HOW DO SUBJECTIVE PERCEPTION OF SAFETY AND RISK TAKING TENDENCIES MANIFEST IN HELMET USAGE OUTCOMES DURING CYCLING IN URBAN ENVIRONMENTS?

Word count: 5498

1. Literature Review

1.1 Introduction

Growing number of cities see cycling as a promising solution to problems introduced by their automobile-centric designs; namely congestion, parking problems, climate change and road traffic injuries [1]. Benefits expand to an individual level, too: daily bicycle commuters had a 46% lower risk of developing heart disease and a 45% lower risk of developing cancer in the span of their lives [2]. Moreover, in many cities, using the bike instead of a car may very well result in shorter faster commute time overall, sometimes by as much as 50% [3].

One of the largest consulting firms in the world, Deloitte, is predicting that the number of people who bike to work will double in many major cities around the world by 2022 [4]. This rise is further amplified amidst the risks introduced by and measures taken following the Covid-19 pandemic – with cycling levels increasing by as much as 27% compared with the same time last year in multiple capitals across Europe [5], [6].

The academic scene seems to follow these trends too: as the European Cycling Federation [7] reports, the academic research on cycling has been "booming". This hints at a tangible need to fully address and understand implications of our actions when it comes to cycling: from efficient infrastructure designs, through bike sharing systems to individuals and their very safety on the road.

1.2 Bike Helmets

There's no doubt as to why cycling helmets are generally regarded as an effective means of head protection and injury prevention. According to [8] from the New England Journal of Medicine, riders with helmets had an 85% reduction in their risk of head injury and an 88% reduction in their risk of brain injury. This particular, but also other studies examining the effectiveness of bike helmets, such as [9], do, however have one thing in common: they study helmet effectiveness solely on post-accident subjects. Taking a closer look at these articles shows that both the experiment and the control groups have already been hospitalized following their respective bike injuries. It is equally as important to investigate how wearing a helmet influences the overall safety of a cyclist – not only that after collisions: a narrative that often goes unmentioned in the bicycle safety discourse.

This issue was raised to the general public for the first time by the New York Times. In 2001, Barnes [10] reports that the rate of head injuries per active cyclist has increased by 51 percent just as bicycle helmet use has risen sharply, which sounds very counterintuitive at first. As even a CPSC (Consumer Product Safety Commission) assistant executive director Ronald L. Medford concluded, "It's puzzling to me that we can't find the benefit of bike helmets here". Lacking further scholarly work, the author only concludes that "there is more to bicycle safety than helmets", and, alongside promoting the usage of helmets, safety officials must teach and promote good driving practices to create a safer environment for people to ride in.

More importantly, similar trends could be observed across the entire planet. In [11], Clarke examined patterns of both helmeted and non-helmeted cyclists' injuries based on evidence from published papers and institutional databases such as the *US Centers for Disease Control and Prevention* or *Australian Health and Welfare Institute*. He presented his findings at Great Britain's National Road Safety Conference and found that

> Accident data from Australia, the United States, Canada, the United Kingdom and New Zealand indicate the accident rate per hour cycled or per miles cycled has increased with greater helmet usage, most likely from a greater proportion and number of upper limb injuries. [11]

There are multiple theories that try to explain why this piece of equipment, designed to protect the riders, apparently increases the risk of an injury. As [11] points out, "In nearly all cases they are difficult to evaluate and may require further research"; however, the researchers do have an idea.

1.3 Risk compensation theory

Multiple sources suggest that risk compensation theory (RCT) may give grounds as to why this phenomenon occurs and is a good starting point of the academic inquiry. RCT suggests that

> Individuals provided with a protective device such as a bicycle helmet or an automobile seat belt will act in a riskier manner because of the sense of increased protection from the helmet or seat belt and thereby nullify the protection afforded by the helmet or seat belt. [12]

It is, however, important to note that RCT is not applicable to respective case studies of the sheer protection provided by helmets, such as [8], per se. Rather, we need to think about RCT in the greater context of general helmet usage among the cycling population.

In [13], Phillips et al. studied cyclists riding down a 0.4km hill with and without a helmet. They were observing Heart Rate Variability (HRV), self-reported risk perception and changes in cycling behaviour as objective and subjective measures of experienced risk, respectively. Although they found no significant changes in the HRV data among the two control groups, they reported an ”increased cycling speed and decreased risk perception in a helmet-on compared to a helmet-off condition among cyclists used to wearing helmets”. It was also found that for cyclists not accustomed to helmets, there were no changes in either speed or perceived risk. As even the authors conclude, this finding is in line with RCT, as those who use a helmet routinely seem to perceive a reduced risk of an injury and thus compensate by cycling faster.

While [13] has looked at cyclists aware of using safety equipment and focused specifically on changes in behaviours for certain equipment configurations, in [14], Gamble and Walker observed primal and subconscious behaviour patterns and changes within. They found that

> In a controlled study in which a helmet, compared with a baseball cap, was used as the head mount for an eye tracker, participants scored significantly higher on laboratory measures of both risk taking and sensation seeking. This happened despite there being no risk for the helmet to ameliorate and despite it being introduced purely as an eye tracker. The results suggest that unconscious activation of safety-related concepts primes globally increased risk propensity. [13]

Finally, in [15], Walker used an instrumented bicycle to gather proximity data from overtaking motor vehicles for over 200 miles of riding distance. One of his key findings was that “wearing a bicycle helmet led to traffic getting significantly closer when overtaking.” This suggests that subconscious behaviour changes based on safety perception may be prevalent in automobile drivers, too – as helmeted cyclists are perceived to be better protected, motorists do not tend to give as much effort into their safe overtake maneuvers, thus exposing cyclists to a greater risk of collision.

1.4 The need for further research

Given the contradicting evidence of net safety benefits of helmet usage, many scholars are vocalizing the need for further research in their publications. [16] provides perhaps the most comprehensive look at the relationship between bicycle helmets and risky behaviour. This systematic review from 2019 analysed 23 articles from self-reported surveys, crash or experimental data. While in sum, the "systematic review found little to no support for the hypothesis bicycle helmet use is associated with engaging in risky behaviour", it is important to note the limitations of this particular collection of articles subjected to a review. As authors themselves note,

> Most studies, however, did not directly measure risk compensation through testing whether feeling safer while wearing a helmet leads to actual riskier behaviour (i.e., changes in behaviour). Rather, these studies tested the risk compensation hypothesis by testing the association between helmet wearing and perceived risk of bicycle injury, but not on actual risk-taking behaviour. [16]

In [16], the calls for further research regarding RCT are clear – Esmaeilikia et al. conclude that "there is a lack of consensus in the research literature regarding bicycle helmet use and the risk compensation hypothesis, although this gap in knowledge was identified in the early 2000s". This is a trend across multiple other studies, such as [11] or [17].

1.5 A gap in the current literature

Current academic literature clearly displays a lack of consensus when it comes to evaluating the helmet usage practices as a possible predictor of a change in riding style and a possible increase in injury probability [11, 16, 17]. Many scholars have hinted that this phenomenon may be a case of RCT, where the increased perception of safety provided by the helmet usage leads to subjects exposing themselves to greater risks and thus nullifying the provided net safety benefits.

Existing studies have looked at this issue from multiple perspectives: macroscopically, accident and helmet wearing data were analysed across multiple continents [11]; while [13] and [14] have focused on the activation of subconscious and primal instincts within our cognitive systems.

Few studies have performed a population questionnaire with the aim of looking into the relationships between subjective safety perception, risk taking and helmet wearing outcomes by evaluating the subjective responses of cyclists. In [18], Balogh estimates the effects of selected infrastructure attributes on perceived safety by having participants rate 3D models of certain situations and then evaluating their Subjective Safety Score. In [19], Graser et. al. asked cyclists who stopped at the red traffic light to complete a questionnaire about the dangers of urban cycling – and while they have not focused on helmet wearing outcomes, their approach of subjective safety perception is very similar to the one of this study.

Thus, the leading question of this study emerges: How do subjective perception of safety and risk taking tendencies manifest in helmet usage outcomes during cycling in urban environments?

As most of the aforementioned, similar survey-based population studies have gathered responses either in the very field [19] or in a controlled environment with artificial visualizations of various situations [18], this study aims to give the participants time to reflect on their very own perception of safety during cycling in urban environments and the space to voice their attitudes in the quantitative survey, while still providing an in-depth exploration of these relationships. By contributing to the academic discussion with additional factors that others might have neglected to review, this paper allows the scholars to better understand the complexities involved in this field; and promotes safety among the population of urban cyclists.

In this study, the following is hypothesized:

1. Cyclists with higher levels of self-reported perceived sense of safety (PSS) will be less likely to wear a helmet.
2. Cyclists with higher levels of self-reported risk taking (RT) tendencies will be more prone to wear a helmet.

2. Methodology

2.1 The survey

In order to test the hypotheses, a quantitative data collection will be performed using a self-completion online questionnaire survey. Lacking funds and resources to conduct a study using a qualitative, highly scientific method, such as those in [13] or [14] (where authors employ brain-implanted cognitive measurement devices and heart rate monitors), this method provides a reliable way to shed a light on the desired outcomes and their relationships thanks to the easily collectable and analysable data it yields.

The questionnaire asks the respondents to evaluate their subjective perception of risk and worry about being involved in accidents with other traffic subjects and objects, to evaluate their risk taking tendencies and attitudes theretoward and to disclose their practices when it comes to the usage of helmets and other safety equipment. As a response model, I decided to use the so-called Likert scales: the respondents are given a range of answer choices — from one opposing perspective to another using five options [20]. For the purpose of this research, I changed the wording of the responses when deemed appropriate (e.g. from the usual *Strongly disagree / Strongly agree* to *Always / Never* and etc.). Likert scale model was used because it “is the most widely used scale in survey researches, particularly in social science researches” [21], the consideration criteria is certain and easy to use and gives higher reliability than other rating scale types [22].

Examples of PSS[1] statements include "*Cycling on roads with confusing intersections / against the one-way street direction"*; for RT[2], those are "*It is acceptable to break the rules as a cyclist when no others are involved", "It is acceptable to cycle on red when no others are present";* and finally for the HW[3], they are *"I do tend to wear a helmet when I ride in urban areas"* or *"I find my helmet comfortable".*

In addition to 3 major parts of the survey, the participant is also asked to disclose general information for the purpose of demographic evaluation. The entire questionnaire can be found in Appendix A, where for every statement and question used, the inspirations and/or original authors are appropriately credited, as the majority of PSS and RT statements were inspired by other scholars' works, primarily [17], [18], [19] and [23].

2.2 Sample

2.2.1 Context

The cycling infrastructure in Bratislava, Slovakia (where the vast majority of respondents were from) is hardly up to par with those of Western countries such as the Netherlands or Great Britain – There's "few to tens of kilometers of designated biking paths" in the city itself. The infrastructure is deemed to be inappropriate by many – Cyklokoalícia itself, the most active local organisation involved in promoting cycling, criticized the Bratislava municipality for their inadequate activity and results in facilitating cycling infrastructure [24].

---

[1] Perceived sense of safety.
[2] Risk taking.
[3] Helmet wearing.

These conditions need to be taken into account when evaluating the results of this research; as the overall attitude of the population towards cycling can be different from that of countries with mature cycling networks.

2.2.2 Data Collection

The independent survey was administered in collaboration with the Cycling Coalition (Cyklokoalícia), members of which provided valuable feedback regarding the observed variables and wording of the statements within the questionnaire itself. After mutual agreement, the questionnaire was shared on their official Facebook page as well as sent out in their monthly newsletter; thus fulfilling the intention of primarily targeting the Slovak cycling population. In total, 215 responses were collected.

2.2.3 Data analysis

All the required data manipulation was performed using Python programming language in a Jupyter notebook environment, utilizing the Pandas data analysis library alongside my own tools [25]. The entire source code can be found in the Appendix E.

The questionnaire was designed in a way to introduce the use of custom models. Not only will I be looking at the respective fields themselves (from now on referred to as “primitive fields”), I will also be able to implement a model – a set of fields – that serves as a reduction[4] of fields with similar traits. Basic arithmetic and statistical operations (mean, median, max, sums, correlation

[4] A reduction, in this context, is meant to be a certain function that maps an array of values to a single value (e.g. a mean, median, etc.), thus “reducing” the collection.

tables and etc.) were calculated using native Pandas [25] functions. All the models used can be found in the Appendix B.

Bivariate linear regression plots and KDE (Kernel-Density Estimate, analogous to a histogram) pair grids were rendered using the Seaborn statistical data visualization library [26]. Least absolute shrinkage and selection operator ("Lasso") regression analysis was performed using the scikit-learn machine learning library [27]. Lasso "tends to make coefficients to absolute zero" [28], which is a valuable trait when looking at a problem of this nature and trying to identify a set of predictors. All plots can be found in the Appendix C.

2.2.4 Demographic analysis

A brief overview of the sample is provided below. Full description of the data can be found in the Appendix C.

2.2.4.1 General information

The age of the respondents was distributed approximately normally, with mean age of 36.1 years and a standard deviation of 10.74. Median age of the respondents was 34. From the 215 respondents, 151 identified themselves as males, yielding a 70.2% proportion of males. 29.3% of the respondents identified as female with 1 respondent not disclosing their gender. An overwhelming majority of 76.3% (164) respondents were from the capital – Bratislava – or from the nearby villages and small cities. The second most represented city was Košice, with only 8 (3.7%) respondents being therefrom.

2.2.4.2 Bike usage practices

Almost a half of all the respondents (47.9%) claimed that they primarily use the bicycle for commuting and transportation purposes. 24.2% and 19.1% respondents primarily use their bicycle for sport / exercise and recreational purposes, respectively.

70.7% (152) participants claimed to usually cycle in urban environments. 22.3% (48) stated that they primarily use their bicycle in rural, non-urban areas with the remaining 7% (15) not being able to differentiate.

The majority of the sample were what I consider “active cyclists”: 78.2% (168) of participants use their bike at least twice a week, with even groups of sizes 84 and 84 split between the options of “5 and more than 5 times a week” and “2 to 4 times a week”.

The average bike trip length was spread out very evenly. The majority take an average ride of either 5-10, 10-20 and 3-5km, with 22.3% (48), 19.5% (42) and 16.7% (36) as respective proportions.

3. Results

Out of all participants, 48% (103) reported wearing a helmet in urban environments (answered with a score greater than 3). When cycling outside of the city and in rural areas, participants seem to be more cautious with as much as 66.8% (143) using their helmet. The least popular reasons for avoiding the usage of helmets were aesthetics (68.2% disagreeing, mean score of 2.03) and comfort (63.5%, mean score of 2.33).

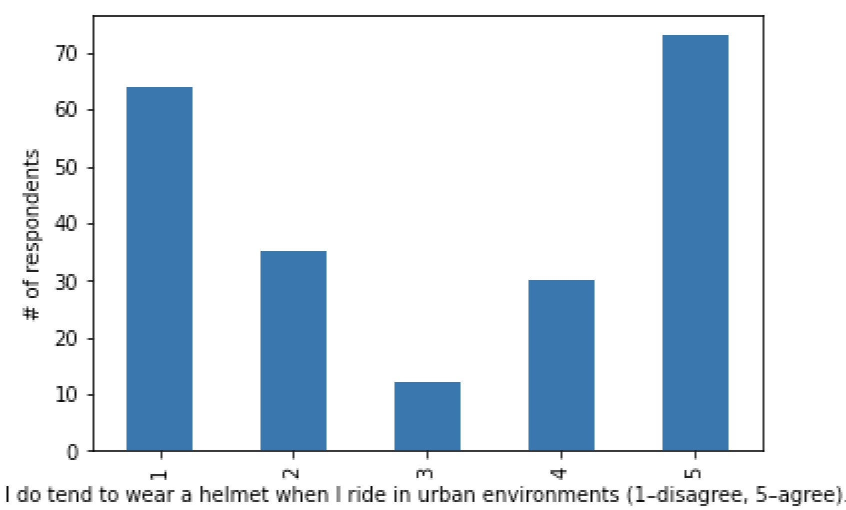


Figure 1: histogram of responses regarding helmet usage in urban environments.

Unless specified otherwise, results and values provided below were calculated based on the entire dataset, not only on the population that indicated primarily cycling in urban environments. All of the indicators were also tested strictly against the urban cycling population only and still remained statistically significant nonetheless.

3.1 Basic models

Fitting a linear regression line for the PSS score (mean of all PSS variables) against one's tendency to wear their helmet when cycling in urban environments (hw_urban_env) yields a statistically significant result with a p-value of 0.004, confirming my hypothesis that cyclists feeling less safe will tend to use a helmet more.

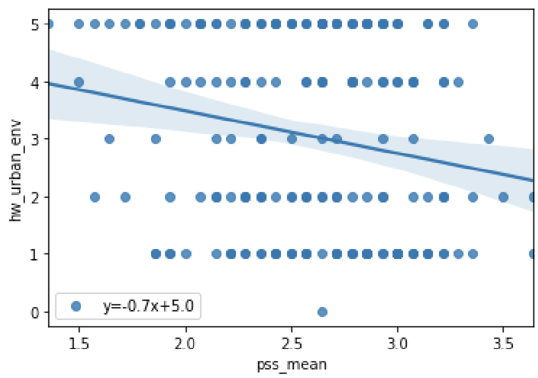
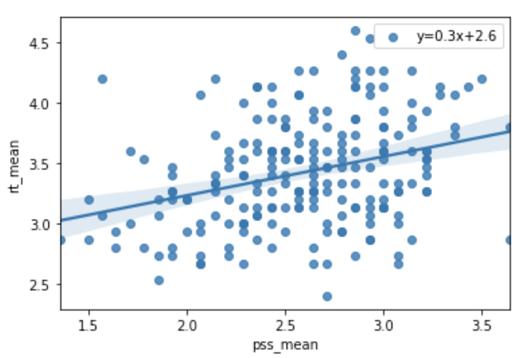
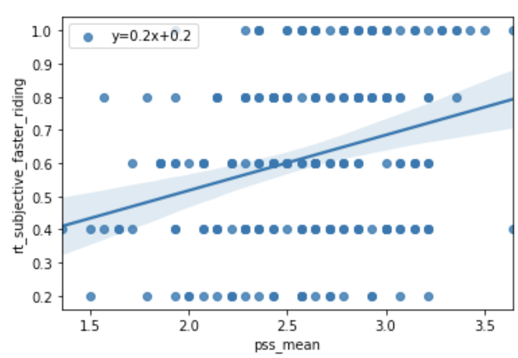


Figure 2: Linear regression graph of PSS score and HW outcomes.

Similarly, PSS score turns out to be a statistically significant predictor of RT tendencies (p = 1.589e-06) as well as the tendency to feel like one is riding faster than other cyclists they see (p = 1.974e-05).



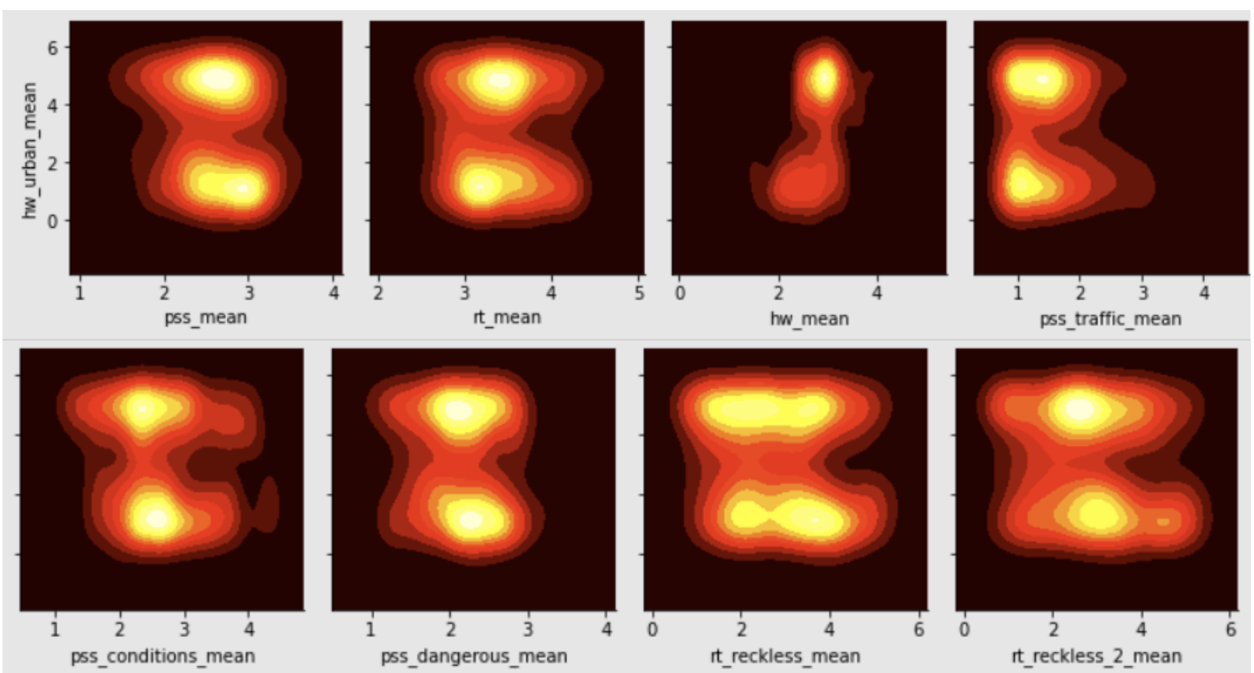


Figures 3 and 4: Linear regression graphs for PSS scores against RT score and perception of relative fastness.

No other relationships of this nature (reduction of PSS, RT or HW) turned out to be statistically significant (p values of 0.33 and 0.69). It is, however, to be expected, as the nature of the questions within respective categories has not been strictly monotonous and neither were they structured in a way to provide a relevant framework for conclusions based on their reductions (means) alone.

3.2 Custom models

Below is a single row of the pair grid visualization, describing the relationship between hw_urban_env (here denoted as hw_urban_mean) and each one of the custom models using a KDE plot. The full 13x13 pair grid and all the custom models can be found in the Appendix C.



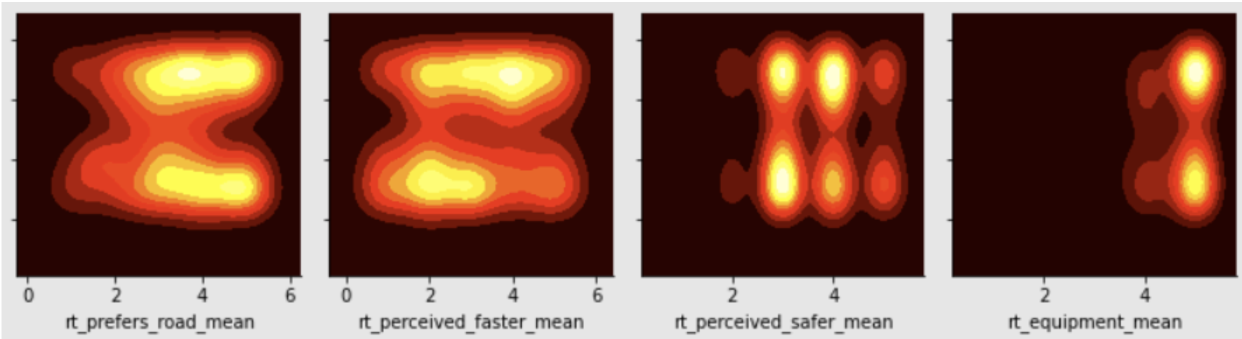


Figure 5: KDE pairgrid of helmet wearing outcomes (vertical axis) and all custom models. Note: rt_perceived_faster_mean[5] and rt_perceived_safer_mean are single field models – thus directly map the values of rt_subjective_faster_riding and rt_perceived_safer_riding, respectively.

Here, we can directly see the manifestation of the hw_urban_env single variable distribution as seen in Figure 1: in every KDE plot, there are 2 clusters of respondents – those who tend to wear a helmet (greater values on the vertical axis) and those who do not (smaller values on the vertical axis). For the majority of the fields, there is no significant difference between the position of these clusters on the horizontal axis, hinting at no relationship between the two variables; promising indicators are propagated and investigated further below.

3.3 Primitive variables

As custom models yielded the most significant results for the single variable, it makes sense to abandon the idea of custom models and analyse the outcomes in terms of the primitive (direct answers) variables only. The full table of Pearson’s correlation coefficients (every variable against hw_urban_env) can be found in the Appendix D.

---

[5] Mapping of variable names to questions from the questionnaire can be found in the Appendix A.

Investigating the two bivariate combinations from the KDE plot and fitting a linear regression least-squares for hw_urban_env line yields a statistically significant result for rt_subjective_faster_riding (p-value = 0.04) as a predictor. Rt_subjective_safer_riding is not significant (p value = 0.58).

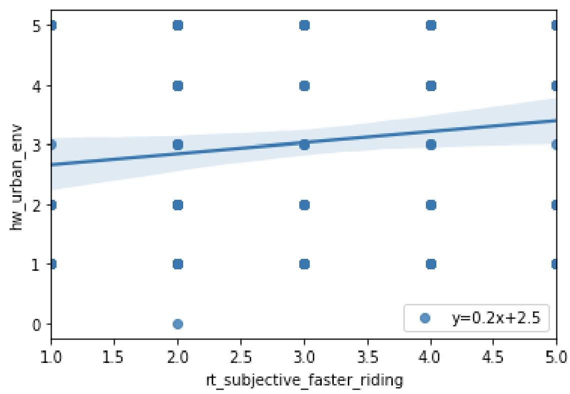
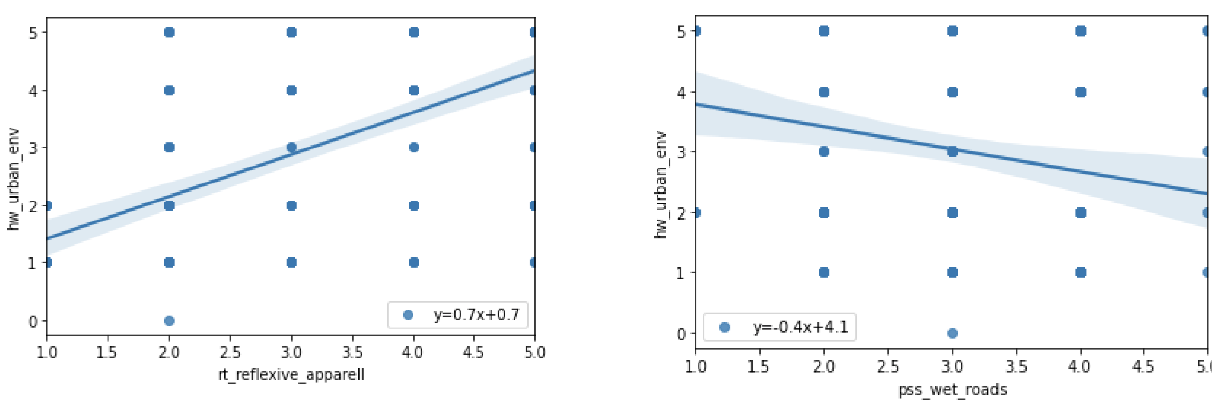


Figure 6: Linear regression plot for subjective perception of fastness when riding their bicycle and HW outcomes.



Figures 7 and 8: Linear regression plots for rt_subjective_faster_riding against HW outcomes and rt_subjective_safer_riding against HW outcomes.

Rt_reflexive apparel (R^2= 0.33, p-value = 2.17E-20) and feelings of safety on wet roads (pss_wet_roads) (p value = 0.005) are statistically significant predictors of hw_urban_env as well.

3.4 Combined predictor model, Lasso

For the purposes of further feature analysis as well as confirming the correlation findings, a least absolute shrinkage and selection operator (Lasso) regression analysis was performed additionally. An optimal lambda value of 0.03 was found analytically by iterating over the possible lambda values ([0,1]), fitting a model with the given lambda using the training set of data and and comparing the R^2 score on the testing data. Computing a Lasso model over the entire set of primitive variables predictors yields a linear linear regression model with following coefficients:

Variable	Weight
rt_reflexive_apparell	3.08
pss_pavements	-0.45
rt_rule_obeying_difficulty	-0.36
rt_subjective_faster_riding	0.35
pss_one_way_street	-0.33
Intercept	1.60251652

Table 1: Weights of variables in the optimal Lasso linear model.

With other variables having weight of 0 as an optimal solution, this model yields a R^2 on the test dataset (30%, randomly selected) of 0.38. P-value is not calculated in this approach.

All of the variables in this model, when put into a bivariate linear regression model fit (variable against hw_urban_env), yield a p-value lower than the regularly accepted significance level (0.05) and thus can be individually considered statistically significant too.

3.5 Summary

The table below provides a summarization of the regression analyses for relevant variable permutations.

	R^2	Correlation coeff.	p-value	Statistically significant
PSS score & hw_mean	0.004	0.063	0.33	no
rt_mean & hw_mean	0.0007	0.026	0.69	no
PSS score & hw_urban_env	0.037	0.192	0.0046	yes
PSS score & rt_mean	0.102	0.319	1.589e-06	yes
PSS score & rt_subjective_faster_riding	0.082	0.289	1.974e-05	yes
rt_subjective_faster_riding & hw_urban_env	0.012	0.110	0.04	yes
rt_subjective_safer_riding & hw_urban_env	0.0014	0.037	0.58	no
rt_reflexive apparel & hw_urban_env	0.33	0.574	2.17E-20	yes

pss_wet_roads & hw_urban_env	0.036	0.190	0.005	yes
pss_pavements & hw_urban_env	0.12	0.346	0.0002	yes
rt_rule_obeying_difficulty & hw_urban_env	0.038	0.195	0.004	yes
pss_one_way_street & hw_urban_env	0.04	0.02	0.003	yes
rt_rule_breaking & hw_urban_env	0.035	0.187	0.006	yes

Table 2: All relevant variable permutations and their corresponding statistical measures.

4. Discussion

These were the initial hypotheses:

1. Cyclists with higher levels of self-reported subjective perception of safety will be less likely to wear a helmet.
2. Cyclists with higher levels of self-reported risk taking tendencies will be more likely to wear a helmet.

The data analysis confirms the first of these hypotheses. An inverse, statistically significant relationship between PSS levels and HW tendencies in urban areas was found. It is, however, important to distinguish the cause and the effect in this particular situation; mainly, one needs to ask “does the lack of safety lead them to wear their helmet or is the increased sense of safety a natural result of helmet wearing?” – a question in its nature similar to the popular chicken and egg problem [29]. As a systematic review [16] concludes, “many of [risk compensation theory / PSS and HW] studies, bicycle helmet wearing was associated with safer cycling behaviour”. With “little to no support for the hypothesis bicycle helmet use is associated with engaging in risky behaviour”, inferring these results in the context of this paper hints at the fact that the usage of helmet may be interpreted both as a manifestation of low risk-taking tolerance levels while simultaneously as a tool to increase one’s perceived sense of safety.

The manifestation of the first hypothesis can be seen in a lot of bicycle-mature countries. For instance, in the Netherlands, only 0.5% reported to have been wearing their helmet [30], [31].

Cyclists “by default” feel very safe thanks to their immensely developed bicycle infrastructure and thus do not feel the need to protect themselves further.

However, despite finding that some of the some of the fields in the PSS and RT categories were statistically significant, the coefficient values determined by these relationships seem to be, for the bigger part, relatively weak. Although the analysis using the field reduction did not yield significant results in the context of the second hypothesis, looking closely at the respective primitive fields from the questionnaire did. Multiple predictors of risk taking tendencies were found to be significant predictors of helmet wearing outcomes, with the usage of reflexive apparel being the strongest one.

In addition, cyclists who feel like they ride faster than other cyclists they see seem to be wearing their helmet more often, possibly hinting at their realization of the potential risk exposure and effective measures needed to be taken. Cyclists who agree that it is acceptable to break rules in situations in which they are alone were found to be less likely to wear helmets, which is a finding that contradicts the second hypothesis. A possible explanation would be that these cyclists are less likely to obey the legal rules and give their subjective judgement greater value. This is in line with another statistically significant predictor – rule obeying difficulty. Cyclists who find obeying the rules of traffic difficult at times also seem to be less likely to use their helmet ($p = 0.004$).

Interestingly enough, looking at the distribution of helmet wearing in urban areas showed that respondents are split into two groups – avid wearers and avid non-wearers. These groups were approximately equal in size, and seem to follow an inverse normal distribution shape, as per Figure 1. The fact that no reducing nor custom model seemed to be able to predict the helmet wearing tendency hints that these two groups, albeit having the very opposite outcomes, do not differ significantly when it comes to trends in their self-reported perceived sense of safety nor risk taking tendencies. However, I was able to isolate a few variables (as per Table 1), such as the tendency to use reflexive equipment, subjective evaluation of whether one rides faster than the average cyclist or the preference to ride at the pavements as predictors of one's helmet wearing practices.

Several studies investigated PSS and RT in the context of urban cycling, but very few of them attempted to make the connection to HW. In [19], Graser et al. were looking at the biggest safety concerns of cyclists in Vienna. My findings are the same as theirs, as the cyclists' 4 biggest safety concerns identified in this paper were exactly the same as theirs: high traffic volumes (densities) and speeds, unclear or confusing intersections and cycling next to parked cars (full table can be found in the Appendix D). Thanks to the similar architecture of the questionnaires, a lot of comparison can be done between cyclists' attitudes in Vienna and Bratislava; this is, however, not the primary concern of this study. [18] similarly investigated the role of the road attributes on subjective feelings of safety and came to the same conclusions (see Appendix D) regarding the safest and the most dangerous attributes – physically separated cycling facilities and situations with high traffic speed and/or density, respectively.

A research among regular cyclists in Norway [17] found that "cyclists' risk-taking behaviour was influenced by their attitudes and risk perception", findings that are in line with my results.

Kummeneje and Rundmo conclude that “attitudes were more important for violation of traffic rules, while risk perception was more important for conflicts when cycling” and “cyclists’ risk perception was significantly related to conflicts with other road users when cycling”. Building on the established positive relationship between PSS & RT and a negative one between PSS & HW, assuming their observed relationships are true, it follows that cyclists with greater perception of safety are more likely to engage in riskier manoeuvres. However, as I showed in this paper, greater PSS seems to be a significant inverse predictor for helmet wearing outcomes. Thus, as cyclists feel safer, the likelihood of them wearing their helmet decreases while simultaneously exposing themselves to a greater risk of conflict with other road users, empirically hinting at a net increase in the accident exposure. This conclusion provides evidence in the support of RCT, albeit not a significant one, as mostly single variables needed to be isolated in order to be considered statistically significant as predictors of helmet wearing in urban areas.

While it is clear that certain relationships from the interplay of PSS, RT and HW can be derived, a further long-term research that preferably combines both quantitative and qualitative methods is advised to better understand cyclists’ helmet wearing outcomes in the context of risk compensation theory.

5. Limitations

When evaluating these results and linking them back to the ongoing academic debate about the risk compensation theory, it is important to keep the following limitations in mind.

5.1 Local context and culture

This study speculates that, locally, while using the bicycle as a means of transport is encouraged by the city council (expansion of bike-sharing systems, building new cycling lanes, medialization), it is generally still perceived to be rather dangerous. The modus operandi, especially among the non-cycling populace, is that all cyclists should always wear a helmet. In fact, cyclists were legally bound to wear a helmet until the end of 2019, making Slovakia “one of the last countries in the world to have such a policy” – albeit studies from as early as 2004 demonstrate that enforcing the usage of helmets by law does not only *not contribute* to the overall safety of cyclists, but may harm it due to the “safety in numbers” principle [32], [33], [34]. Therefore this perception, combined with the apparent lack of cycling infrastructure, contributes negatively to the mean perception of bicyclists’ safety across the entire spectrum of both cyclists and non-cyclists, potentially influencing the participants’ responses.

5.2 Bias and ambiguity

Finally, it seems that the majority of previous works utilized more exact, scientific methods of research, such as an instrumented bicycle gathering proximity data or HRV monitors [13], [15]. While a similar quantitative, empirical method of research was used in [17] or [19], it potentially introduces a certain degree of ambiguity and bias, especially given the fact that, possibly, subconscious primal systems are being investigated – as Karpen, PhD. concludes: “psychological mechanisms that underlie bias self-assessment occur below awareness, strategies that attempt to address bias directly are unlikely to succeed” [35].

6. Implications

Rising popularity of bicycles as the means of transportation in cities, currently amplified by the pandemic situation, reopened the debate about cyclists’ safety. The ongoing academic debate regarding risk compensation theory as a possible explanation for an increasing rate of injuries even with increasing rates of helmet wearing has not yet reached a consensus. While the current literature leans towards the rejection of the risk compensation hypothesis [16], scholars continue to encourage further research regarding this very issue [11], [16], [17]. This study shed a light on the association between perceived sense of safety, risk taking tendencies and helmet wearing outcomes among cyclists in urban environments. It was found that cyclists with higher levels of self-reported subjective perception of safety will be less likely to wear a helmet. Moreover, multiple risk-taking indicators, such as the relative perception of one’s fastness or subjective difficulty of obeying rules of traffic seem to hint at one’s helmet wearing practices too. Combining my findings with [17] yields evidence in favor of the risk compensation theory; albeit, due to the limitations proposed, not a strong one. In order to macroscopically increase perceived sense of safety among all cyclists, the primary goal of administrations should be to invest in physically separated bicycle infrastructure, which was proven to provide the biggest net safety benefit [34]. Meanwhile, it is important to challenge the current status quo regarding helmet usage and continue in the ongoing academic debate. Thus, while showing the impacts of

PSS and RT on helmet wearing outcomes, further research is advised in establishing connections between cyclists’ PSS, RT, and HW by considering alternative research methodologies – either population-surveying based quantitative, scientifically exact qualitative, or a combination thereof.

References

[1] E. Fishman, “Cycling as transport,” *Transport Reviews*, vol. 36, no. 1, pp. 1–8, Dec. 2015, doi: 10.1080/01441647.2015.1114271.

[2] C. Celis-Morales and J. Gill, “Cycling to work: major new study suggests health benefits are staggering,” *The Conversation*, Apr. 17, 2017. https://theconversation.com/cycling-to-work-major-new-study-suggests-health-benefits-are-staggering-76292 (accessed Apr. 20, 2021).

[3] U. of Toronto, F. Facebook, and T. Twitter, “New Study Shows Urban Cycling Is Faster Than Driving,” *Treehugger*, Oct. 11, 2018. https://www.treehugger.com/new-study-shows-urban-cycling-is-faster-than-driving-4856565 (accessed Apr. 20, 2021).

[4] Deloitte Insights, “Technology, Media, and Telecommunications Predictions 2020,.” [Online]. Available: https://www2.deloitte.com/content/dam/insights/us/articles/722835_tmt-predictions-2020/DI_TMT-Prediction-2020.pdf.

[5] P. Oja *et al.*, “Health benefits of cycling: A systematic review,” *Scandinavian journal of medicine & science in sports*, vol. 21, pp. 496–509, Apr. 2011, doi: 10.1111/j.1600-0838.2011.01299.x.

[6] Kate Vandy, “Coronavirus: How pandemic sparked European cycling revolution,” *BBC News*, Oct. 02, 2020.

[7] F. Küster, “Academic research on cycling is booming,” *ECF*, Nov. 30, 2017. https://ecf.com/news-and-events/news/academic-research-cycling-booming (accessed Apr. 20, 2021).

[8] R. S. Thompson, F. P. Rivara, and D. C. Thompson, “A Case-Control Study of the Effectiveness of Bicycle Safety Helmets,” *New England Journal of Medicine*, vol. 320, no. 21, pp. 1361–1367, May 1989, doi: 10.1056/nejm198905253202101.

[9] J. Olivier and P. Creighton, “Bicycle injuries and helmet use: a systematic review and meta-analysis,” *International Journal of Epidemiology*, vol. 46, no. 1, p. dyw153, Jul. 2016, doi: 10.1093/ije/dyw153.

[10] J. E. Barnes, “A Bicycling Mystery: Head Injuries Piling Up,” *The New York Times*, Jul. 29, 2001.

[11] C. Clarke, “(PDF) Effects of bicycle helmet wearing on accident and injury rates,” *ResearchGate*, Nov. 2019. https://www.researchgate.net/publication/337367329_Effects_of_bicycle_helmet_wearing_on_accident_and_injury_rates.

[12] D. C. Thompson, “Risk compensation theory should be subject to systematic reviews of the scientific evidence * The risk compensation theory and bicycle helmets,” *Injury Prevention*, vol. 8, no. 2, pp. 1e1, Jun. 2002, doi: 10.1136/ip.8.2.e1.

[13] R. O. Phillips, A. Fyhri, and F. Sagberg, “Risk Compensation and Bicycle Helmets,” *Risk Analysis*, vol. 31, no. 8, pp. 1187–1195, Mar. 2011, doi: 10.1111/j.1539-6924.2011.01589.x.

[14] T. Gamble and I. Walker, “Wearing a Bicycle Helmet Can Increase Risk Taking and Sensation Seeking in Adults,” *Psychological Science*, vol. 27, no. 2, pp. 289–294, Jan. 2016, doi: 10.1177/0956797615620784.

[15] I. Walker, “Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender,” *Accident Analysis & Prevention*, vol. 39, no. 2, pp. 417–425, Mar. 2007, doi: 10.1016/j.aap.2006.08.010.

[16] M. Esmaeilikia, I. Radun, R. Grzebieta, and J. Olivier, “Bicycle helmets and risky behaviour: A systematic review,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 60, pp. 299–310, Jan. 2019, doi: 10.1016/j.trf.2018.10.026.

[17] A.-M. Kummeneje and T. Rundmo, “Attitudes, risk perception and risk-taking behaviour among regular cyclists in Norway,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 69, pp. 135–150, Feb. 2020, doi: 10.1016/j.trf.2020.01.007.

[18] S. Balogh, “Perceived safety of cyclists The role of road attributes SAMU MÁRTON BALOGH KTH ROYAL INSTITUTE OF TECHNOLOGY SCHOOL OF ARCHITECTURE AND THE BUILT ENVIRONMENT,” 2017. Accessed: Apr. 20, 2021. [Online]. Available: https://www.diva-portal.org/smash/get/diva2:1143808/FULLTEXT01.pdf?platform=hootsuite.

[19] A. Graser, M. Aleksa, M. Straub, P. Saleh, S. Wittmann, and G. Lenz, “Safety of urban cycling: A study on perceived and actual dangers,” Apr. 2014.

[20] BUREAU OF EDUCATIONAL AND CULTURAL AFFAIRS, “TIPS FOR DEVELOPING SURVEY INSTRUMENTS/QUESTIONNAIRES,.” Accessed: Apr. 20, 2021. [Online]. Available: https://eca.state.gov/files/bureau/eca_survey_best_practices.pdf.

[21] J. Pimentel, “A note on the usage of Likert Scaling for research data analysis,” vol. 18, pp. 109–112, Dec. 2010.

[22] R. Chomeya, “Quality of psychology test between likert scale 5 and 6 points,” *Journal of Social Sciences*, vol. 6, Jan. 2010.

[23] J. Dollisson, W. Cox, and Z. Zheng, “Comparison of Motorists’ and Cyclists’ perception of bicycle safety,” Oct. 2013. Accessed: Apr. 20, 2021. [Online]. Available: http://www.connectedandautonomoustransport.com/uploads/2/5/2/6/25268286/safety_perceptions_on_cycling_weebly.pdf.

[24] “Magistrátu sa nepáči kritika Cyklokoalície, ktorá ho prirovnáva k brzde,” *www.bakurier.sk*, Apr. 12, 2017. https://www.bakurier.sk/sekcie/cyklodoprava-1/clanok-magistratu-sa-nepaci-kritika-cyklokoalicie-ktora-ho-prirovnava-k-brzde (accessed Apr. 20, 2021).

[25] W. McKinney, “Data structures for statistical computing in python,” in *Austin, TX*, 2010, vol. 445, pp. 51–56.

[26] M. Waskom *et al.*, “mwaskom/seaborn: v0.8.1 (September 2017),” Sep. 2017, doi: 10.5281/zenodo.883859.

[27] F. Pedregosa *et al.*, “Scikit-learn: Machine learning in python,” *Journal of machine learning research*, vol. 12, Art. no. Oct, 2011.

[28] H. Zou and T. Hastie, “Addendum: Regularization and variable selection via the elastic net,” *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, vol. 67, no. 5, pp. 768–768, Nov. 2005, doi: 10.1111/j.1467-9868.2005.00527.x.

[29] A. Manikutty and D. Mahendran, “Which Came First -- the Chicken or the Egg?,” *papers.ssrn.com*, Feb. 07, 2015. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2562098 (accessed Apr. 21, 2021).

[30] Statista Research Department, “Topic: Bicycle usage in the Netherlands,” *Statista*, Nov. 24, 2020. https://www.statista.com/topics/7230/bicycle-usage-in-the-netherlands/ (accessed Apr. 21, 2021).

[31] BICYCLE HELMET RESEARCH FOUNDATION, “Why are Dutch cyclists more likely to be injured if they wear helmets?,” *www.cyclehelmets.org*. https://www.cyclehelmets.org/1261.html#:~:text=they%20wear%20helmets%3F-.

[32] M. Sarvaš, “Prilbu nemusíte mať na hlave už ani mimo obce a e-kolobežky musia preč z chodníkov, hovorí nový cestný zákon,” *Biker.sk*, Dec. 03, 2019. https://www.biker.sk/43142/prilbu-nemusite-mat-na-hlave-uz-ani-mimo-obce-a-e-kolobezky-musia-prec-z-chodnikov-hovori-novy-cestny-zakon/ (accessed Apr. 21, 2021).

[33] D. L. Robinson, “No clear evidence from countries that have enforced the wearing of helmets,” *BMJ : British Medical Journal*, vol. 332, no. 7543, pp. 722–725, Mar. 2006, Accessed: Apr. 21, 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1410838/.

[34] P. L. Jacobsen, “Safety in numbers: more walkers and bicyclists, safer walking and bicycling,” *Injury Prevention*, vol. 9, no. 3, pp. 205–209, Sep. 2003, doi: 10.1136/ip.9.3.205.

[35] S. C. Karpen, “Biased self-assessment: Causes, consequences, and countermeasures,” *American Journal of Pharmaceutical Education*, vol. 82, no. 5, p. ajpe6299, Nov. 2017, doi: 10.5688/ajpe6299.

[36] J. Pucher and R. Buehler, “Safer Cycling Through Improved Infrastructure,” *American Journal of Public Health*, vol. 106, no. 12, pp. 2089–2091, Dec. 2016, doi: 10.2105/ajph.2016.303507.

Appendix A: The questionnaire

Rows that have ‘x’ as a source have been created by me. For the explicit sources, please refer to the References.

Category	**Prompt [English]**	**Prompt [Slovak]**	**Responses**	**source**	**Variable name**
GI	Gender	Identifikujem sa ako	F/M/Other/Prefer not to say	x	gender
GI	Age	Vek	0-99	x	age
GI	City of residence	Mesto pobytu	Text Input	x	location
GI	Highest Degree of Education obtained	Najvyšší dosiahnutý level vzdelania	Not finished high school yet/High school diploma/Bachelor's degree/ Master’s degree/Doctorate	x	education
GI	What purpose do you usually ride for?	Bicykel používam najčastejšie na	Recreation/Exercise/Transport/Competitive/Work (bike courier or similar)	[23]	bike_usage
GI	What environment do you usually ride in? /	Primárne jazdím v prostredí	Countryside or village / Urban or city / Can not evaluate	x	bike_env

GI	How often do you use your bicycle?	Bicykel používam	Less than once a month / 1 - 3 times a month / Once a week / 2-4 times a week / More than 4 times a week	[23]	bike_freq
GI	How many kilometers do you usually cycle per trip?	Priemerná dĺžka jednej mojej jazdy na bicykli je	OneOf<(1 / 1 - 3 / 3 - 5 / 5 - 10, 10 - 20, 20 - 30, 30 - 50, 50+)>	[23]	bike_trip_length
GI	What % of your usual route do you ride in a cycling lane?	Subjektívne odhadujem, že ___% mojej najazdenej vzdialenosti je na cyklotrasách.	NumberInput<(0-100)>	x	bike_lanes_estimate
	Cycling on / in …	**Jazdenie na …**			
PSS	roads with a lot of automobile traffic	cestách s vysokou hustotou automobilovej premávky	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_traffic_high_density
PSS	roads with high traffic speeds	cestách s vysokou rýchlosťou premávky	Likert (1 – perceived very dangerous, 5 – perceived very	[19]	pss_traffic_high_speed

			safe)		
PSS	roads with rail infrastructure /	cestách so železničnou infraštruktúrou (električkové trate alebo priecestia, napr. Špitálska či Radlinského v Bratislave)	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_rail_infra structure
PSS	roads with unclear/confusing intersections	cestách s nejasnými / mätúcimi križovatkami	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_confusing _xsections
PSS	poorly lit roads or in darkness	zle osvetlených cestách alebo v tme	Likert (1 – perceived very dangerous, 5 – perceived very safe)	x	pss_poorly_lit
PSS	cycling lanes painted on the road /	cyklistických pruhoch namaľovaných na ceste	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_road_bike _lanes
PSS	cycling lanes fully separated from the road and intended	cyklistických pruhoch	Likert (1 – perceived very dangerous, 5 –	x	pss_separate_ bike_lanes

	for the use of cyclists only / úplne oddelených od vozovky		perceived very safe)		
PSS	pavements and other lanes intended for pedestrians	chodníkoch a iných cestách určených pre chodcov	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_pavements
PSS	roads next to doorways / garage entrances	cestách vedľa vchodov, východov a garážach	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_entrances_exits
PSS	against the one-way street direction	proti smeru v jednosmernej ulici	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_one_way_street
PSS	bad road surface conditions	cestách so zlými povrchovými podmienkami	Likert (1 – perceived very dangerous, 5 – perceived very safe)	[19]	pss_poor_road_conditions
PSS	winter / snowing weather	zime (ročnom období) / snehu	Likert (1 – perceived very	x	pss_winter

			dangerous, 5 – perceived very safe)		
PSS	rainy weather and wet roads	mokrých cestách a daždivom počasí	Likert (1 – perceived very dangerous, 5 – perceived very safe)	x	pss_wet_roads
PSS	next to parked cars (with the possibility of them entering the road / opening their door)	popri zaparkovaných automobiloch (ktoré môžu nepredvídateľne vojsť do cesty / otvoriť dvere)	Likert (1 – perceived very dangerous, 5 – perceived very safe)	x	pss_parked_cars
RT	It is acceptable to break the rules as a cyclist when no others are involved.	Ako cyklista je prijateľné porušiť pravidlá, pokiaľ sa v situácii nenachádzajú žiadne iné osoby.	Likert (1 – disagree, 5 – agree)	[17]	rt_rule_breaking
RT	It is acceptable to cycle on red when no others are present.	Je prijateľné ísť na červenú, pokiaľ nikto iný nie je v situácii prítomný.	Likert (1 – disagree, 5 – agree)	[17]	rt_red_light_run

RT	It is acceptable to take chances as a cyclist when only you are exposed to risk.	Je prijateľné na bicykli riskovať, pokiaľ ste riziku vystavení iba vy.	Likert (1 – disagree, 5 – agree)	[17]	rt_risk_taking_alone
RT	Breaking rules does not necessarily make you a less safe cyclist compared with those who always follow the rules.	Porušením pravidiel cestnej premávky sa nutne nestávam menej bezpečným cyklistom v porovnaní s tými, ktorí pravidlá vždy dodržiavajú.	Likert (1 – disagree, 5 – agree)	[17]	rt_rule_breaking_relative_risk
RT	It is acceptable to cycle after drinking alcohol (<0.5‰)	Je prijateľné bicyklovať po miernom užití alkoholu (<0.5‰).	Likert (1 – disagree, 5 – agree)	[17]	rt_alcohol
RT	Many traffic rules for cyclists are impossible to comply with	Z pohľadu cyklistov, mnoho dopravných pravidiel nie je možné dodržať.	Likert (1 – disagree, 5 – agree)	[17]	rt_rule_obeying_difficulty
RT	I do choose to use a front light anytime it’s needed	Na bicykli používam predné svetlo vždy, keď je to potrebné.	Likert (1 – disagree, 5 – agree)	x	rt_front_light

RT	I do choose to use a backlight anytime it's needed	Na bicykli používam zadné svetlo vždy, je to potrebné.	Likert (1 – disagree, 5 – agree)	x	rt_back_light
RT	I do choose to wear reflective clothing when cycling.	Počas jazdy na bicykli nosím reflexné oblečenie / oblečenie s reflexnými prvkami.	Likert (1 – disagree, 5 – agree)	x	rt_reflexive_apparell
RT	I do tend to switch from cycling on the road to cycling on the pavement when possible.	Pokiaľ je to možné, pri bicyklovaní prejdem z automobilovej cesty na chodník / medzi chodcov.	Likert (1 – disagree, 5 – agree)	x	rt_road_to_pavement_switch
RT	I do tend to switch from cycling on the pavement to cycling on the road when possible.	Pokiaľ je to možné, pri bicyklovaní prejdem z chodníku na automobilovú cestu.	Likert (1 – disagree, 5 – agree)	x	rt_pavement_to_road_switch
RT	I feel like I ride faster than other cyclists I usually see.	Mám pocit, že jazdím rýchlejšie ako ostatní cyklisti, ktorých zvyčajne vidím.	Likert (1 – disagree, 5 – agree)		rt_subjective_faster_riding
RT	I feel like I ride safer than other	Mám pocit, že jazdím bezpečnejšie ako	Likert (1 – disagree, 5 – agree)		rt_subjective_safer_riding

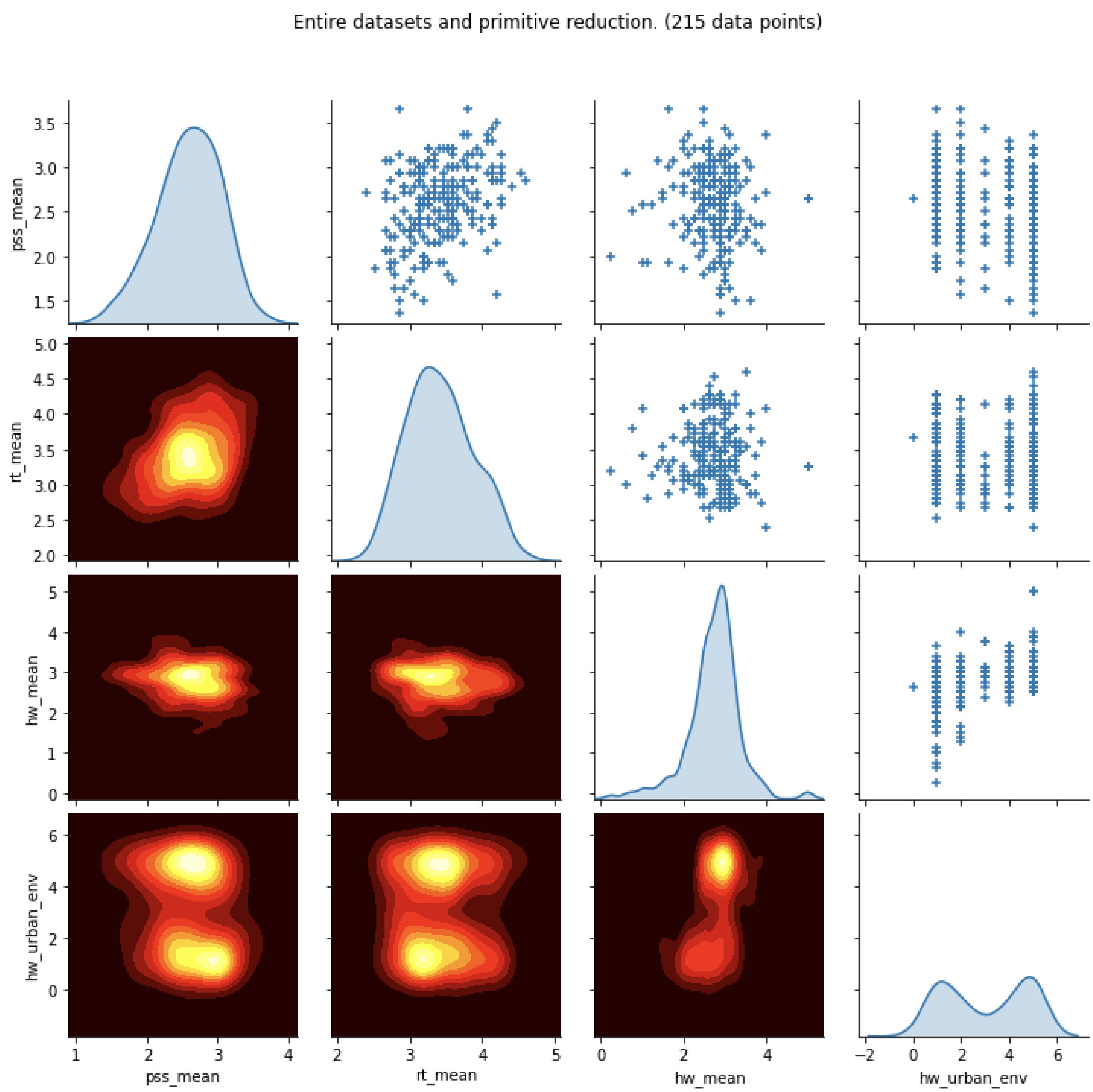
	cyclists I usually see.	ostatní cyklisti, ktorých zvyčajne vidím.			
RT	I do tend to use hand signals when making turns.	V zákrutách a pri odbočovaní zvyknem používať ručné signály.	Likert (1 – disagree, 5 – agree)		rt_hand_signals
HW	I do tend to wear a helmet when I ride in urban environments.	Pri jazdení v mestskom prostredí zvyknem mať helmu.	Likert (1 – disagree, 5 – agree)	x	hw_urban_env
HW	(if applicable) I do tend to wear a helmet when I ride outside urban environments.	(ak relevantné) Pri jazdení v mimomestskom prostredí zvyknem mať helmu.	Likert (1 – disagree, 5 – agree)	x	hw_rural_env
HW	I find my helmet comfortable.	Moja helma mi príde pohodlná.	Likert (1 – disagree, 5 – agree)	x	hw_comfort
HW	I invested, relatively to my means, a lot into my helmet.	Relatívne k mojim finančným možnostiam, do svojej helmy som investoval veľa.	Likert (1 – disagree, 5 – agree)	x	hw_financial_investment
HW	I do not wear a helmet for practical reasons.	Helmu nenosím z praktických dôvodov. (napr. je to ďalšia vec, ktorú treba strážiť,	Likert (1 – disagree, 5 – agree)	x	hw_practical_reasons

		nezmestí sa mi do batohu či tašky, musel/a by som ju nosiť v ruke a pod.)			
HW	I do not wear a helmet for comfort reasons.	Helmu nenosím z dôvodu nepohodlia a nepríjemnosti používania. (napr. nesedí mi na hlave, škrabe ma, je mi príliš veľká / malá a pod.)	Likert (1 – disagree, 5 – agree)	x	hw_comfort_reasons
HW	I do not wear a helmet for aesthetic / visual reasons.	Helmu nenosím z estetických / vizuálnych dôvodov.	Likert (1 – disagree, 5 – agree)	x	hw_aesthetic
HW	Bad weather conditions (e.g. intensive snow, rain or cold) influence me to such an extent that I decide to take my helmet when I otherwise wouldn't /	Počasie má vplyv na to, či nosím helmu.	Likert (1 – disagree, 5 – agree)	x	hw_weather_influence

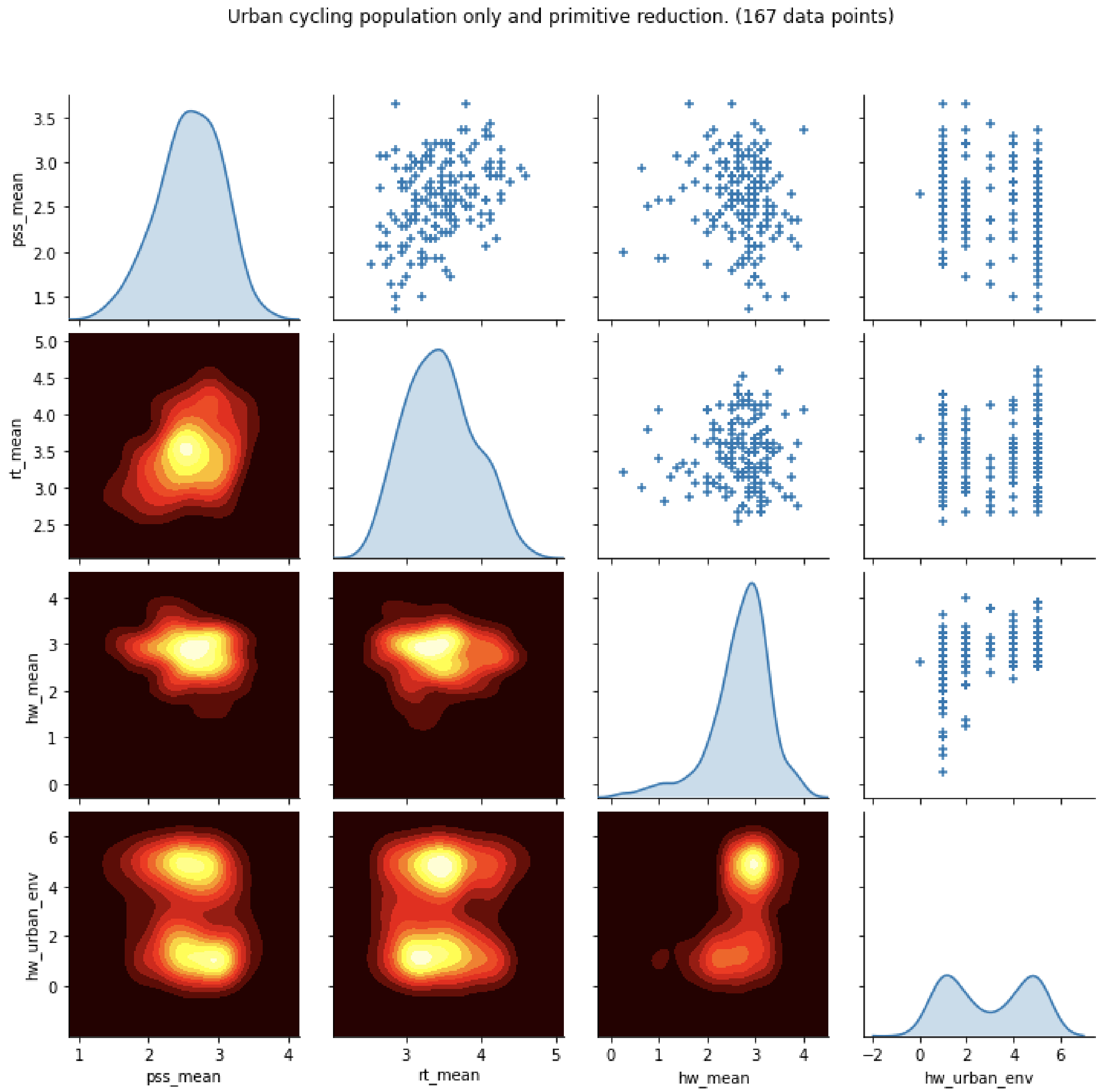
Appendix B: Custom models.

Category	**Custom model name**	**Variables included**
PSS	pss_traffic	pss_traffic_high_density, pss_traffic_high_speed
PSS	pss_conditions	pss_poor_road_conditions, pss_winter,pss_wet_roads
PSS	pss_dangerous	pss_traffic_high_density, pss_traffic_high_speed, pss_rail_infrastructure, pss_confusing_xsections, pss_poorly_lit, pss_entrances_exits, pss_one_way_street, pss_parked_cars
RT	rt_reckless	rt_rule_breaking, rt_red_light_run, rt_risk_taking_alone
RT	rt_reckless	rt_red_light_run, rt_alcohol
RT	rt_prefers_road	rt_prefers_road, rt_pavement_to_road_switch
RT	rt_perceived_faster	rt_subjective_faster_riding
RT	rt_perceived_safer	rt_subjective_safer_riding
RT	rt_equipment	rt_front_light, rt_back_light
HW	hw_urban	hw_urban_env

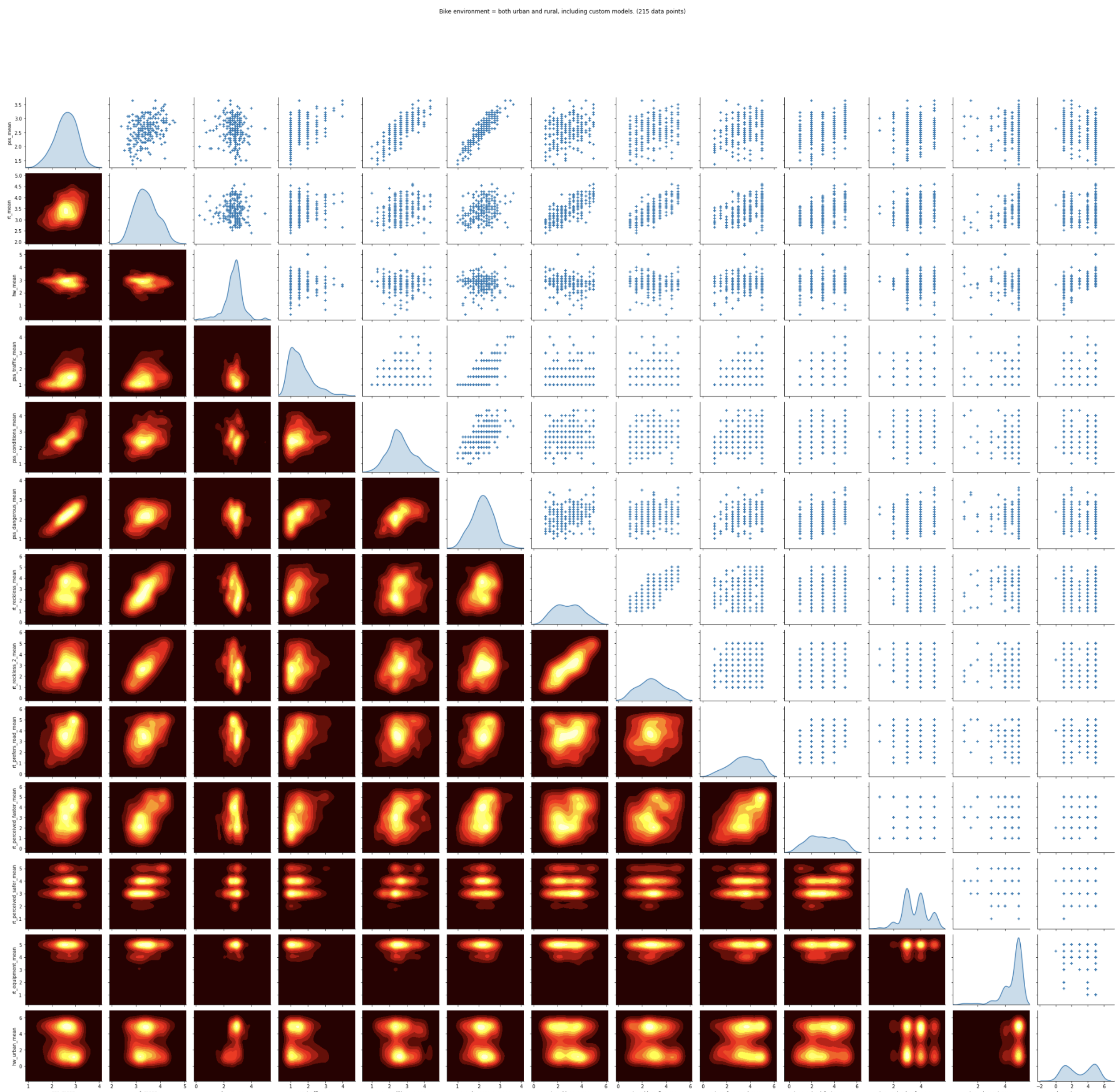
Appendix C: Plots.



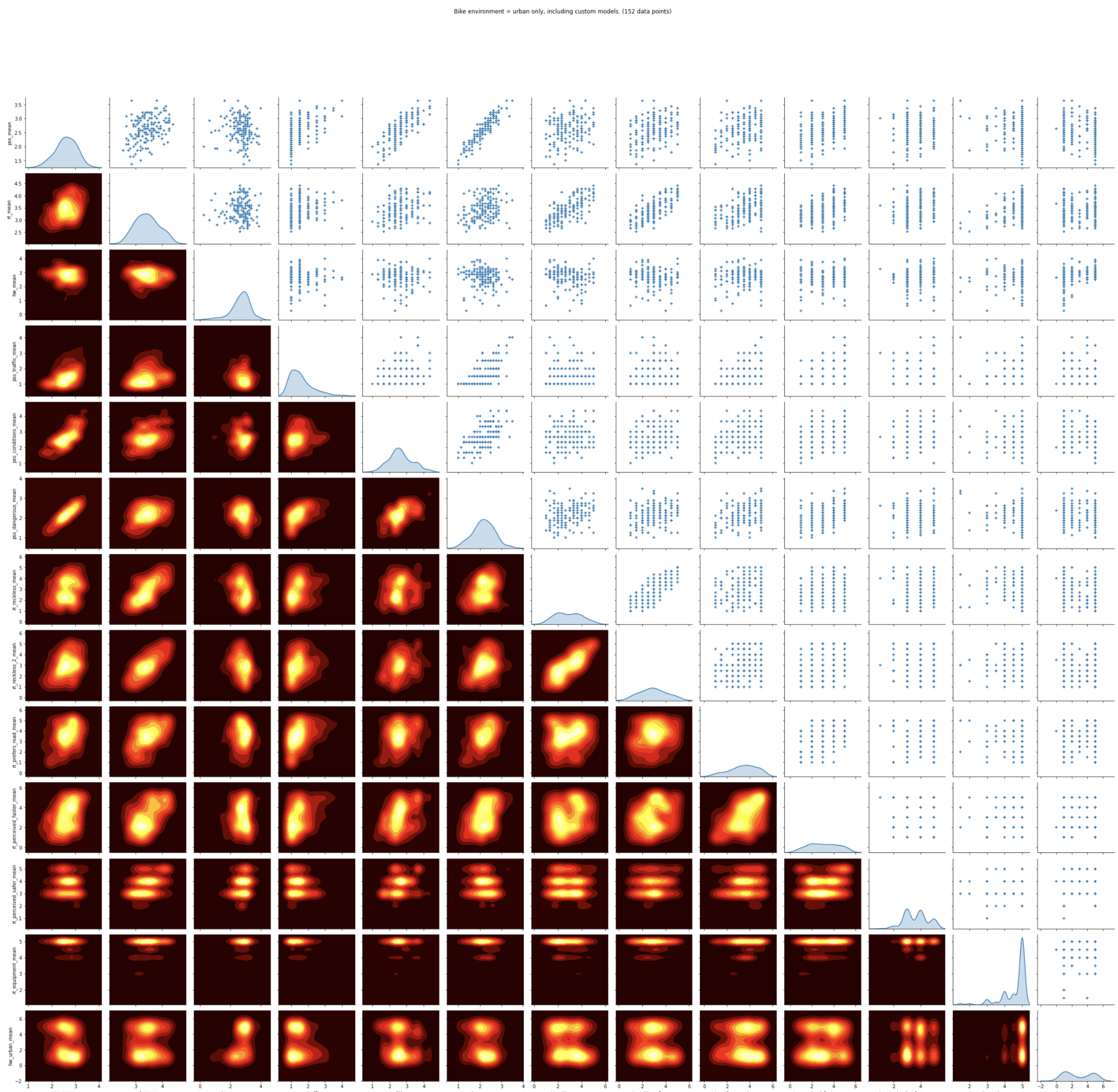
Pair grid of primitive reductions for the entire dataset only.



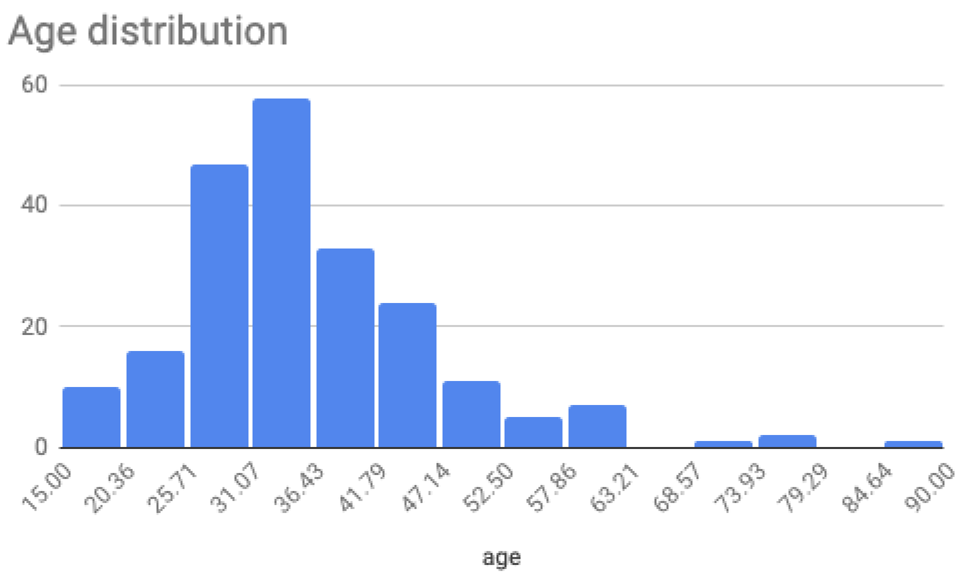
Pair grid of primitive reductions for the urban cycling population only.

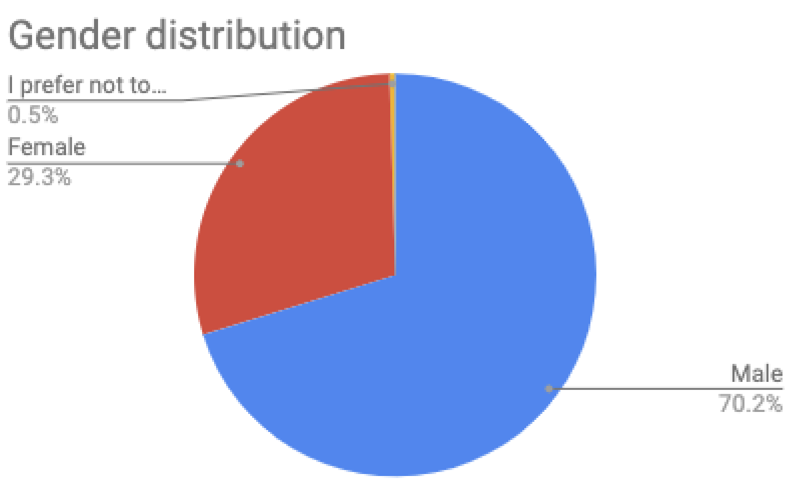


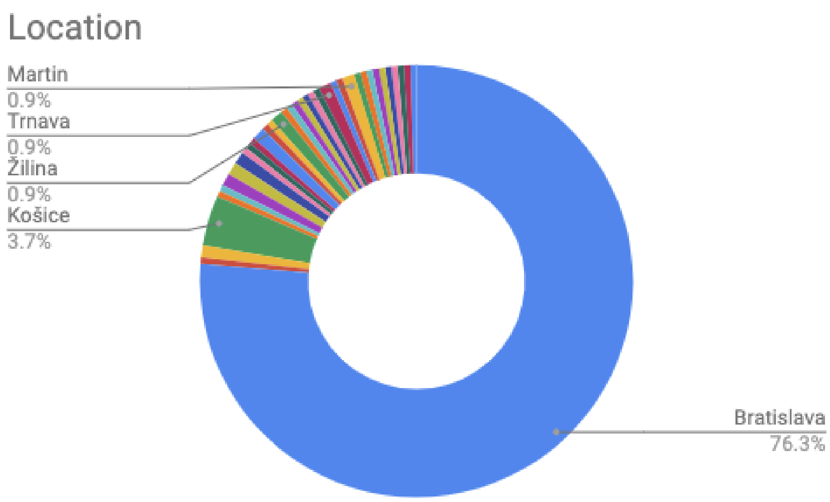
Pair grid of all custom models for the entire dataset. The relevant part is the very last row – hw_urban_env. This row is also shown in 3.2 Custom models.

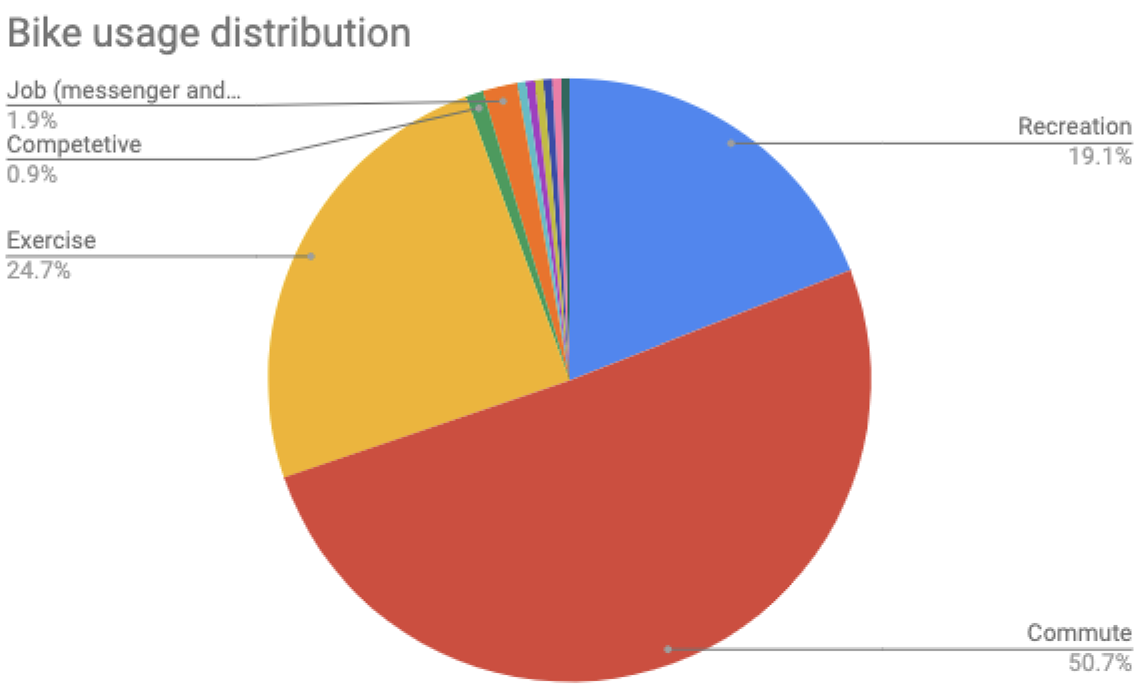


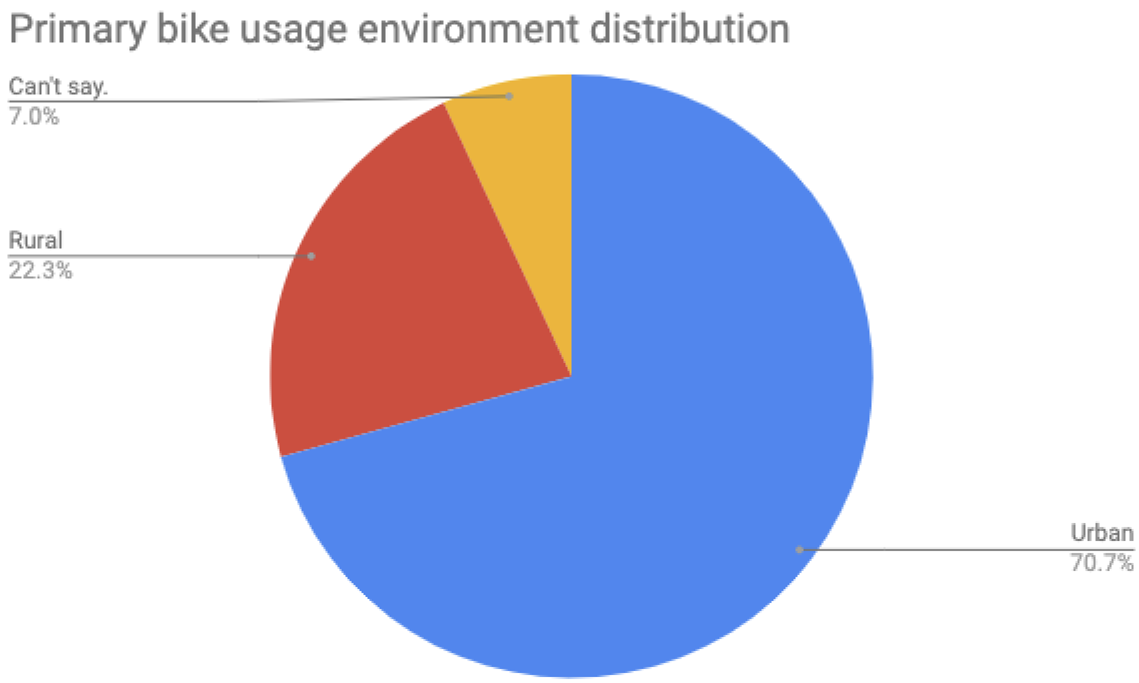
Pair grid of all custom models for the urban cyclists only. The relevant part is the very last row – hw_urban_env.

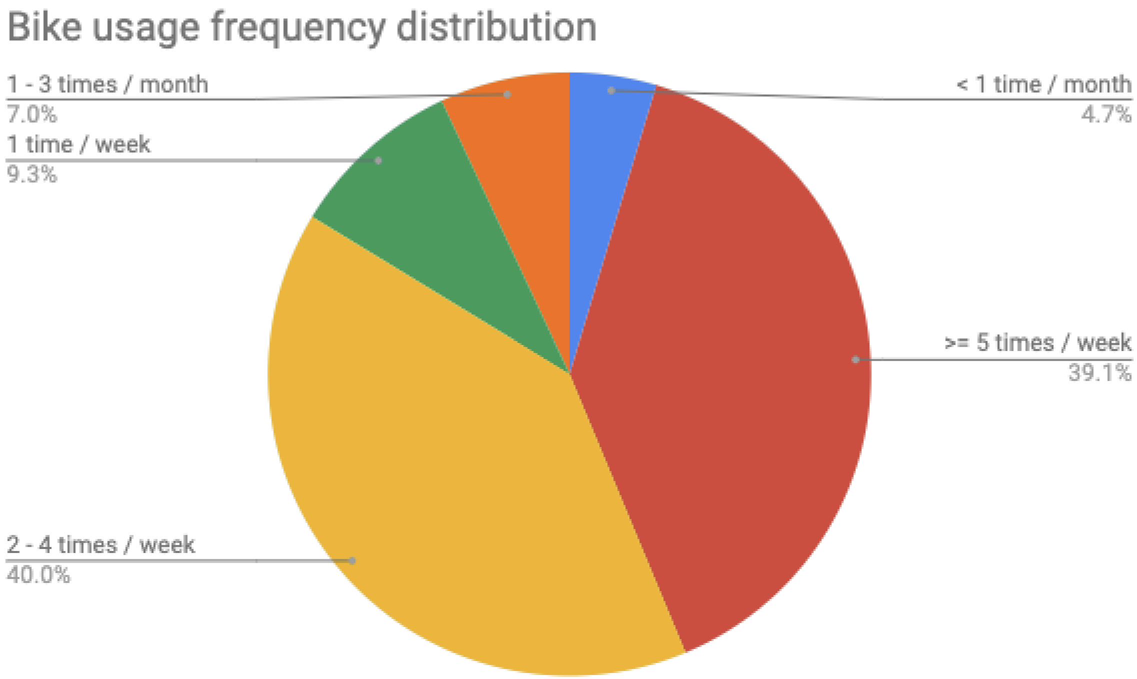

Age distribution
60
40
20
0
15.00
20.36
25.71
31.07
36.43
41.79
47.14
52.50
57.86
63.21
68.57
73.93
79.29
84.64
90.00
age

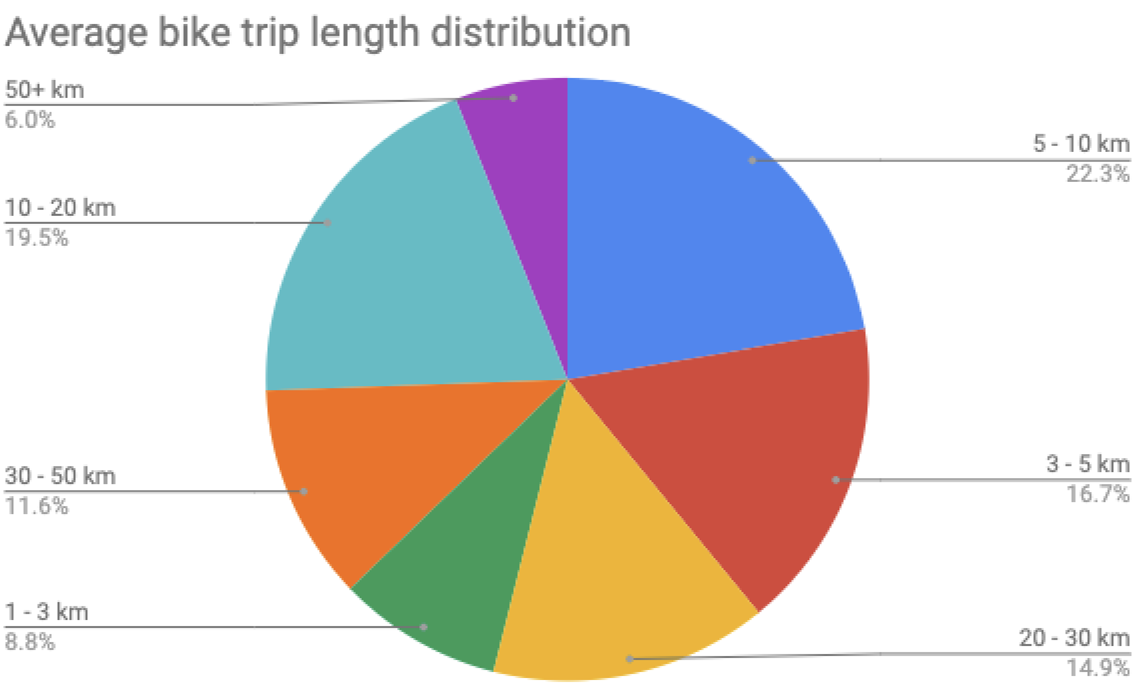

Gender distribution
I prefer not to...
0.5%
Female
29.3%
Male
70.2%

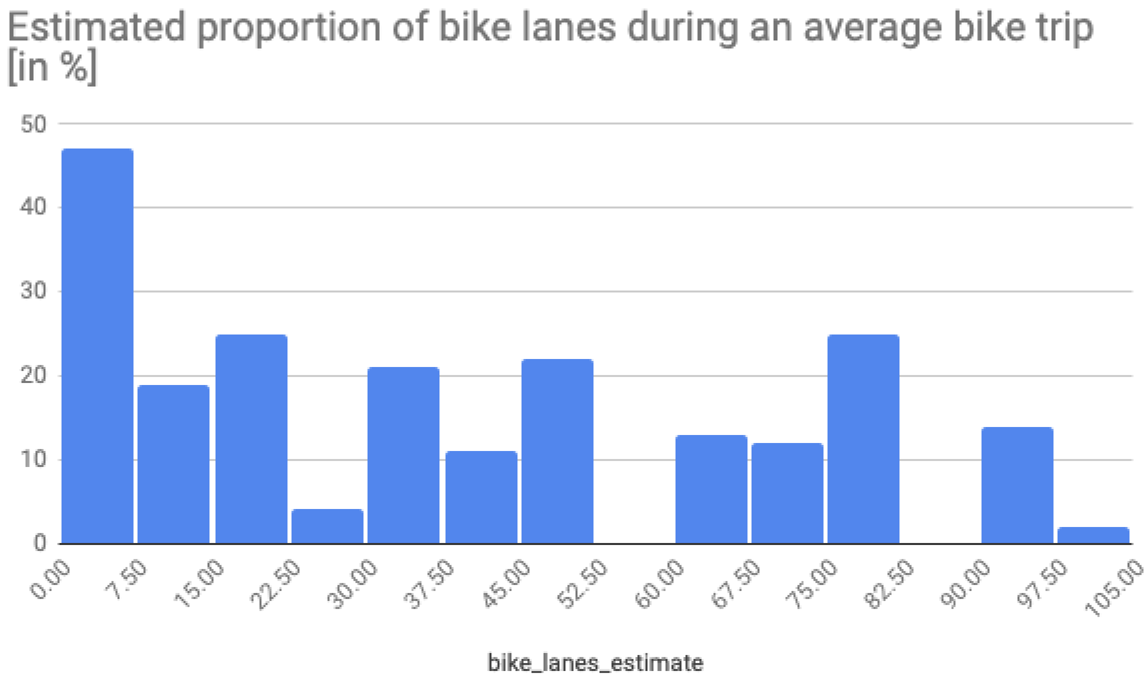

Location
Martin
0.9%
Trnava
0.9%
Žilina
0.9%
Košice
3.7%
Bratislava
76.3%


Bike usage distribution
Job (messenger and...
1.9%
Competetive
0.9%
Exercise
24.7%
Recreation
19.1%
Commute
50.7%


Primary bike usage environment distribution
Can't say.
7.0%
Rural
22.3%
Urban
70.7%


Bike usage frequency distribution
1 - 3 times / month
7.0%
1 time / week
9.3%
< 1 time / month
4.7%
>= 5 times / week
39.1%
2 - 4 times / week
40.0%


Average bike trip length distribution
50+ km
6.0%
10 - 20 km
19.5%
5 - 10 km
22.3%
30 - 50 km
11.6%
3 - 5 km
16.7%
1 - 3 km
8.8%
20 - 30 km
14.9%


Estimated proportion of bike lanes during an average bike trip [in %]
50
40
30
20
10
0
0.00
7.50
15.00
22.50
30.00
37.50
45.00
52.50
60.00
67.50
75.00
82.50
90.00
97.50
105.00
bike_lanes_estimate

Appendix D: Correlation of all primitive variables with hw_urban_env.

Variable	**R (entire dataset)**	**R (urban cyclists only)**
bike_lanes_estimate	0.11561	0.193853
pss_traffic_high_density	-0.042805	-0.055004
pss_traffic_high_speed	-0.024548	-0.039362
pss_rail_infrastructure	-0.025479	-0.041946
pss_confusing_xsections	-0.048532	-0.052937
pss_poorly_lit	-0.003823	-0.013578
pss_road_bike_lanes	-0.110345	-0.082042
pss_separate_bike_lanes	-0.162811	-0.135027
pss_pavements	-0.248779	-0.228666
pss_entrances_exits	-0.074469	-0.079836
pss_one_way_street	-0.201857	-0.196298
pss_poor_road_conditions	-0.029017	-0.082054
pss_winter	-0.083894	-0.095528
pss_wet_roads	-0.188544	-0.22704
pss_parked_cars	-0.068214	-0.109963
rt_rule_breaking	-0.187334	-0.160709
rt_red_light_run	-0.104363	-0.087199
rt_risk_taking_alone	-0.086135	-0.072463
rt_rule_breaking_relative_risk	-0.150911	-0.106505
rt_alcohol	-0.116588	-0.02102
rt_rule_obeying_difficulty	-0.194975	-0.153687

rt_front_light	-0.006086	0.075092
rt_back_light	0.089611	0.181986
rt_reflexive_apparell	0.575861	0.60264
rt_road_to_pavement_switch	-0.036691	-0.047155
rt_pavement_to_road_switch	0.017569	-0.018999
rt_prefers_road	0.022338	0.02528
rt_subjective_faster_riding	0.139776	0.102533
rt_subjective_safer_riding	0.037864	0.039701
rt_hand_signals	0.10894	0.079011
hw_urban_env	1	1
hw_rural_env	0.666378	0.698568
hw_comfort	0.643048	0.652779
hw_financial_investment	0.414054	0.402111
hw_practical_reasons	-0.478188	-0.509872
hw_comfort_reasons	-0.544498	-0.589738
hw_aesthetic	-0.360203	-0.42013
hw_weather_influence	-0.133566	-0.158151

Appendix E: PSS variables means and medians, ordered by mean (entire dataset)

Variable	**mean**	**median**
pss_traffic_high_speed	1.367442	1
pss_traffic_high_density	1.8	2
pss_confusing_xsections	1.888372	2

pss_parked_cars	2.04186	2
pss_poorly_lit	2.125581	2
pss_poor_road_conditions	2.35814	2
pss_rail_infrastructure	2.465116	2
pss_entrances_exits	2.590698	3
pss_winter	2.618605	3
pss_wet_roads	2.981395	3
pss_road_bike_lanes	3.069767	3
pss_one_way_street	3.106977	3
pss_pavements	3.274419	3
pss_separate_bike_lanes	4.613953	5

RT variables means and medians, ordered by median (entire dataset).

Variable	**mean**	**median**
rt_risk_taking_alone	2.567442	2
rt_red_light_run	2.655814	2
rt_road_to_pavement_switch	2.823256	3
rt_rule_breaking_relative_risk	2.911628	3
rt_subjective_faster_riding	3.083721	3
rt_alcohol	3.125581	3
rt_rule_obeying_difficulty	3.227907	3
rt_reflexive_apparell	3.24186	3
rt_prefers_road	3.339535	4

rt_rule_breaking	3.451163	4
rt_subjective_safer_riding	3.6	4
rt_pavement_to_road_switch	3.623256	4
rt_front_light	4.497674	5
rt_hand_signals	4.572093	5
rt_back_light	4.623256	5

Reasons for not wearing a helmet, ordered by median (entire dataset).

Variable	**mean**	**median**
hw_aesthetic	2.032558	1
hw_weather_influence	1.851163	1
hw_comfort_reasons	2.330233	2
hw_financial_investment	2.590698	3
hw_practical_reasons	2.8	3
hw_comfort	3.581395	4

Appendix E: Custom analysis code

https://github.com/4b1dden/ap-research-2021/blob/main/source_code_for_paper.py