50366	6732	14121	20853	0,32	6819	14034	20853	0,33	0,00
1969	35761	3212	11679	14891	0,22	2213	12678	14891	0,15	0,07
2406	51494	12786	8516	21302	0,60	8541	12761	21302	0,40	0,20
2811	37726	1464	14148	15612	0,09	1552	14060	15612	0,10	-0,01
kicra	53711	6486	15711	22197	0,29	5735	16462	22197	0,26	0,03
m2	47286	2705	16891	19596	0,14	5263	14333	19596	0,27	-0,13
m3	46060	8703	10345	19048	0,46	4253	14795	19048	0,22	0,23
m4	67043	14634	13118	27752	0,53	16411	11341	27752	0,59	-0,06
m5	37468	6155	9353	15508	0,40	6039	9469	15508	0,39	0,01
m6	41439	5424	11706	17130	0,32	3379	13751	17130	0,20	0,12
m20	40119	11998	4600	16598	0,72	10640	5958	16598	0,64	0,08
m21	36626	1672	13505	15177	0,11	1561	13616	15177	0,10	0,01
m30	48545	11849	8195	20044	0,59	14454	5590	20044	0,72	-0,13
m33	36771	8583	6653	15236	0,56	6862	8374	15236	0,45	0,11
m46	37739	10316	5320	15636	0,66	8546	7090	15636	0,55	0,11

m50	41533	12763	4454	17217	0,74	11795	5422	17217	0,69	0,06
m55	46836	11019	8370	19389	0,57	12884	6505	19389	0,66	-0,10
m60	61026	12360	12930	25290	0,49	13532	11758	25290	0,54	-0,05
m70	7794	1416	1815	3231	0,44	712	2519	3231	0,22	0,22
tijama 21	55480	2054	20890	22944	0,09	2644	20300	22944	0,12	-0,03
tsunami	47202	8172	11376	19548	0,42	6830	12718	19548	0,35	0,07
ž1	57815	3334	20613	23947	0,14	1843	22104	23947	0,08	0,06
ž3	65025	4796	22094	26890	0,18	3938	22952	26890	0,15	0,03
ž6	49660	15021	5505	20526	0,73	12565	7961	20526	0,61	0,12
ž11	38634	4347	11611	15958	0,27	6118	9840	15958	0,38	-0,11
ž12	49386	2649	17803	20452	0,13	3376	17076	20452	0,17	-0,04
ž13	50988	4667	16490	21157	0,22	3507	17650	21157	0,17	0,05
ž42	72838	17363	12792	30155	0,58	12109	18046	30155	0,40	0,17
ž60	59835	2154	20108	22262	0,10	2773	19489	22262	0,12	-0,03
ž70	47771	12342	7362	19704	0,63	12374	7330	19704	0,63	0,00

Descriptive statistics of participant ride measurements

Table 6. Participant 123

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,297912575	0,354596517	1,284975823	0
Sensor Logger Ride Smoothness over time (m/s³)	0	0,376924409	0,99272189	-1,284975823
Strava Acceleration (phone) (m/s²)	0,000830649	0,479140253	2,30786705	-1,883734749
Strava Ride Smoothness over time (phone) (m/s³)	-0,008630167	0,471137836	1,8615793	-2,023617762
Strava Acceleration (watch) (m/s²)	-0,000670292	0,315436722	0,985197912	-1,170991626
Strava Ride Smoothness over time (watch) (m/s³)	-0,004614038	0,152062955	0,542444302	-0,452479668
Tobii Acceleration (m/s²)	9,987290298	0,221345158	10,89042491	9,256941738
Tobii Ride Smoothness over time (m/s³)	1,03806E-07	0,010763222	0,035181289	-0,034059314
Tobii Pupil Diameter Left (mm)	1,956600722	0,280648631	3,892	1,387
Tobii Pupil Diameter Right (mm)	2,353849829	1,199433544	5,6473	1,516
Tobii Pupil Diameter Filtered (mm)	1,955793451	0,29084471	3,892	1,3826

Table 7. Participant 321

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,38857113	0,376075637	1,265574866	0
Sensor Logger Ride Smoothness over time (m/s³)	0,000760242	0,363541758	1,101081825	-0,994368116
Strava Acceleration (phone) (m/s²)	-0,01365062	0,384764839	1,519700921	-1,393422466
Strava Ride Smoothness over time (phone) (m/s³)	-0,002707797	0,438574011	1,512594122	-1,69505678
Strava Acceleration (watch) (m/s²)	0,000188148	0,321874443	0,99498963	-1,052130412
Strava Ride Smoothness over time (watch) (m/s³)	-0,002989929	0,143730945	0,625383268	-0,343052373
Tobii Acceleration (m/s²)	10,02633539	0,156105732	10,71528951	9,480777397
Tobii Ride Smoothness over time (m/s³)	-3,0166E-06	0,011995417	0,034889052	-0,032542153
Tobii Pupil Diameter Left (mm)	1,877280048	0,106880488	2,183666667	1,3515
Tobii Pupil Diameter Right (mm)	1,863449184	0,118725501	2,194692308	1,398882353
Tobii Pupil Diameter Filtered (mm)	1,876765176	0,091525301	2,239425	1,406173913

Table 8. Participant 1112

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,471584043	0,379969126	0,997324669	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,00163059	0,501812442	0,997324669	-0,997025816
Strava Acceleration (phone) (m/s²)	-0,002211991	0,896797411	7,282144386	-6,40322679
Strava Ride Smoothness over time (phone) (m/s³)	-0,005108321	1,274242815	7,271361535	-7,40637954
Strava Acceleration (watch) (m/s²)	-0,000933772	0,197637593	0,449400165	-0,716734879
Strava Ride Smoothness over time (watch) (m/s³)	-0,002640685	0,096440122	0,366321303	-0,246438739
Tobii Acceleration (m/s²)	10,00420249	0,118734593	10,56444008	9,299484483
Tobii Ride Smoothness over time (m/s³)	-4,69711E-05	0,013341825	0,053754137	-0,033640042
Tobii Pupil Diameter Left (mm)	2,049284341	0,604502532	5,745	1,368
Tobii Pupil Diameter Right (mm)	2,077864565	0,615376797	5,842428571	1,381666667
Tobii Pupil Diameter Filtered (mm)	2,054491679	0,512900173	5,745	1,464142857

Table 9. Participant 1969

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,513548587	0,37845017	1,24230928	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,000469787	0,43165705	1,24230928	-1,065151756
Strava Acceleration (phone) (m/s²)	0,000186269	0,343266864	1,133284515	-1,320440881
Strava Ride Smoothness over time (phone) (m/s³)	-0,003409399	0,305074385	1,24690477	-1,212486175
Strava Acceleration (watch) (m/s²)	9,19993E-05	0,306617447	0,732985025	-1,222884688
Strava Ride Smoothness over time (watch) (m/s³)	-0,002834328	0,148754773	0,540390356	-0,372953211
Tobii Acceleration (m/s²)	9,963508361	0,181746102	10,93382244	9,397933248
Tobii Ride Smoothness over time (m/s³)	6,90139E-05	0,008705397	0,042919419	-0,028655743
Tobii Pupil Diameter Left (mm)	1,988528658	0,920464755	5,571	1,166
Tobii Pupil Diameter Right (mm)	2,173588792	1,208373794	7,101	1,325
Tobii Pupil Diameter Filtered (mm)	2,044998588	0,967630321	5,644666667	1,307666667

Table 10. Participant 2406

Category	Mean	Standard deviation	Maximum	Minimum

Sensor Logger Acceleration (m/s²)	0,624686909	0,299054698	1,267840917	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,001824225	0,319535461	1,031913153	-0,97439067
Strava Acceleration (phone) (m/s²)	0,000587803	0,421602757	1,377229977	-1,27806942
Strava Ride Smoothness over time (phone) (m/s³)	-0,00517137	0,636691707	1,897436007	-1,880186508
Strava Acceleration (watch) (m/s²)	-0,000124453	0,163819114	0,398076118	-0,598412797
Strava Ride Smoothness over time (watch) (m/s³)	-0,001433256	0,078158813	0,286518347	-0,266996077
Tobii Acceleration (m/s²)	9,921920104	0,085930454	10,18978603	9,547485629
Tobii Ride Smoothness over time (m/s³)	-9,34993E-05	0,006951492	0,019961155	-0,024483536
Tobii Pupil Diameter Left (mm)	1,801424648	0,52209056	5,452	1,304
Tobii Pupil Diameter Right (mm)	2,235437394	0,975277423	5,854833333	1,2755
Tobii Pupil Diameter Filtered (mm)	1,944825655	0,60711851	5,452	1,304

Table 11. Participant 2811

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,379028432	0,229784526	0,952360229	0
Sensor Logger Ride Smoothness over time (m/s³)	0,000266791	0,19626102	0,651670265	-0,795170512
Strava Acceleration (phone) (m/s²)	0,001661228	0,411556855	1,669701068	-1,603482726
Strava Ride Smoothness over time (phone) (m/s³)	-0,006301128	0,340249754	1,364676793	-1,358870584
Strava Acceleration (watch) (m/s²)	-4,38892E-05	0,320548748	0,997868058	-1,12829152
Strava Ride Smoothness over time (watch) (m/s³)	-0,002189444	0,166321431	0,831545995	-0,382483645
Tobii Acceleration (m/s²)	10,02840869	0,164925454	10,75706189	9,373461783
Tobii Ride Smoothness over time (m/s³)	3,01032E-05	0,010204262	0,046130158	-0,048465146
Tobii Pupil Diameter Left (mm)	3,381095692	1,301356478	6,655	1,613166667
Tobii Pupil Diameter Right (mm)	2,964690382	1,138177429	6,3575	1,4
Tobii Pupil Diameter Filtered (mm)	3,368268972	1,249805709	6,655	1,741

Table 12. Participant dostojevski

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,344379474	0,209924224	1,198470932	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,001703244	0,235690914	0,916757753	-0,914689759
Strava Acceleration (phone) (m/s²)	0,002002571	0,453968784	1,793643145	-1,731500889

Strava Ride Smoothness over time (phone) (m/s³)	-0,001756206	0,467195687	2,010675032	-1,603058374
Strava Acceleration (watch) (m/s²)	0,000216357	0,317813646	0,678818903	-1,223689493
Strava Ride Smoothness over time (watch) (m/s³)	-0,00341468	0,139487226	0,440117643	-0,355844357
Tobii Acceleration (m/s²)	/	/	0	0
Tobii Ride Smoothness over time (m/s³)	/	/	0	0
Tobii Pupil Diameter Left (mm)	/	/	0	0
Tobii Pupil Diameter Right (mm)	/	/	0	0
Tobii Pupil Diameter Filtered (mm)	/	/	0	0

Table 13. Participant kicra

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,176521924	0,276722326	0,979826262	0
Sensor Logger Ride Smoothness over time (m/s³)	2,07925E-18	0,325624009	0,950474066	-0,979826262
Strava Acceleration (phone) (m/s²)	0,001634031	0,43566588	2,07513903	-1,381250938
Strava Ride Smoothness over time (phone) (m/s³)	-0,003946725	0,499041951	2,188701757	-1,749144996
Strava Acceleration (watch) (m/s²)	0,000882317	0,239253651	0,642057061	-0,490328371
Strava Ride Smoothness over time (watch) (m/s³)	-0,002440315	0,104603503	0,31802667	-0,267544463
Tobii Acceleration (m/s²)	9,982291491	0,178449636	10,90983646	9,148161509
Tobii Ride Smoothness over time (m/s³)	-1,89167E-06	0,010972474	0,057614188	-0,04228659
Tobii Pupil Diameter Left (mm)	1,810959073	0,366140481	4,031	1,260333333
Tobii Pupil Diameter Right (mm)	1,738957773	0,2400812	2,8608	1,028
Tobii Pupil Diameter Filtered (mm)	1,777326616	0,318291962	3,801833333	1,141333333

Table 14. Participant m2

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	-3,22831E-17	0,598489622	4,517481839	-4,874412539
Strava Ride Smoothness over time (phone) (m/s³)	-0,003344153	0,733679541	5,355551252	-5,006864447
Strava Acceleration (watch) (m/s²)	0,002291091	1,320067963	13,222303	-12,93009421
Strava Ride Smoothness over time (watch) (m/s³)	-0,065965703	1,525976869	12,29616544	-13,24866594

Tobii Acceleration (m/s²)	10,01862798	0,137849189	10,75061545	9,408733854
Tobii Ride Smoothness over time (m/s³)	4,08205E-06	0,009990977	0,060955154	-0,06289994
Tobii Pupil Diameter Left (mm)	2,34415735	1,080981243	6,14	1,316
Tobii Pupil Diameter Right (mm)	2,380060198	0,980318744	7,136	1,188
Tobii Pupil Diameter Filtered (mm)	2,395686915	0,945540506	5,978	1,3294

Table 15. Participant m3

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	0,000884724	0,386439357	1,616560445	-0,996432873
Strava Ride Smoothness over time (phone) (m/s³)	-0,006454175	0,377407806	1,543744001	-1,358555732
Strava Acceleration (watch) (m/s²)	-0,000402624	0,311570457	0,86741229	-0,748889461
Strava Ride Smoothness over time (watch) (m/s³)	-0,003210676	0,151779478	0,502998942	-0,429175178
Tobii Acceleration (m/s²)	9,969608107	0,182211758	10,92106709	9,135157681
Tobii Ride Smoothness over time (m/s³)	0,00020575	0,009684252	0,050535012	-0,040663185
Tobii Pupil Diameter Left (mm)	1,648512604	0,123002959	2,276	1,209
Tobii Pupil Diameter Right (mm)	1,61205858	0,175978021	2,569	1,1796
Tobii Pupil Diameter Filtered (mm)	1,635512988	0,11970176	2,276	1,253444444

Table 16. Participant m4

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	-0,002524659	0,533720297	2,764695132	-2,52132896
Strava Ride Smoothness over time (phone) (m/s³)	-0,005855121	0,57630158	2,646953058	-2,267718883
Strava Acceleration (watch) (m/s²)	0,000918649	0,339907724	0,902534372	-0,953015668
Strava Ride Smoothness over time (watch) (m/s³)	-0,004388606	0,177598831	0,559664728	-0,533959339
Tobii Acceleration (m/s²)	10,00453025	0,150600767	11,0579432	9,558086511
Tobii Ride Smoothness over time (m/s³)	1,77271E-05	0,01140724	0,067887941	-0,086776346
Tobii Pupil Diameter Left (mm)	1,999971735	0,67297724	4,815	1,341625

Tobii Pupil Diameter Right (mm)	1,544101256	0,101443315	2,159206897	1,33625
Tobii Pupil Diameter Filtered (mm)	1,772290877	0,382514381	3,465545455	1,397066667

Table 17. Participant m5

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,414096945	0,303485405	1,158414001	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,0012424	0,313107546	0,935578332	-1,022390521
Strava Acceleration (phone) (m/s²)	-0,001109399	0,617599339	2,148812767	-1,888534026
Strava Ride Smoothness over time (phone) (m/s³)	-0,001350954	0,686210537	1,884393174	-2,3440306
Strava Acceleration (watch) (m/s²)	-0,004490566	0,267010039	1,060004489	-1,022241445
Strava Ride Smoothness over time (watch) (m/s³)	-0,001023478	0,137409157	0,841106521	-0,483031932
Tobii Acceleration (m/s²)	10,02388178	0,223256706	11,19696921	9,294491155
Tobii Ride Smoothness over time (m/s³)	0,000136702	0,012629823	0,099761342	-0,07062265
Tobii Pupil Diameter Left (mm)	1,458096279	0,398304991	6,622	1,042
Tobii Pupil Diameter Right (mm)	1,602445778	0,478514588	4,1605	1,119
Tobii Pupil Diameter Filtered (mm)	1,532128963	0,3692153	3,849	1,156

Table 18. Participant m6

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,036723888	0,170036005	1,110891134	0
Sensor Logger Ride Smoothness over time (m/s³)	0,002887099	0,163207775	1,110891134	-0,981793418
Strava Acceleration (phone) (m/s²)	-0,001123979	0,509242162	3,40623616	-1,508495965
Strava Ride Smoothness over time (phone) (m/s³)	-0,004127667	0,473039536	1,88095445	-1,679326196
Strava Acceleration (watch) (m/s²)	-6,16318E-07	0,389835287	1,503206338	-0,81772412
Strava Ride Smoothness over time (watch) (m/s³)	-0,004121417	0,18862033	0,634805531	-0,535184607
Tobii Acceleration (m/s²)	10,01524476	0,188351733	10,68420441	9,293382937
Tobii Ride Smoothness over time (m/s³)	2,48281E-05	0,008535921	0,037846532	-0,026946772
Tobii Pupil Diameter Left (mm)	1,770987015	0,516176697	6,028333333	1,074
Tobii Pupil Diameter Right (mm)	1,771430718	0,173810296	2,173	1,3105
Tobii Pupil Diameter Filtered (mm)	1,765969067	0,514018183	6,028333333	1,074

Table 19. Participant m20

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,168229094	0,344491651	0,999355503	0
Sensor Logger Ride Smoothness over time (m/s³)	6,58405E-05	0,420660017	0,999355503	-0,991186908
Strava Acceleration (phone) (m/s²)	-0,00016175	0,487573046	2,830229096	-1,38698283
Strava Ride Smoothness over time (phone) (m/s³)	-0,006973265	0,487899937	3,08835538	-2,573604468
Strava Acceleration (watch) (m/s²)	0,000319965	0,371756652	1,371192312	-1,243766023
Strava Ride Smoothness over time (watch) (m/s³)	-0,002008059	0,198862989	0,940793473	-0,541271655
Tobii Acceleration (m/s²)	10,06550405	0,301927843	11,84340252	9,34297235
Tobii Ride Smoothness over time (m/s³)	-0,000214858	0,01101905	0,054534469	-0,04645293
Tobii Pupil Diameter Left (mm)	1,912064326	0,260970648	3,603166667	1,547131579
Tobii Pupil Diameter Right (mm)	1,835789074	0,226869778	3,213615385	1,441333333
Tobii Pupil Diameter Filtered (mm)	1,865009797	0,195463146	2,872833333	1,55825

Table 20. Participant m21

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,209610231	0,175347417	0,831015441	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,000669312	0,20017839	0,712626918	-0,625237308
Strava Acceleration (phone) (m/s²)	-0,000789017	0,489088048	2,690558314	-1,643290205
Strava Ride Smoothness over time (phone) (m/s³)	-0,005901076	0,464586887	1,759199236	-2,563976416
Strava Acceleration (watch) (m/s²)	-0,000213621	0,317598136	0,823878748	-1,094499546
Strava Ride Smoothness over time (watch) (m/s³)	-0,003686313	0,146756505	0,429173491	-0,367171723
Tobii Acceleration (m/s²)	9,995490028	0,159388029	10,67907568	9,471618158
Tobii Ride Smoothness over time (m/s³)	1,57886E-05	0,009447454	0,031414336	-0,03464796
Tobii Pupil Diameter Left (mm)	1,705709259	0,337617588	2,409	1,271
Tobii Pupil Diameter Right (mm)	3,938218444	1,955394949	8,937	1,865
Tobii Pupil Diameter Filtered (mm)	3,377164064	1,952464483	8,937	1,558428571

Table 21. Participant m30

Category	Mean	Standard deviation	Maximum	Minimum

Sensor Logger Acceleration (m/s²)	0,557961015	0,309619025	1,25749039	0
Sensor Logger Ride Smoothness over time (m/s³)	0,000607699	0,370744397	0,984320957	-0,933904927
Strava Acceleration (phone) (m/s²)	-0,000750217	0,496271183	2,325062361	-1,441134668
Strava Ride Smoothness over time (phone) (m/s³)	-0,001661071	0,428833726	1,668055123	-1,612257687
Strava Acceleration (watch) (m/s²)	0,003251559	0,420489338	1,273267247	-1,23541244
Strava Ride Smoothness over time (watch) (m/s³)	-0,002385474	0,18144057	0,639593778	-0,470318962
Tobii Acceleration (m/s²)	10,06468404	0,327817499	11,63968093	9,128149876
Tobii Ride Smoothness over time (m/s³)	0,000197753	0,018854464	0,099288637	-0,079131988
Tobii Pupil Diameter Left (mm)	1,707521905	0,089363511	2,113761905	1,442
Tobii Pupil Diameter Right (mm)	1,722825262	0,090705611	2,23715	1,470375
Tobii Pupil Diameter Filtered (mm)	1,713771903	0,07571224	2,260296296	1,463642857

Table 22. Participant m33

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	0,00021179	0,53165128	2,934623328	-1,714044803
Strava Ride Smoothness over time (phone) (m/s³)	-0,001827062	0,47812595	2,935737085	-3,243834864
Strava Acceleration (watch) (m/s²)	-0,000115089	0,365500686	1,358805073	-0,831193139
Strava Ride Smoothness over time (watch) (m/s³)	-0,003188857	0,166943883	0,593000063	-0,629116811
Tobii Acceleration (m/s²)	9,983447223	0,193553565	11,11520643	9,410502734
Tobii Ride Smoothness over time (m/s³)	0,000234739	0,013181713	0,056882698	-0,043908236
Tobii Pupil Diameter Left (mm)	1,874416103	0,389894701	4,339857143	1,34125
Tobii Pupil Diameter Right (mm)	1,911937624	0,499793443	5,727	1,346
Tobii Pupil Diameter Filtered (mm)	1,909958967	0,481822271	5,727	1,326888889

Table 23. Participant m46

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,033014146	0,14667888	0,997561418	0
Sensor Logger Ride Smoothness over time (m/s³)	0,002211602	0,107564821	0,66227488	-0,709333125
Strava Acceleration (phone) (m/s²)	0,000880534	0,467117515	1,950413941	-1,566362996

Strava Ride Smoothness over time (phone) (m/s³)	-0,009021052	0,488384876	1,853159562	-2,029367319
Strava Acceleration (watch) (m/s²)	7,70566E-05	0,34473366	1,115990863	-1,024021158
Strava Ride Smoothness over time (watch) (m/s³)	-0,002998905	0,148731187	0,473263241	-0,638804937
Tobii Acceleration (m/s²)	10,04037454	0,203611835	10,80667606	9,347771841
Tobii Ride Smoothness over time (m/s³)	-1,6251E-06	0,010327405	0,049445824	-0,036548106
Tobii Pupil Diameter Left (mm)	1,602495556	0,129628744	2,141944444	1,089
Tobii Pupil Diameter Right (mm)	1,741810379	0,506073494	5,878	1,315652174
Tobii Pupil Diameter Filtered (mm)	1,659482499	0,256758471	3,377970588	1,089

Table 24. Participant m50

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,433652898	0,308149743	1,001547581	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,002844604	0,364459644	0,892183435	-0,936260747
Strava Acceleration (phone) (m/s²)	0,000919904	1,122280098	6,954607137	-6,491413338
Strava Ride Smoothness over time (phone) (m/s³)	-0,004615442	1,559871412	7,20541179	-7,27066947
Strava Acceleration (watch) (m/s²)	-0,000683092	0,343473163	1,068895763	-0,837518475
Strava Ride Smoothness over time (watch) (m/s³)	-0,003834475	0,165005577	0,559081643	-0,411452612
Tobii Acceleration (m/s²)	10,05798862	0,177376301	11,25416991	9,127769432
Tobii Ride Smoothness over time (m/s³)	1,12157E-05	0,012432465	0,031896621	-0,034465897
Tobii Pupil Diameter Left (mm)	1,559021774	0,167580708	2,9665	1,115
Tobii Pupil Diameter Right (mm)	1,678161267	0,32896751	5,766857143	1,296666667
Tobii Pupil Diameter Filtered (mm)	1,595843787	0,172681881	2,9665	1,115

Table 25. Participant m55

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,49730154	0,324587805	0,981301368	0
Sensor Logger Ride Smoothness over time (m/s³)	0,002791764	0,33596007	0,950277394	-0,97187003
Strava Acceleration (phone) (m/s²)	-0,00060488	0,858613513	5,643634244	-5,531331959
Strava Ride Smoothness over time (phone) (m/s³)	-0,001856361	1,200548843	6,454632752	-5,999053143
Strava Acceleration (watch) (m/s²)	/	/	0	0
Strava Ride Smoothness over time (watch) (m/s³)	/	/	0	0

Tobii Acceleration (m/s²)	9,93202201	0,167446286	11,20928325	9,355543976
Tobii Ride Smoothness over time (m/s³)	4,64811E-05	0,008902359	0,04021609	-0,038527759
Tobii Pupil Diameter Left (mm)	1,932149829	0,435926485	5,69	1,293
Tobii Pupil Diameter Right (mm)	2,046346161	0,171801317	2,902230769	1,61375
Tobii Pupil Diameter Filtered (mm)	2,002168168	0,320710107	5,69	1,715714286

Table 26. Participant m60

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	0,000767125	0,610288831	4,123153808	-2,317456823
Strava Ride Smoothness over time (phone) (m/s³)	-0,004559396	0,616550193	3,909183627	-4,138085316
Strava Acceleration (watch) (m/s²)	/	/	0	0
Strava Ride Smoothness over time (watch) (m/s³)	/	/	0	0
Tobii Acceleration (m/s²)	9,963545053	0,187712216	10,90226538	9,454212483
Tobii Ride Smoothness over time (m/s³)	1,96225E-05	0,005961749	0,0293676	-0,022804913
Tobii Pupil Diameter Left (mm)	1,677437236	0,134360816	2,169	1,134
Tobii Pupil Diameter Right (mm)	1,747300502	0,403321466	5,828	1,272666667
Tobii Pupil Diameter Filtered (mm)	1,739182087	0,421768769	5,828	1,3461875

Table 27. Participant m70

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	-0,000410376	0,362495934	1,215923202	-1,316824019
Strava Ride Smoothness over time (phone) (m/s³)	-0,003164714	0,462856683	1,798557353	-1,910360636
Strava Acceleration (watch) (m/s²)	-0,000629864	0,228478683	0,746179583	-0,830254161
Strava Ride Smoothness over time (watch) (m/s³)	-0,002119462	0,088777188	0,396123022	-0,239965468
Tobii Acceleration (m/s²)	9,970448729	0,295563348	11,00523527	9,365109672
Tobii Ride Smoothness over time (m/s³)	-0,000578091	0,018048275	0,035331395	-0,060067818
Tobii Pupil Diameter Left (mm)	3,31242388	0,621898142	4,393404762	2,155588235

Tobii Pupil Diameter Right (mm)	3,169388076	0,677352681	4,154903226	2,01
Tobii Pupil Diameter Filtered (mm)	3,264734255	0,620382778	4,303090909	2,01

Table 28. Participant m78

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,563573324	0,374814851	1,229112487	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,001828219	0,278663215	0,974472763	-0,891895669
Strava Acceleration (phone) (m/s²)	-0,000695325	0,396968753	1,292663235	-1,189734862
Strava Ride Smoothness over time (phone) (m/s³)	-0,002087751	0,474180238	1,810817584	-1,679268434
Strava Acceleration (watch) (m/s²)	-5,26463E-05	0,287281124	0,815480108	-0,681797131
Strava Ride Smoothness over time (watch) (m/s³)	-0,00291941	0,12612757	0,372205442	-0,435273315
Tobii Acceleration (m/s²)	/	/	0	0
Tobii Ride Smoothness over time (m/s³)	/	/	0	0
Tobii Pupil Diameter Left (mm)	/	/	0	0
Tobii Pupil Diameter Right (mm)	/	/	0	0
Tobii Pupil Diameter Filtered (mm)	/	/	0	0

Table 29. Participant tijama21

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,559869074	0,338141011	1,349888508	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,000475952	0,415976983	1,116996615	-1,235645197
Strava Acceleration (phone) (m/s²)	0,001204892	0,777662143	5,490272624	-4,83266153
Strava Ride Smoothness over time (phone) (m/s³)	-0,001179008	1,121017823	6,789811612	-6,029119025
Strava Acceleration (watch) (m/s²)	0,000747823	0,189691169	0,455200562	-0,634373815
Strava Ride Smoothness over time (watch) (m/s³)	-0,00213986	0,08714849	0,338134802	-0,318143473
Tobii Acceleration (m/s²)	9,982715511	0,147546915	11,28542563	9,351254026
Tobii Ride Smoothness over time (m/s³)	-0,000206866	0,014230197	0,054139795	-0,093223521
Tobii Pupil Diameter Left (mm)	1,910053369	0,420407284	4,778	1,391
Tobii Pupil Diameter Right (mm)	1,992610524	0,580655481	5,784833333	1,348
Tobii Pupil Diameter Filtered (mm)	1,961863591	0,528302537	5,632333333	1,348

Table 30. Participant tsunami

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,009853111	0,093189353	0,980905683	0
Sensor Logger Ride Smoothness over time (m/s³)	0	0,110599259	0,980905683	-0,980905683
Strava Acceleration (phone) (m/s²)	-0,000671537	0,713381154	5,968223596	-5,489894959
Strava Ride Smoothness over time (phone) (m/s³)	-0,00259327	0,951062564	6,563745856	-6,260740426
Strava Acceleration (watch) (m/s²)	0,000782366	0,27852061	0,979321684	-0,692753281
Strava Ride Smoothness over time (watch) (m/s³)	-0,001992323	0,114778855	0,570578465	-0,310991025
Tobii Acceleration (m/s²)	10,0145631	0,214597107	11,3629729	9,385312159
Tobii Ride Smoothness over time (m/s³)	-8,11006E-05	0,014891106	0,085496152	-0,070541282
Tobii Pupil Diameter Left (mm)	1,767359675	0,398234839	3,77525	1,4115
Tobii Pupil Diameter Right (mm)	1,908527048	0,912583284	9,124	1,3
Tobii Pupil Diameter Filtered (mm)	1,812124358	0,443420479	4,1082	1,415606061

Table 31. Participant ž1

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,641151405	0,227732725	1,314635077	0
Sensor Logger Ride Smoothness over time (m/s³)	0,00151171	0,227637769	0,977160317	-0,904463469
Strava Acceleration (phone) (m/s²)	-0,01001739	0,358864062	1,438815951	-1,527275128
Strava Ride Smoothness over time (phone) (m/s³)	-0,000264529	0,411698893	1,66332103	-1,447996633
Strava Acceleration (watch) (m/s²)	/	/	0	0
Strava Ride Smoothness over time (watch) (m/s³)	/	/	0	0
Tobii Acceleration (m/s²)	10,04868296	0,167207471	10,74618429	9,443974845
Tobii Ride Smoothness over time (m/s³)	-0,000222469	0,011957844	0,078940245	-0,067265576
Tobii Pupil Diameter Left (mm)	2,612188297	1,022321297	5,72375	1,164
Tobii Pupil Diameter Right (mm)	3,317396744	1,273176513	6,335	1,522285714
Tobii Pupil Diameter Filtered (mm)	2,749845624	1,023417785	5,507214286	1,164

Table 32. Participant ž2

Category	Mean	Standard deviation	Maximum	Minimum

Sensor Logger Acceleration (m/s²)	0,360797977	0,275713264	1,36656365	0
Sensor Logger Ride Smoothness over time (m/s³)	0,001306586	0,25554953	1,06850543	-1,0908634
Strava Acceleration (phone) (m/s²)	-8,41897E-05	0,672229001	1,712702808	-1,409432206
Strava Ride Smoothness over time (phone) (m/s³)	-0,00140163	1,242579259	2,272171061	-2,104941296
Strava Acceleration (watch) (m/s²)	-0,000416259	0,124504558	0,617869541	-0,481779637
Strava Ride Smoothness over time (watch) (m/s³)	-0,001138323	0,066340461	0,256968612	-0,22983215
Tobii Acceleration (m/s²)	/	/	0	0
Tobii Ride Smoothness over time (m/s³)	/	/	0	0
Tobii Pupil Diameter Left (mm)	/	/	0	0
Tobii Pupil Diameter Right (mm)	/	/	0	0
Tobii Pupil Diameter Filtered (mm)	/	/	0	0

Table 33. Participant ž3

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,676671337	0,353840693	1,386470348	0
Sensor Logger Ride Smoothness over time (m/s³)	0,000489131	0,456361141	1,386470348	-1,198309641
Strava Acceleration (phone) (m/s²)	0,002942488	0,695484064	6,140230215	-5,895140043
Strava Ride Smoothness over time (phone) (m/s³)	-0,005135556	1,029241537	7,8738598	-7,049192147
Strava Acceleration (watch) (m/s²)	-0,000840906	0,224900507	0,685343926	-0,775496616
Strava Ride Smoothness over time (watch) (m/s³)	-0,002659729	0,113323637	0,520720676	-0,619361027
Tobii Acceleration (m/s²)	9,951773149	0,115335416	10,64718956	9,556504914
Tobii Ride Smoothness over time (m/s³)	4,78075E-05	0,009773287	0,031970249	-0,037531789
Tobii Pupil Diameter Left (mm)	1,863816578	0,218077916	3,337	1,378
Tobii Pupil Diameter Right (mm)	1,811998753	0,18917086	2,78	1,218
Tobii Pupil Diameter Filtered (mm)	1,83574797	0,179609492	2,565	1,218

Table 34. Participant ž6

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,242726157	0,403015737	0,998551398	0
Sensor Logger Ride Smoothness over time (m/s³)	0	0,488349501	0,998551398	-0,998551398
Strava Acceleration (phone) (m/s²)	0,002040694	0,384868071	2,232738562	-1,204858545

Strava Ride Smoothness over time (phone) (m/s³)	-0,011045697	0,38022729	1,147847165	-2,207791584
Strava Acceleration (watch) (m/s²)	/	/	0	0
Strava Ride Smoothness over time (watch) (m/s³)	/	/	0	0
Tobii Acceleration (m/s²)	10,00841823	0,133358331	10,62789428	9,498885156
Tobii Ride Smoothness over time (m/s³)	4,8412E-05	0,010397297	0,029680126	-0,035633998
Tobii Pupil Diameter Left (mm)	1,984353888	0,10448366	2,2746	1,521708333
Tobii Pupil Diameter Right (mm)	1,883841828	0,135834298	2,21988	1,419432432
Tobii Pupil Diameter Filtered (mm)	1,939062924	0,096332889	2,18674	1,59156

Table 35. Participant ž11

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,614921989	0,32019062	1,239109438	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,002490908	0,396056395	1,133038973	-1,075805805
Strava Acceleration (phone) (m/s²)	1,31097E-05	0,730124111	5,338765115	-4,115166079
Strava Ride Smoothness over time (phone) (m/s³)	-0,006008358	1,088746961	6,213632525	-6,733318335
Strava Acceleration (watch) (m/s²)	-0,000888473	0,279033577	0,746909673	-0,818705738
Strava Ride Smoothness over time (watch) (m/s³)	-0,00279122	0,125588871	0,530753277	-0,478132957
Tobii Acceleration (m/s²)	10,01392236	0,152369434	10,59645378	9,403717213
Tobii Ride Smoothness over time (m/s³)	-2,44543E-05	0,013146167	0,093051602	-0,075308497
Tobii Pupil Diameter Left (mm)	1,97015799	0,500930075	4,4145	1,206
Tobii Pupil Diameter Right (mm)	2,114348794	0,593044213	5,833	1,327
Tobii Pupil Diameter Filtered (mm)	2,086573135	0,608087809	5,833	1,206

Table 36. Participant ž12

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,494038908	0,295365194	1,170932379	0
Sensor Logger Ride Smoothness over time (m/s³)	0,000575839	0,359286949	0,993689351	-0,991557395
Strava Acceleration (phone) (m/s²)	-0,00034318	0,383165603	1,861120362	-1,242658814
Strava Ride Smoothness over time (phone) (m/s³)	-0,002451104	0,4438815	1,99759712	-1,905873246
Strava Acceleration (watch) (m/s²)	0,000126431	0,29364425	0,840174903	-0,842321599
Strava Ride Smoothness over time (watch) (m/s³)	-0,00266271	0,146248229	0,601602582	-0,40557777

Tobii Acceleration (m/s²)	9,991819724	0,177041894	10,71482958	9,289330727
Tobii Ride Smoothness over time (m/s³)	-3,68647E-05	0,009272642	0,028858706	-0,027109233
Tobii Pupil Diameter Left (mm)	2,040152787	0,90891126	5,862	1,343
Tobii Pupil Diameter Right (mm)	2,433364567	1,168686359	6,224	1,332833333
Tobii Pupil Diameter Filtered (mm)	2,407258385	1,152611559	6,224	1,318181818

Table 37. Participant ž13

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,614147259	0,308216819	1,211095171	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,000898252	0,366823491	0,976785941	-0,992529658
Strava Acceleration (phone) (m/s²)	-0,001459436	0,761927971	5,746858191	-4,858198428
Strava Ride Smoothness over time (phone) (m/s³)	-0,001576435	0,939710815	5,622177175	-5,780751959
Strava Acceleration (watch) (m/s²)	-0,000602365	0,350616393	0,785333941	-0,879767988
Strava Ride Smoothness over time (watch) (m/s³)	-0,003111686	0,163675442	0,496261392	-0,370663141
Tobii Acceleration (m/s²)	10,02669808	0,200918596	11,24154804	9,214347791
Tobii Ride Smoothness over time (m/s³)	1,5497E-05	0,009683386	0,032314473	-0,035655946
Tobii Pupil Diameter Left (mm)	1,741856459	0,55585469	4,462	1,229
Tobii Pupil Diameter Right (mm)	1,75860432	0,513966503	4,473	1,167
Tobii Pupil Diameter Filtered (mm)	1,7793393	0,610794747	4,625083333	1,167

Table 38. Participant ž42

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	0,414041029	0,326844546	0,998742461	0
Sensor Logger Ride Smoothness over time (m/s³)	-0,00168675	0,329525747	0,99601185	-0,99601185
Strava Acceleration (phone) (m/s²)	0,000594355	0,7462664	6,105329273	-6,151860958
Strava Ride Smoothness over time (phone) (m/s³)	-0,003700122	1,205570227	7,058140937	-7,210840547
Strava Acceleration (watch) (m/s²)	-0,000219107	0,161453191	0,932615022	-1,171926319
Strava Ride Smoothness over time (watch) (m/s³)	-0,001594594	0,116025535	1,151982414	-1,37443047
Tobii Acceleration (m/s²)	9,956361844	0,068810166	10,38287892	9,743956982
Tobii Ride Smoothness over time (m/s³)	-1,34614E-05	0,005639246	0,01694267	-0,017163131
Tobii Pupil Diameter Left (mm)	1,576045651	0,084725005	2,064571429	1,23

Tobii Pupil Diameter Right (mm)	1,565542054	0,294032625	5,75	1,288
Tobii Pupil Diameter Filtered (mm)	1,584644913	0,252231027	5,75	1,2344

Table 39. Participant ž60

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	0,001111977	0,340049017	1,409657826	-1,430381109
Strava Ride Smoothness over time (phone) (m/s³)	-0,005112046	0,451010013	1,866463691	-1,732366203
Strava Acceleration (watch) (m/s²)	0,000589404	0,215841376	0,802141228	-0,760116908
Strava Ride Smoothness over time (watch) (m/s³)	-0,001604011	0,111892732	0,437511034	-0,362306844
Tobii Acceleration (m/s²)	9,976788077	0,132767589	11,47821794	9,347659692
Tobii Ride Smoothness over time (m/s³)	0,000147583	0,011201582	0,047309529	-0,034299895
Tobii Pupil Diameter Left (mm)	2,19163487	0,767488912	3,939	1,296
Tobii Pupil Diameter Right (mm)	2,207845854	0,898715623	5,12025	1,277
Tobii Pupil Diameter Filtered (mm)	2,265650498	0,919585977	5,1018	1,277

Table 40. Participant ž70

Category	Mean	Standard deviation	Maximum	Minimum
Sensor Logger Acceleration (m/s²)	/	/	0	0
Sensor Logger Ride Smoothness over time (m/s³)	/	/	0	0
Strava Acceleration (phone) (m/s²)	0,000121268	0,399322303	1,084991939	-1,211435535
Strava Ride Smoothness over time (phone) (m/s³)	-0,002723357	0,672419796	2,003844276	-1,953079602
Strava Acceleration (watch) (m/s²)	-0,000278281	0,199204651	0,675577617	-0,82858721
Strava Ride Smoothness over time (watch) (m/s³)	-0,002265765	0,096679064	0,479108261	-0,263625472
Tobii Acceleration (m/s²)	9,961480966	0,174054393	11,19598714	9,392520708
Tobii Ride Smoothness over time (m/s³)	8,16151E-05	0,012763873	0,076383336	-0,067825831
Tobii Pupil Diameter Left (mm)	2,085690593	0,884731057	10,861	1,201
Tobii Pupil Diameter Right (mm)	2,419475096	0,835384215	7,748	1,256
Tobii Pupil Diameter Filtered (mm)	2,28496626	0,71310125	6,3795	1,456

Basic eye tracking parameters analysis

Table 41 presents the participants included in the controlled test ride conducted on the closed course polygon. The total sample consisted of 33 individuals, of whom 31 generated usable eye-tracking ride recordings. Nine participants reported prior experience riding an e-scooter. The study population included male and female riders aged between 17 and 53 years.

The table also summarizes the gaze quality data, expressed as percentages, obtained using Tobii Pro Smart Glasses. These values represent the entire duration of each recording, from the beginning to the end of data capture, and therefore include both the preparation phase and the finalization phase of the study procedure.

During the preparation phase, participants were fitted with additional measurement equipment (described in an earlier section of the report). They received an explanation of the route, instructions to follow traffic regulations, guidance on operating the e-scooter's throttle and brake, and the opportunity to ask questions or try basic handling. In the finalization phase, the last portion of the recording typically captures the participant walking back to the designated station, where the measurement equipment was removed and the recording session concluded.

Across the entire recording, gaze quality ranged from 12% to 81%, with 50% of participants falling between 23% and 68.5%.

For the actual riding interval, only the period from the start of the ride on the polygon to the moment the participant parked the e-scooter was included in the analysis. The gaze percentage for this segment was computed by comparing the total driving interval with the duration during which valid fixations were detected. Within the riding interval quality ranged from 0.13% to 67.39%, with 50% of participants falling between 4.55% and 32.74%.

Table 41. Description of the sample and assessment of the quality of the full recording and the driving segment.

Participant	User	Gender	Age	Gaze % of the entire recording	Gaze % of driving
123	not user	male	47	13	2,42
321	not user	female	22	69	46,02
1112	not user	female	32	43	9,66
1969	not user	male	21	24	5,65
2406	not user	male	20	67	17,02
2811	not user	male	19	13	1,50
kicra	not user	male	18	35	10,14
M2	not user	male	53	30	6,21
M20	user	male	21	80	32,80

M21	user	male	19	12	0,13
M3	not user	male	45	49	22,63
M30	user	male	34	78	32,67
M33	not user	male	51	63	27,17
M4	not user	male	32	68	36,09
M46	user	male	47	71	36,81
M5	unknown	unknown	unknown	55	13,97
M50	user	male	17	81	49,42
M55	not user	male	20	75	36,70
M6	not user	male	45	32	7,10
M60	unknown	unknown	unknown	59	25,52
Tijana21	not user	female	20	15	1,73
Tsunami	not user	male	35	51	4,56
Ž1	not user	female	47	15	0,90
Ž11	user	female	19	43	14,61
Ž12	user	female	19	22	4,54
Ž13	user	female	19	26	10,80
Ž3	not user	female	19	21	2,54
Ž42	not user	female	45	62	21,09
Ž6	user	female	18	77	67,39
Ž60	not user	female	49	14	0,87
Ž70	not user	female	44	70	32,91

Table 42 presents the descriptive statistics of the primary eye-movement parameters obtained using Tobii Pro Lab for each participant, values related to the detection of fixations and saccades recorded by the Tobii Pro Glasses. The number of detected eye-movement events depends strongly on the quality of the initial calibration and the stability of the tracking signal throughout the recording. As a result, participants with lower event counts typically correspond to segments with a lower gaze quality percentage during the ride.

The average fixation duration across participants was 212 ms. Higher fixation-duration values generally indicate a more cognitively demanding task, as longer fixations are typically associated with increased visual processing requirements. For saccades, the mean saccade duration was 218 ms.

The mean saccade amplitude, expressed in degrees of visual angle, reflects the magnitude of eye movements. Lower amplitudes suggest that participants primarily focused on the near visual field and performed localized scanning of the environment. In contrast, higher amplitudes indicate broader visual exploration, including the monitoring of more distant elements in the riding environment. In this study, mean amplitudes ranged from 4.13° to 10.36°, representing small to medium eye-movement excursions typical of structured and predictable riding conditions on a closed-course track.

	Fixation		Saccades					
Participant	Number	Mean duration	Number	Mean duration	Minimum duration	Maximum duration	Standard deviation	Mean amplitude
123	25	218	26	249,88	101,79	2157,55	394,49	6,52
321	360	308	301	205,15	100,14	2466,24	175,05	5,99
1112	138	188	124	207,95	100,41	455,83	83,13	6,03
1969	58	223	45	203,51	100,22	457,18	94,74	6,22
2406	286	199	214	208,64	100,42	1614,07	145,5	5,61
2811	20	191	13	327,75	102,68	1345,52	351,3	10,36
kicra	134	220	103	212,38	100,05	511,89	101,14	6,74
M2	117	150	76	242,39	100,53	1018,44	159,69	6,69
M20	494	172	299	234,51	100,04	1565,98	171,68	6,65
M21	1	301	0	/	/	/	/	/
M3	249	226	211	214,19	100,52	665,4	112,8	6,57
M30	366	223	314	211,41	100,09	671,53	99,79	6,45
M33	235	272	190	203,78	100	668,09	97,42	5,3
M4	437	206	311	197,62	100,27	997,62	99,84	5,76
M46	332	266	263	238,51	100,35	1246,7	140,05	6,69
M5	173	203	155	205,08	100,09	868	114,83	7,13
M50	383	317	334	246,08	100,15	1650,4	138,33	7,73
M55	526	196	382	240,95	100,47	1017,85	136,35	7,82
M6	77	212	50	225,09	100,28	1564,29	209,27	6,9
M60	259	258	201	195,38	100,34	672,02	95,63	5,54
Tijana21	37	160	17	171,68	103,06	303,75	59,86	4,43
Tsunami	92	141	56	177,79	100,16	529,47	82,99	4,54
Ž1	27	109	17	181,35	102,92	376,29	94,14	5,83
Ž11	169	216	120	203,84	100,13	502,13	90,98	6
Ž12	76	158	40	214,8	101,43	611,49	116,47	6,4
Ž13	116	234	78	164,04	100,11	410,81	59,72	4,13
Ž3	41	194	30	289,16	102,31	1013,83	233,33	7,74
Ž42	461	200	336	274,3	100,7	1670,22	223,03	6,89
Ž6	581	272	461	205,61	100,08	486,32	87,14	6,69
Ž60	21	131	17	175,26	102,06	402,65	78,8	4,88
Ž70	599	208	399	200,18	100,4	577,54	85,62	6,2

Literature

Big Bang. (n.d.). ECO Speed 10X električni skiro. Retrieved February 9, 2026, from https://www.bigbang.si/eco-speed-10x-elektricni-skiro-izdelek-686308/

Appendixes

Appendix A

SOGLASJE ZA SODELOVANJE V RAZISKAVI IN UPORABO PRIDOBLJENIH REZULTATOV

Zaradi lažje berljivosti so v nadaljevanju uporabljene moške slovnične oblike (npr. podpisani), ki se nanašajo na vse osebe ne glede na spol. Izrazi se uporabljajo nevtralno in vključujejo vse spolne identitete.

Spodaj podpisani ____ (ime in priimek) potrjujem, da v raziskavi vizualne pozornosti voznikov električnih skirojev, ki jo izvaja Fakulteta za logistiko UM, sodelujem prostovoljno, in da sem seznanjen s sledečim:

- S sodelovanjem potrjujem, da sem polnoleten.
- Nisem pod vplivom alkohola ali drugih substanc, ki bi vplivale na mojo sposobnost vožnje ali odgovarjanja na vprašalnike.
- Seznanjen sem, da se bodo rezultati mojega sodelovanja vodili izključno pod dodeljeno šifro, moje ime in drugi osebni podatki, razen demografskih, ne bodo nikjer vodeni ali zabeleženi.
- Dovoljujem obdelavo rezultatov mojega sodelovanja v raziskavi za namene raziskave ter izobraževanja javnosti. Posnetki, ki bodo posredovani tretjim osebam ali uporabljeni v izobraževalne namene, bodo vedno anonimizirani, tako da iz njih ni mogoče identificirati posameznikov. Pred obdelavo bodo namreč vse razpoznavne lastnosti posameznikov (npr. obrazne poteze, glas, identifikacijski elementi) tehnično zakrite (npr. zameglitev, izrez, utišanje), s čimer bo zagotovljena anonimizacija posnetkov.
- Pri odgovarjanju na vprašalnik o voznih navadah, osebnostnih lastnostih ter demografskih karakteristikah bom odgovoril resnično, natančno in premišljeno.
- Zavezujem se, da bom po svojih najboljših močeh upošteval navodila raziskovalcev in varnostne ukrepe.
- Seznanjen sem, da bom med vožnjo nosil očala za sledenje pogledu (eye tracking), ki beležijo vizualno pozornost, ter uro za merjenje biometričnih podatkov in spremljanje lokacije, pri čemer se podatki ne bodo uporabljali za identifikacijo.

- Razumem, da morebitne nenamerne napake ali prekrški, ki jih naredim tekom voženj na poligonu v okviru raziskave, name ne bodo imele pravnih ali kazenskih posledic.
- V raziskavi sodelujem na lastno odgovornost in se zavezujem, da bom med vožnjo ravnal previdno ter upošteval varnostna navodila.

Kraj in datum: Podpis

Celje, 8. oktober 2025 ___________________________

OBVESTILO O ZBIRANJU IN OBDELAVI PODATKOV

Raziskava, v kateri sodelujete, je del temeljnega raziskovalnega projekta, ki proučuje uporabo električnih skirojev v urbanih okoljih. Projekt "eSCURB: Električni skiroji v urbanih okoljih: Študija varnosti, infrastrukture in dinamike mobilnosti" financirata Javna agencija za znanstvenoraziskovalno in inovacijsko dejavnost Republike Slovenije (projekt J5-60090) in Hrvatska zaklada za znanost (projekt IPS-2024-02-3188) kot del iniciative Lead Agency Multilateral Scheme (Weave) Agreement za (so)financiranje raziskovalnih projektov.

Vsi zbrani podatki iz raziskave bodo obdelani skladno z načelom najmanjšega posega in v skladu z raziskovalnimi cilji projekta.

Podatki, zbrani z anketnimi vprašalniki, tretjim osebam ne bodo posredovani samostojno, temveč bodo vključeni v agregirane analize, kjer posamezni odgovori ne bodo več povezani ali povezljivi z identiteto udeleženca.

Vaši podatki, zbrani v okviru te raziskave, bodo hranjeni v varovanem okolju za obdobje 1 leta po zaključku raziskave. V izvorni obliki bodo hranjeni na varovanem zunanjem disku ali na oblačni storitvi z omejenim dostopom in dvojno avtentikacijo, dostop do njih pa bo imela izključno raziskovalna skupina, ki izvaja projekt. Vsi podatki bodo zaščiteni skladno z internimi varnostnimi protokoli in zakonodajo (GDPR, ZVOP-2). Podatki bodo uporabljeni izključno za znanstvene namene in obdelani v skladu z veljavno zakonodajo (GDPR, ZVOP-2). Po preteku obdobja hrambe bodo podatki, iz katerih so razvidni osebni podatki ali identifikatorji, trajno izbrisani. Imate pravico kadarkoli zahtevati dostop do svojih podatkov, njihov popravek ali izbris, pri čemer preklic ne vpliva na zakonitost obdelave podatkov pred preklicem.

Kontaktna oseba glede informacij o varovanju podatkov ali pravic v zvezi z obdelavo podatkov je vodja projekta, doc. dr. Tina Cvahte Ojsteršek. Nanjo se lahko obrnete z vsemi vprašanji preko elektronskega naslova: tina.cvahte@um.si.

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