

Emotion Sensing for (E-)Bicycle Safety and Mobility Comfort

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Abstract: The “Emotion Sensing for (E-)Bicycle Safety and Mobility Comfort” approach, in short, “ESSEM”, funded by the mFUND program of the Federal Ministry of Digital Affairs and Transport (BMDV), investigates the subjective safety perception of cyclists in urban traffic. Identifying Moments of Stress in the bicycle network in Ludwigsburg and Osnabrück is done by collecting biophysiological data using sensor technologies and surveys. Besides developing a practical tool for evaluating bicycle infrastructures with emotion-sensing data, bicycle components are designed and assessed within the project.

Keywords: Urban planning, cycling planning, emotion sensing, EmoCycling

1 Introduction

Commuting to work or school, travelling to leisure activities, and in everyday life – mobility shapes our social lives and thus reflects individual needs. As an alternative to private cars and as a supplement to public transport and walking, bicycle mobility is becoming increasingly relevant. Due to the Covid pandemic and the rising development of pedelecs, the bicycle is taking on a key role in mobility, especially in urban traffic. Furthermore, cycling is environmentally friendly and can improve personal well-being and health. These arguments for bicycle use are still not reflected in the modal split of many cities. One reason that restricts widespread bicycle use is the limited subjective perception of safety. Factors such as travel time, costs, and mode choice also depend on the perceived safety of the mobility form. The “National Cycling Plan 2020” states that cyclists who feel particularly unsafe also cycle less often (BMDV 2022). In urban planning, the difficulty in identifying stress-triggering and dangerous spatial situations, such as critical intersections and forms of guidance, often exists. While infrastructure improvements are implemented based on statistically relevant road crash hotspots, so-called near misses are often unrecognized. These events are not included in accident statistics, preventing undecided cyclists from using bicycles.

Mobility design develops people-friendly mobility that should enable a smooth and safe transition from one form of mobility to another. Accordingly, using different individual, shared, or public transport modes on one route – the intermodal transport chains – should be comfortable and easily provide people with a positive mobility experience (ECKART & VÖCKLER 2021). The (e-)bicycle plays a key element here on the “last mile.” Research in the context of design and bicycle traffic identifies design elements such as materials, water, green spaces, and markings, but also guidance systems or icons in projects that can increase subjective safety (ALBRECHT & ECKART 2020). In addition, detecting stress points within the city can help identify issues of planning deficits, reflect the infrastructures on site, and upgrade them according to new design findings.

2 State of Research

2.1 Objective and Subjective Safety Perception of Cyclists

In general, bicycle safety comprises objective and subjective dimensions and their correlation (JOHANNSEN 2013). Objective safety describes a quantitative view of road crashes. The basis for this is the publication of police road crash reports. Subjective safety, on the other hand, is an emotional view of the threat posed by a traffic situation by the road users themselves (FULLER 2005). Critical conditions, near misses, or obstructions in traffic primarily influence this subjective perception of safety among cyclists. Cycling experts, therefore, consider the “reduction of stress” in cycling as an essential factor for increasing the modal share of cycling (GRAF 2016). In everyday life, cyclists use bicycles as their primary means of transportation only if they feel safe while cycling. This circumstance significantly affects people who are non-users or occasional users of bicycles. Individual mobility behavior thus depends not only on structural or interactive factors but also on “exogenous” factors. The effect of exogenous influencing factors also varies depending on personal characteristics. These include gender, age, mobility profile (people with or without disabilities), trip purposes, habit (means of transport, local knowledge), and psychological dispositions (SCHMIDT-HAMBURGER 2022).

2.2 Classification into Cycling Types

Table 1: Characteristics of the cycling groups according to GELLER (2009) & GRAF (2016)

Cycling types	The strong and fearless (Fearless cyclists)	The enthusiastic and sovereign (Everyday cyclists)	The interested but concerned (Interested Cyclists)	No chance, no matter how!
Characteristics	Uses bicycle always, safe and confident	Drives daily routes, confident but medium safety needs	No everyday mobility by bicycle; concerned about safety but open to bicycle	As a rule, no bicycle use
Driving skills	Excellent control of the bicycle	Confident, partly defensive because of safety	Less confident	Insufficient control over the bicycle, lack of riding experience
Stress tolerance	High	Medium	Low	Very Low

It seems evident that the subjective safety perception in road traffic can vary between people due to individual characteristics and circumstances. One way to compare the subjective safety perception is by categorizing cyclists into previously defined cyclist types. Besides other models for distinguishing cyclist types, Geller's categorization allows four groups to be distinguished based on their cycling behavior (GELLER 2009). The ESSEM project uses this approach as a basis. The affiliation to a group can change dynamically – depending on changes in mobility behavior and personal situation – and is not assignable for some individuals. Nevertheless, the classification into Geller's four groups provides a basis for analyzing the abilities, desires, and needs of different cyclist types.

On the one hand, regarding cycling promotion, and thus also for the ESSEM project, the focus is on the “Interested Cyclists” group. These people are generally open to cycling but are concerned about their safety and therefore do not yet use the bicycle for their daily trips. On the other hand, the groups “Fearless Cyclists” and “Everyday Cyclists” are only marginal target groups, as they already use bicycles regularly for everyday mobility. Here the motivation is to continue encouraging them to use bikes. A particular case is the group “*No chance, no matter how!*”, for whom cycling as a mobility alternative is generally not an option, even though they would physically be able to.

2.3 EmoCycling

Christian Nold introduced his “Emotional Cartography” methodology in 2009, which serves as the inspiration and foundation for the “Emocycling” method. A core element of this was a specially developed “bio-mapping” device that geolocates biostatistical data and visualizes it as a map (NOLD 2009). This approach allowed humans and their physiological responses to act as a sensor for the first time, recording the level of stress or arousal in an urban context. Following several research papers, ZEILE et al. (2016) revealed the most common triggers for stress responses from cyclists using wearables, cameras, and smartphone-based applications. One finding of this research highlighted traffic as a significant stress trigger.

Besides measuring the test person's vital data (e. g., skin conductivity and temperature) during bicycle use, the sensor wristband synchronizes these data points with the corresponding GPS data using a smartphone. A stress reaction (Moment of Stress) occurs when the skin conductivity increases and the skin temperature decreases simultaneously. Combining this method with a (personal) interview makes more detailed results possible for the Moments of Stress. When researching stress phenomena and their harmful effects on the human body, the extent of individual perception of stress is highly relevant. Further specification of the assessed subjective stress level is possible by adding the mobility profile as well as sociodemographic and sociopsychological assumptions. The endogenous influencing factors refer to individuals' personal demographic, socioeconomic, and sociocultural attributes and their social environment, significantly affecting perception (WERMUTH 2005). Examples include gender, age, physical constitution, local knowledge, and familiarity with the mode of transportation.

Furthermore, from a biopsychological point of view, there are indications that genetic or psychological predispositions can intensify or weaken stress reactions. Here, personality, locus of control, and risk-taking are particularly relevant (SCHANDRY 2016, KOVALEVA et al. 2012). The information is collected in standardized questionnaires and complements sensor measurements as a component of data analysis. Overall, the aim is to identify vulnerable user groups in stress perception and learn about barriers to equality for cyclists on the road. The main advantage of mixed-method approaches is the combination of quantitative data analyses and qualitative surveys, leading to more reliable and comprehensive results than singularly applied measurement techniques. Moreover, the methods used complement each other and thus partially compensate for their shortcomings. (RESCH et al. 2020).

3 ESSEM – Project Goals

ESSEM deals with identifying impact factors on the subjectively perceived safety of cyclists. The aim is to increase the comfort and safety of cyclists and thus contribute to sustainable

and climate-neutral mobility. The EmoCycling mixed-method approach helps to identify and analyze Moments of Stress in bicycle infrastructure in Ludwigsburg and Osnabrück.

The data collected in the project will be used to develop mechanisms for measuring safety, the perception of safety, and mobility comfort in cycling. The infrastructure, environmental influences, the bicycle used itself, and the cycling accessories are tested as influencing factors. The insights will help identify the need to optimize urban bicycle infrastructures and safety products. The participating model cities promote user-oriented and data-based cycling planning. Further, in Osnabrück, the environmentally sensitive traffic management system (UVM) will be further advanced. The long-term goal is to develop an innovative tool that holistically assesses urban cycling infrastructure and helps planners optimize it.

Additionally, the project consortium initiated an innovation network in cooperation with industry partners, existing networks, city representatives, and associations to support the development of data-driven solutions for bicycle-related products and services.

4 Procedure and First Results of the Data Collection Phases

Previous project approaches use the Body Monitor Smartband (ENGELNIEDERHAMMER et al. 2019), Galvanic Skin Response (GSR) (OSBORNE & JONES 2019, SHOVAL et al. 2018, BIRENBOIM et al. 2019), or other variables such as Heart Rate Variability (PAÛL I AGUSTÍ et al. 2019). In contrast, the presented approach allows an independent implementation of the measurement routine by the test persons.

4.1 Phase 1: Initial Data Collection

Initial data collection includes the acquisition of participants by project partner Bike Citizens (BIKE CITIZENS 2023) via their same-named application “Bike Citizens,” and the Bike Citizens Analytics tool “BCA” delivers the analysis (CYCLINGDATA 2023).

A link to the ESSEM website then provides further information on data collection. As soon as users agree to participate in the data collection, the application records routes used by approximately 350 subjects. Participants collected data daily during a determined period. The analysis of the anonymized datasets happens in the last step and maps a combined graphic showing the main infrastructure networks and the frequency of bicycle use. Data from the initial data collection phase forms the basis for the multi-phase EmoCycling measurements carried out during the summer of 2022.

4.1.1 Results of Initial Data Collection in Ludwigsburg

The user data collection happens in the BCA's analysis portal, where it calculates various bike-specific conclusions based on the trajectories. For example, it is possible to determine the intensity concerning the number of cyclists in the network to show the average speed per road segment. Another feature is to identify (forced) waiting zones about their frequency, determine the action radius of the participants, and calculate the attractiveness of the road segment compared to the whole network. The attractiveness function identifies cyclists preferred and avoided paths. These segments are displayed in red if cyclists take a detour and avoid the shortest route. Popular detours appear in green. The line thickness indicates the intensity.

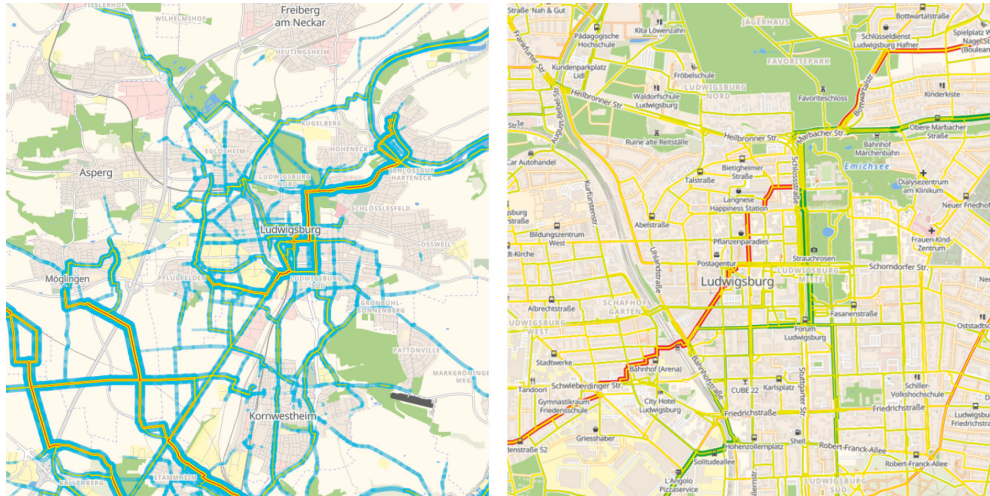


Fig. 1: Initial data collection in Ludwigsburg: main route network (left) and attractions (right)

Figure 1 shows the results of the analysis. On the left, the main road network shows the intensity of all tracks driven in the form of a heat map of the road network. The thicker the blue line, the more frequent the road use. The particularly intensive main routes have a red marking. The identification of the heavy frequency of the central axis in the north-south direction, along the baroque palace park of Ludwigsburg, can be seen well.

Furthermore, the road towards the Neckar in the eastern direction and the arterial roads towards the west can be identified as essential axes. On the right, in the focus “city center”, the attractiveness analysis shows that many cyclists from the city center avoid the direct route to the station and prefer to use the orthogonal streets. Despite the high traffic intensity on both streets, this is an excellent example of how good bicycle infrastructure, such as along Stuttgarter Straße, can motivate or discourage cyclists from using the route.

4.1.2 Results of Initial Data Collection in Osnabrück

In Osnabrück, the intensive use of paths in the city center is a special characteristic (Fig. 2). The western areas (especially Katharinenstraße, which is designated as a bicycle lane), as well as the 30 km/h zones in the Wüste district, have a high level of bicycle use. In contrast, many cyclists avoid Martinstraße, which runs parallel to Katharinenstraße in the south with a strong MPT dominance, and Lotter Straße in the north.



Fig. 2: Initial data collection in Osnabrück: main route network (left) and attractions (right)

Cyclists also avoid the southwestern inner city ring road. In the south in Kalkhügel, Suthauser Straße is bypassed in favor of Burenkamp. In the southeast, the participating cyclists prefer Meller Straße to the four-lane Hannoversche Straße.

4.2 Interview Process and Subject Selection Phase 2

Standardized surveys will supplement the sensor-based data from the survey phases. The aim is to obtain further information about the participants that provide insight into their mobility behavior and personal dispositions. This information supports the observations on stress perception. The survey is accessible via LimeSurvey, which ensures a quick creation of a first statistical analysis. The data is collected anonymized. To comply with data protection regulations and also to correlate data from the survey with data from the sensor-based measurement, each participant creates a pseudonym. Simultaneously, the survey results provide information for ensuring that the sample for the sensor-based measurements is as representative of a cross-section of the population as possible. Therefore, the participants can voluntarily provide their email addresses as a contact option.

4.3 Phase 2: Emo-Cycling Data Collection in Ludwigsburg and Osnabrück

The second data collection phase began in Ludwigsburg in July 2022 and in Osnabrück in September 2022. For this purpose, the 30 test persons selected through the initial data collection and the standardized questionnaires were divided into two groups of 15 test persons each for each city and equipped with the measuring instruments.

During the collection, the physiological stress reactions of the participants are recorded, located, and mapped according to the EmoCycling method. Empatica E4 Smartbands are used to record near-body data, locate it via GPS using a smartphone, and collect them in the E-Diary app. A unique feature of the ESSEM project is that, after a brief introduction, the participants could take the data collection equipment home with them and independently connect the devices before each trip in their everyday life. Data acquisition with the smartphone provides a packed Spatial-Lite database. The outcome data with the identified Moments of Stress

was stored in machine-readable CSV format (cf. KYRIAKOU et al. 2019, TEIXEIRA et al. 2019). Further collected attributes besides geocoordinates longitude and latitude are Unix timestamp, MOS score, raw GSR and ST values, time_iso, speed, and acceleration.



Fig. 3: Heatmap of stress points during bicycle trips in Ludwigsburg (left) and Osnabrück (right), focusing on the city center on a scale of 1:100.000

During the survey phase Ia, we could already gain the aimed-for results from the technical side by the first test persons in Ludwigsburg. Therefore, the detection of the MOS can be evaluated as expected and show first indications of situations in the road network where cyclists perceive stress during their daily rides. In the evaluation, it is noticeable that the participants showed an increased stress reaction on the diagonal from the city center to the train station, like in the initial phase. Another stress hotspot for cyclists is a large construction site.

The results from the data collection in Osnabrück after partly completed analyses look promising, too. A concentration of Moments of Stress is detected along Natruper Straße in the north, at the section at Westlicher Wall, Burkenkamp, Lotter Straße/Lineschweg, Magdalenenweg, and further. Further, it shows in contrast to the preferred routes according to the attractiveness analysis that, for example, many Moments of Stress occur on the popular road of the Burkenkamp. All these hotspots are relevant areas for investigation in the ESSEM project. In further experiments and analyses, these are the focus areas for studying infrastructure conditions and their design to increase the perceived safety of cyclists through targeted interventions. From a planning point of view, the speed limit planned for the middle of the year 2023 on the southern access road (Iburger Straße) into the city center will increase the attractiveness for cyclists. This then can lead to a reduction of perceived stress on the route.

5 Conclusion and Outlook

The setup presented and the initial results are promising, so it seems realistic to use mixed-method approaches to actively integrate new perspectives in the context of subjective perception of safety and comfort, when cycling, into planning processes and demonstrator development.

The interim conclusion of the data collection process in the ESSEM project is that without direct contact with the municipality, such a long-term study with the participant acquisition is not feasible. On the one hand, this may be due to the framework conditions of a city: The cycling-specific DNA of society, the existing modal split, or topography. Thus, it seems evident that the acquisition of participants in the cities of Ludwigsburg and Osnabrück started with different preconditions. On the one hand, an active and comprehensive press campaign in Osnabrück recruited almost 300 participants. On the other hand, despite the direct approach by the German Bicycle Club (ADFC) to its members in Ludwigsburg, the proportion of potentially interested persons was only 10% of the participants compared to Osnabrück. Consequently, the active participation of communities in exploratory processes and the political legitimization of projects are crucial for their success. This support also succeeds in further integrating relevant institutions such as schools, churches, and disability associations to acquire a diverse user group early. Nevertheless, the project presented here impressively highlights the potential of cooperation projects between science, business, municipalities, and associations. In addition to “classic” location-based services and trajectory detection of cyclists, the project attempts to collect biostatistical data on stress detection for the first time on a large scale over a long period to a) identify potentially existing stress hotspots, b) evaluate and optimize bicycle components with the help of sensor technology c) detect potential positive effects of road closures for cars in the context of environmentally sensitive traffic management on the stress perception of cyclists, and d) create alternative route suggestions for bicycle navigation with the help of stress hotspots (emo-routing).

In addition to formal criteria for maintaining the objective safety of infrastructures, the identified stress hotspots can also be used as a basis for further research to improve the design of roads in the context of mobility design. Routing, pavements, and the general design of (bicycle) roads help promote cyclists' well-being. At the same time, reducing stress in bicycle and pedestrian traffic increases subjective safety. This way, good design can also increase safety and improve traffic turnaround.

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