The Effect of Overtaking Distances on the Stress Occurrence of Cyclists in Urban Areas

Jan Hauenstein, Jochen Eckart, Peter Zeile, Jule Merk

(Jan Hauenstein, M Sc., Planersocietät, jan.hauenstein@gmx.de)
(Prof. Dr. Jochen Eckart, Hochschule Karlsruhe, Professur Verkehrsökologie, jochen.eckart@h-ka.de)
(Dr.-Ing. Peter Zeile, Karlsruher Institut für Technologie KIT, Professur Stadtquartiersplanung STQP, peter.zeile@kit.edu)
(Jule Merk, M.Sc., Hochschule Karlsruhe, IMM, jule.merk@h-ka.de)

1 ABSTRACT

To further promote the share of cyclists in urban and rural areas, the focus lieson both improving objective road safety and increasing the subjective feeling of safety among cyclists. The subjective feeling of insecurity often forms a barrier to more frequent bicycle use for people who have so far cycled little or not at all, and who are therefore important for increasing the cycling share in urban and rural areas.

The focus of the research is to examine overtaking interactions involving bike and car traffic. Overtaking cars is one of the main causes of stress for cyclists. Not only does overtaking have physical suction and pressure effects on bike traffic because of air displaced by the car body, but also psychological stressors. There are proximity boundaries where people feel unsafe when someone does not maintain them, especially when imposed upon by large, fast vehicles. During overtaking interactions, there is no direct opportunity for communication due to the separation effect of the car body. The cyclist also cannot confirm that the driver is aware of their presence.

Since 2020, Germany has mandated that car drivers may only overtake cyclists on the roadway with a distance greater than 1.5 m in the inner city, and 2.0 m out of town. Other countries have similar regulations for overtaking interactions involving cyclists. France, Portugal and Spain have also adopted the 1.5 m law, in Australia, the distance is usually 1 meter on roads with speed limits less than 60 km/h and 1.5 meters on roads with higher speed limits. Distances set in the traffic regulations across different countries are primarily based on court rulings. Research is missing on which overtaking distance cyclists feel most safe and at which distance they are stressed.

This paper analyzes the effect of overtaking distances on cyclist stress. The research is based on test rides with 14 cyclists on urban streets. The bikes were equipped with sensors measuring the lateral distance between the bikes and overtaking cars. With the help of a stress-measuring method using medical fitness wristbands, stress-inducing overtaking interactions could be detected. The distance of the overtaking car and the stress events were compared by geometric and temporal coincidence. Through the Pearsons chi-squared test and the use of Cramer´s V, the results show a statically significant between closer overtaking distances and stress-triggering effects on cyclists: At distances under 1.6 meters, significantly more overtaking situations triggered stress.

The research has shown that the distance of cars overtaking cyclists has a big effect on the subjective safety of cyclists. The research also suggests that the 1.5 m approach is close to the measured “feel-safe” distance for cyclists and therefore supports regulations and enforcement around this value when planning streets to improve the safety of cyclists.

Keywords: overtaking cars, urban emotions, cycling, subjective safety , mobility planning

2 SUBJECTIVE SAFETY IN CYCLING TRAFFIC

2.1 Subjective and objective safety

The safety of cycling is composed of an objective and a subjective dimension and their interactions (Johannsen, 2013; Klebelsberg, 1982). Objective safety focuses on quantitative analysis of accidents and is usually based on an analysis of police accident statistics. Subjective safety looks at road users' emotional perception of the threat posed by a traffic situation (Fuller, 2005).

The term subjective safety describes the self-assessment of safety; i.e., how safe one feels in certain situations(Lange und Gasch 2006). From the Encyclopedia of Psychology of the scientific journal “Spektrum der Wissenschaft”, subjective safety is described as a “typical experience-descriptive variable in the motivation theory-oriented research tradition on intraindividual conflicts and decisions” (Wenninger 2020). Thus, it is characterized by experiencesthat affect personal decisions (Jurczok 2019).

In road traffic, especially in cycling, the focus in recent years has been on objective safety. The goal is to use data to design the use and form of road infrastructure to prevent accidents or conflicts between road users. In recent years, however, the focus has increasingly turned to the "specific requirements and needs of local people and their perception of traffic"(Gehl 2018), hence subjective safety. The goal is now to incorporate aspects of subjective safety into the technical planning of transport infrastructure. The motivation behind the goal is to increase the acceptance of cycling in generalgeneral and thepotentialfor more frequent bicycle use. For many potential cyclists, a subjective feeling of insecurity is a barrier to more frequent use of the bicycle. In particular, for people who cycle infrequently – are also therefore highly important for increasing the cycling mode share - the subjective feeling of insecurity forms a barrier to more frequent cycling use (Aldred and Woodcock, 2015;Bill et al. 2015).

Since an objectively safer cycling infrastructure has no added value if it is not accepted by road users, cycling safety must be a combination of both subjective and objective road safety.

2.2 Factors of subjective safety in bicycle traffic

In recent years, the individual subjective feeling of safety among cyclists in Germany has grown steadily. This is shown, among other things, by data from the representative online survey "Fahrradmonitor" (Jurczok 2019), p. 48) conducted several times in Germany. A comparison of different years shows that the proportion of cyclists who feel “very/mostly safe” has increased from 53 % in 2017 to 63 % in 2021 (SINUS 2021, p. 48). This result shows that an improvement in subjective safety is achievable. In order to achieve an improvement in subjective safety, it must first be clear what stresses cyclists in traffic. In the study, dangers perceived by cyclists in the traffic flow are “too much car traffic,” “no bike lanes,” “inconsiderate behavior of other road users,” “insufficient separation of bike lanes or bike paths from the lanes of cars” or “missing turn lanes”. “Not sufficiently wide bike lanes or bike paths” tend to play a more subordinate role in the study (SINUS 2021, p. 121). Many of the stress triggers or uncertainty factors mentioned could also be related to overtaking: To much traffic means that cyclists are frequently overtaken. Reckless car drivers could be an indication of overtaking distance, and too-few separated bike lanes shows a clear general skepticism towards motor vehicle traffic.

A study by the Department of Transport (Gibbard et al. 2004) in Great Britain asked cyclists about elements that caused the most stress or feelings of vulnerability. Respondents perceive large roundabouts (36.4 %), fast traffic (11.2 %), a high proportion of heavy vehicles (17.8 %), and right turns in traffic (12.2 %) as most stressful or vulnerability-inducing. Many of the aforementioned points cover similar problems to the “Fahrradmonitor 2021” study. Due to the crossing of many conflict points when turning right - or, in countries with right-hand traffic, when turning left --it seems logical that cyclists tend to be more stressed than when riding through fewer conflict points.

In the study by Dennis Groß (2015), the stress of cyclists was made objectively measurable for the first time. By using a medical wristband, stress reactions of the human body were made visible. The evaluation of the study revealed a wide variety of stress triggers, which can be divided into three subcategories:

Horizontal effects are always related with the direction of travel of the cyclists. These include, in particular, intersections, merging into traffic, curves, road surface, obstacles, or narrow sections. Vertical effects involve the bicycle moving in a perpendicular direction. This is the case when cyclists ride over curbs, uneven pavement, or when the road has an incline or decline. Anthropogenic effects refer to all interactions triggered by other road users, such as an overtaking vehicle, oncoming traffic, pedestrians, or dooring. The various effects can also occur in combination, making it more difficult to identify the main trigger for the stressful situation. In addition, there may be other effects brought to the situation by the cyclist themselves (individual effects): Personal experiences and near-accidents at certain sections, but also the individual stress tolerance influences stress measurement (Merk 2019; Merk et al. 2021).

Another approach to measuring subjective stress is offered by the studiesof FixMyCity Team (2020)and Richter et al. (2019) about the safety and usability of cycling guidance. In both studies, cyclists were asked about their perception of safety when considering different traffic situations under variable infrastructure designs. The results of this showed that the street space design has a big impact of how safe cyclists feel on the street.

3 OVERTAKING INTERACTIONS INVOLVING BIKE AND CAR TRAFFIC

3.1 Legal Framework

Since 2020, Germany has mandated that car drivers may only overtake cyclists on the roadway with a distance greater than 1.5 m in the inner city, and 2.0 m out of town. Other countries have similar regulations for overtaking interactions involving cyclists. France, Portugal and Spain have also adopted the 1.5 m law.In Australia, the distance is usually 1 m on roads with speed limits less than 60 km/h and 1.5 m on roads with higher speed limits.

Distances set in the traffic regulations across different countries are primarily based on court rulings,such as the court decision from Hamm: "When overtaking, car drivers have to maintain a distance of at least 150 cm to the side and , when travelling above 90 km/h, they must maintain a 200 cm distance"(OLG Hamm, Az. 9 U 66/92).

However, no concrete justification forrecognizing these distances as "sufficient overtaking distances" (StVO, Germany) can be found in the technical literature.

3.2 Overtaking interactions in reality

Given that streets often have insufficient widths to allow for overtaking at a 1.5 m distance, many studies show non-compliance with prescribed minimum distances. Overtaking still takes place it is not legally permitted In the “SensorBike” project at the Karlsruhe University of Applied Sciences, only about 50% of recorded overtaking events had an overtaking distance of more than 150 cm (n=255 overtaking events). About 20% of recorded overtakes occurred at a distance of less than one meter (Röder et al. 2020). Other studies on overtaking distances also show corroborating results (Welz 2020; Baum 2019; Richter et al. 2019). Studies regarding overtaking distances under 150 cm in particular show that only about 50% of overtaking distances were greater than 150 cm in urban areas.

A closer look at the literature shows that the overtaking distances between motor vehicles and bicycles do not depend solely on the behaviour of the road users, but are influenced by the corresponding design of the road space. Although overtaking distances vary in different cities, the influencing factors are the same.

The lateral overtaking distance between motor vehicles and bicycles depends in particular on the width of the cycling infrastructure. A 100 cm wider cycling infrastructure leads to 33 cm wider overtaking distances. From a width of 1.85 m, cycling infrastructure leads to significantly larger overtaking distances than guiding cyclists in mixed traffic. Only the width of the cycling infrastructure is important, the type of cycling infrastructure is not decisive. If the width of the cycling infrastructure is smaller, the guidance in mixed traffic can lead to a smaller number of narrow overtaking distances. Thus, although overtaking does not occur at greater distances in mixed traffic, there are significantly more rejected overtaking manoeuvres than with cycling infrastructure under 1.5 m wide. In the case of cycle lanes or protective lanes less than 1.5 m wide, their benefits for the guidance of cycling traffic (e.g., recognisable guidance of cycling traffic, guidance in the field of vision of motor vehicle traffic, etc.) must be weighed against the lower overtaking distances compared to mixed traffic. It may be necessary to check whether a sequence of pictograms is suitable for the guidance of mixed traffic.

The width of the lane used by motor vehicle traffic also has an influence on the overtaking distances. Up to a lane width of 9.0 m, a widening of the lane results in an increase in overtaking distances. For every100 cm increase in lane width, the overtaking distances increase by 7 cm. Above 9.0 m, however, the lane width no longer has any influence on the overtaking distances. Overtaking by cyclists from oncoming traffic (encounter between car and bicycle) is rarely observed but is associated with narrow overtaking distances. On stretches of road with frequent overtaking manoeuvres with oncoming traffic, particular attention should be paid to ensuring sufficient overtaking distances. No influence on the overtaking distances between motor vehicles and bicycles was found for stationary traffic, the maximum permitted speed or the type of overtaking vehicle.

Objectively, motor vehicles overtaking bicycle traffic officially has only a minor negative influence on accidents. In accident statistics on cycling, overtaking rarely appears as a direct cause of accidents. According to a nationwide search engine query for online press reports of bicycle fatalities by Wordpress from early 2013 to 2018, only 6% of fatal bicycle accidents were due to ramming/striking with motor vehicles(Wordpress 2018). The main causes of bicycle fatalities, according to this source, are solo accidents (32%) and right-of-way/crossings (28%). Other analyses of cycling accident statistics also assume a low direct involvement from overtaking motor vehicles(Peters 2010).

3.3 Potential factors influencing the occurrence of stress while overtaking interactions

Stress is generally understood as a reaction of the body to external or internal stimuli: so-called stressors. Stressors can be physical, psychological, or social. The body reacts to stressors when they disturb the balance in the body and the calmness of the person (Selye 1956). Stress can be seen as a type of adaptive response. As soon as a perceived stimulus is classified as relevant to the safety of the person, a protective mechanism takes place in the body through the release of hormones, such as adrenaline and cortisol, which puts the body on alert. A part of the autonomic nervous system, the sympathetic nervous system, is activated. The activation ensures "brain performance and behavioral responses of the body" (Zimbardo 1995). Evolutionarily, stress is a response that used to ensure human survival. The term "fight or flight," coined by the U.S. physiologist Walter Cannon (1915), plays a major role. By reacting to a stimulus with stress, the body was prepared for possible reactions necessary for survival and physical functions were ensured by hormones ("fight or flight"). Whether stimuli are perceived as threatening or irrelevant varies from person to person. The evaluation results from previous personal experiences, adoption of evaluations of others, change of knowledge and information, and personal theories (Tausch 2017). The subjective sense of safety starts here. Stress is seen as a reaction: the unsafe moments felt by each individual. In today's world, stress is mostly psychological in origin (Tausch 2017). In road traffic, however, stress can still be related to its former relevance. Thus, stress is mainly seen in pedestrian and bicycle traffic as a direct reaction to actual dangerous situations. Factors that function as stressors in everyday traffic are: Noise, proximity of stronger road users (fear of collision) or indirect factors, such as pressure or suction effects by other road users. All these stressors can be identified during (close) overtaking. For cyclists, potential stressors are triggered by their role as weaker road user on the roadway compared to motor vehicle traffic. Bicyclists, as weaker road users, are greatly outnumbered by faster motor vehicle traffic in a potential encounter and can thus feel a sense of being at their mercy. From the cyclist's point of view, this fear seems very understandable at first, but is not perceived as such by motor vehicle drivers. The car and the associated protective space act to separate from the real, threatening situation in possible collisions (Peters 2010).

A possible approach for maintaining sufficient overtaking distances can be derived from the four distance zones theory of ethnologist Edward Hall in 1982(Hall 1982). Hall assumes that every person allows certain distances to other groups of people without feeling uncomfortable. The intimate zone of a person or intimate sphere is reserved only for friends, family, or partners. It corresponds to an arm's length distance of60 cm. Strangers are perceived as threatening or intrusive in this zone their ejection of this intrusion can amass aggression ("stress"). The second zone is the personal zone, extending up to about 1.2m. Within this zone, only acquaintances or colleagues are tolerated. Sensory perception of these persons is already complete, but they are not perceived as directly unpleasant. In the social zone, people do not feel directly bothered or threatened by other people. In this zone, strangers are also tolerated; they are no longer fully perceived, sensory-wise. A direct threat or relevance for the well-being can be excluded. Overtaking can be assigned to this personal zone. Vehicles are therefore no longer completely sensory perceived from this distance and are therefore not seen as a nuisance or threat. With this approach, however, it must be considered that vehicles have a greater effect on cyclists due to their size, noise and other sensory perceptible influences and thus can still be perceived as threatening at distances beyond 1.2 meters.

So all in all overtaking by cars take a big role in the subjective safety of cyclists. There many reasons cycling people feels unsafe by big cars overtaking them real close. Also objective numbers show that there is no real reason to be really scared about. So what is the result of this inconsistency?: Is it really necessary to have rules which regulate the overtaking distances or is in the end the distance not that significant as it seems? These questions are to be investigated by the study of this work to increase the number of people cycling. In reality at least to enforce the rules you need more place for cyclists, otherwise near overtaking still will often take place on the streets. So the big question is has the overtaking distance impact on the stress occurrence of cyclists in urban areas and if so, at which distance the cyclists feel safe enough?

4 METHOD FOR DETERMINING STRESS PERCEPTION

4.1 Stress detection with the EmoCycling method

The EmoCycling methodology used in the project finds its origin in the "emotional cartography" initiated by Christian Nold in 2009. An essential component was the specially developed "Bio Mapping" device, which recorded biostatistical data in a georeferenced manner (Nold 2009). The recording of individual physiological responses is thus possible, with the individual acting as a "human sensor." Following a series of other research papers, Zeile et al. (Höffken et al. 2014) revealed the most common triggers for stress responses in cyclists using wearables, cameras, and smartphone-based applications. Specific traffic situations such as guidance patterns, high traffic volumes, dangerous overtaking, or the condition of the road surface were the most common stressors.

To measure the "stress level,“ the medical fitness wrist band “Empatica E4”is used(https://www.empatica.com/en-eu/research/e4/, 2020). The background use of this device is to generate real-time medical data for research purposes in order to perform analyses and visualizations. It records vitals data-- more precisely, the skin conductivity and temperature of the test persons during cycling -- and synchronizes the corresponding GNSS data to a smartphone. The basis for the recognition of moments of stress in the collected physiological data is done via a rule-based algorithm (Kyriakou et al. 2019). This assigns a stress moment when there is an increase in electrodermal activity (EDA) Activity (EDA) in conjunction with decreases in skin temperature values (ST).
When under stress, the human nervous system initially reacts with sweat production and an increased pulse. The sweat serves as a reaction to the imminent possible activation of corresponding body functions and the pulse is increased in order to supply corresponding body areas with sufficient blood. The extracted stress moments are each labelled with a timestamp and a geo-position so that they can be analyzed both spatially and temporally.

4.2 Structure and procedure of the study

When selecting the type of bicycle traffic routing, care is taken to select as balanced a proportion as possible of marked bicycle infrastructure (protective lanes/cycle lanes) and bicycle traffic routing in mixed traffic. For mixed traffic sections, both speed limits of 30 km/h and 50 km/h are included in the planning. Furthermore, when selecting the route, attention was paid to a clear course of the route, so that the route can be ridden by test persons without much prior knowledge. The test track has a length of about 7 km and leads across the inner city of Karlsruhe, Germany.

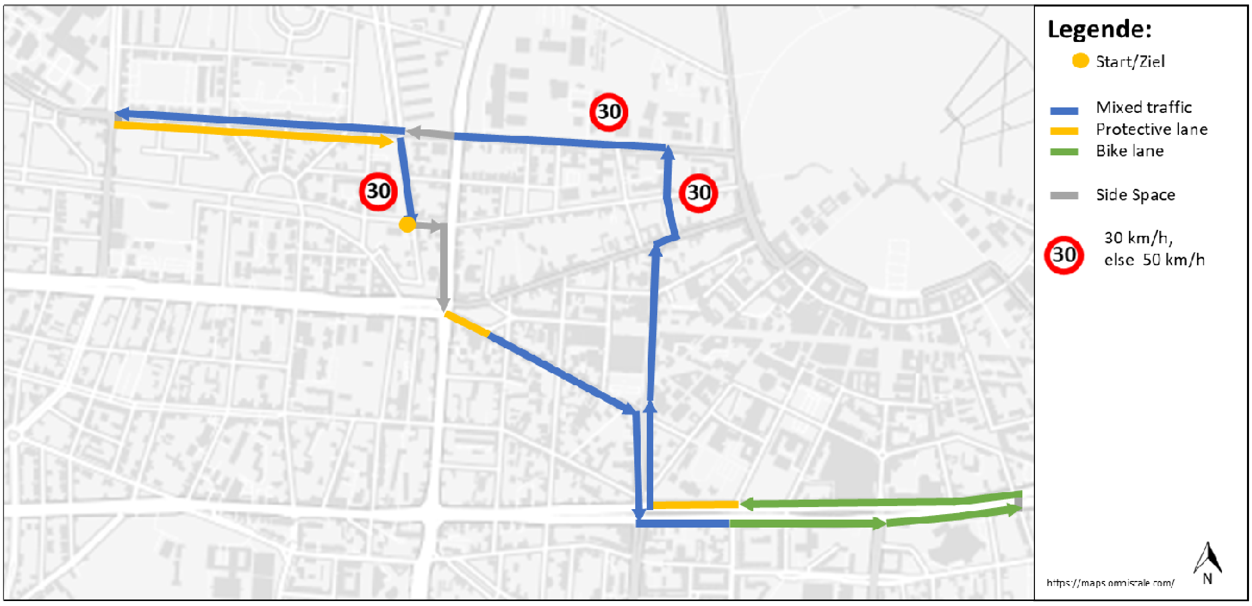

Fig. 1: Test Route in Karlsruhe, Germany

The test persons are selected according to two criteria. First, the subjects should have experience with cycling in urban traffic. Second, subjects should have a fairly homogeneous composition in terms of age and socio-cultural backgrounds. According to Geller's cyclist types, only people who can be classified as either

"Strong and the Fearless" or "Enthused and the Confident"are eligible for the survey. This grouping has already been used in several studies (Dill and McNeil, 2013, 2016; Portland State University et al. 2014) and are used as the basis for the present study.

The 14 test persons achieve good comparability within the group while controlling the study to focus only the effect of overtaking distances and the guidance of the bicycle infrastructure.

Test persons are equipped with anE4 to measure the occurrence of stress according to the EmoCycling method from Höffken et al. 2014. The bike is equipped with a OpenBikeSensor, cameras, and a GPS Tracker. OpenBikeSensor is an open-source project that has evolved over the last few years from a group of active everyday cyclists into an association. The goal of this project is mainly to provide and further develop a distance measuring sensor for the bicycle to record the lateral distance to other vehicles. It consists of ultrasonic sensors, an event trigger and GPS-recording.(OpenBikeSensor 2023)

In the present study, video recordings, distance measurements, and psychophysiological reactions of the test persons including GPS data are collected. In the analysis, the collected data is temporally connected to determine correlations between environmental parameters and overtaking distances and stress occurrences.

The processing and cleaning of the generated data sets of this research work is done by several steps:

First, the trips records from the camera are visually analysed for motor vehicle overtaking events. By overlaying the GPS points of the overtaking events and the distance data between bicycles and cars, a distance is assigned to each overtaking event. Since the GPS location of the distance data is sometimes very inaccurate, the overlay is verified using video time stamps and distance measurements. For this purpose, significant trip points such as the start and end of the test drive are overlaid with the respective time stamps.

The psychophysiological data of the fitness wristband are evaluated for stress moments by an algorithm based on the EmoCycling-method. Stress moments are identified and imported into a geographic information system using their GPS coordinates. By overlaying the stress moments with the overtaking distances, it can be determined in which overtaking events stress moments occurred. This results in a comprehensive data set with overtaking events, their lateral distance data, occurrences of stress, and other environmental parameters.

Statistical evaluation is performed using the chi-square test at the 95 % confidence level. Lower frequencies of expressions ($n < 20$) were not considered statistically, but only descriptively. The effect size of possible statistically significant parameters on the number of stress-inducing overtaking events is determined by the Cramer's V value. Additionally, two-step clustering is performed using the statistical software SPSS to identify possible groups of parameters "favouring" stress-inducing overtaking.

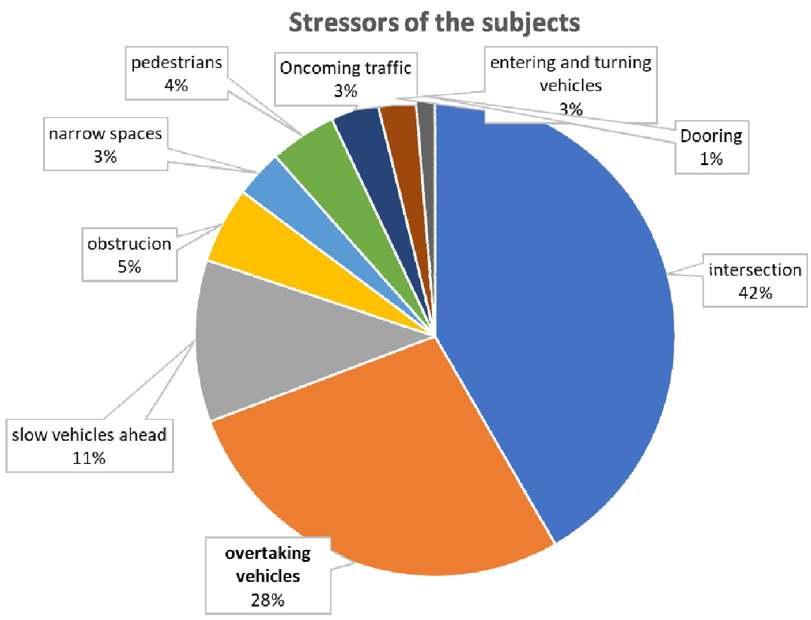

Fig. 2: Stressors of the test persons

4.3 Results of the study

A total of 232 moments of stress were recorded in the study. These stress moments were first assigned to the overtaking processes and, in a further step, the remaining moments were assigned to other stressors through a second video analysis. With 42 %, the intersection aspect corresponds to the most stress occurrences. Overtaking vehicles occur as stressors in 28% of the assignable stress moments. At 11 %, slow vehicles ahead of the cyclist are a frequently occurring stressor in the study. The remaining stressors, including obstacles, bottlenecks, pedestrian traffic, oncoming traffic, and entering and turning vehicles, occur only sporadically as stressors. The classification of stressors according to Groß (2015)in the EmoCycling method, also used by previous studies, serves as an orientation. This first analysis shows that overtaking is the second largest stressor in this study.

A total of 226 overtaking events were recorded in this study. 38 (17 %) of the overtaking events can be attributed to a stress occurrence in the participants. 188 overtaking events are associated with no detected stress moments (83 %). Figure 17 shows the distances of all recorded overtaking events. The maximum overtaking distance is 230 cm and the minimum 70 cm. The 25 % quantile limit is at 130 cm and the 75 % quantile limit is 170 cm. Thus, the median 50 % of the values are between 130 and 170 cm. The median of all passing distances is 150 cm and the average of all passing distances is 152 cm. 50 % of the measured overtaking distances are above the often-used 150 cm and 50 % are below.

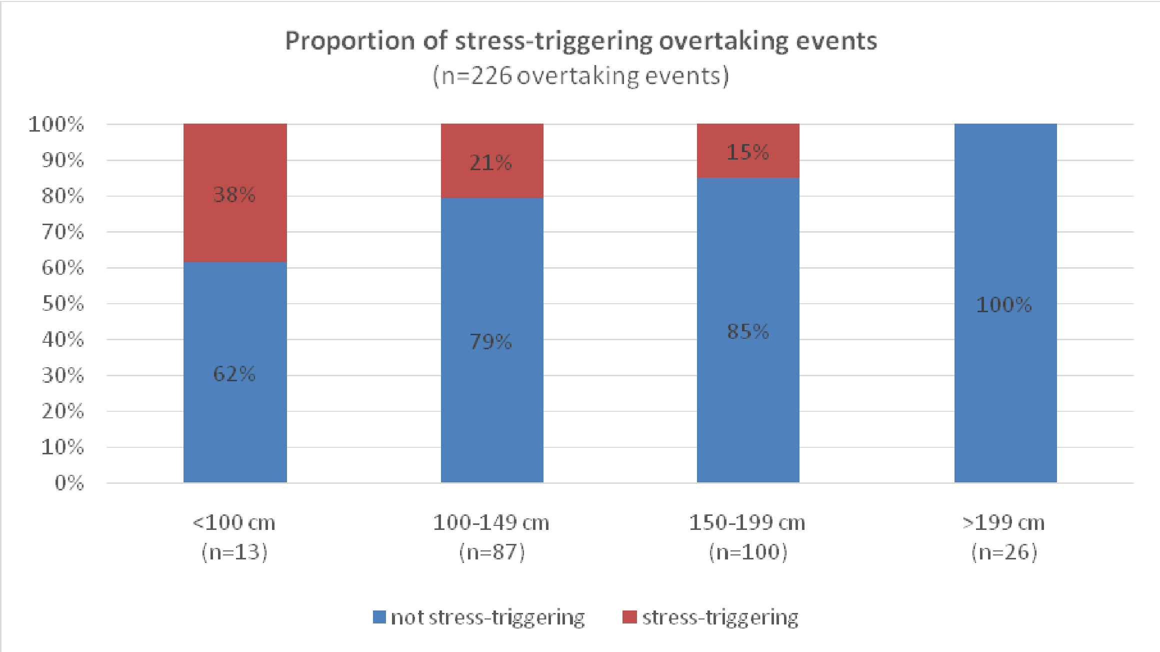

Fig. 3: Proportion of stress-triggering overtaking events

Using the Pearson's Chi-square test, the results show a statically significant between smaller overtaking distances and stress-inducing effects on cyclists:

For overtaking widths below 100 cm, the proportion of stress-triggering overtaking events was 38 %, for widths between 100-149 cm, it was 21 %, and for overtaking widths between 150-199 cm it was 15 %. At distances below 160 cm, significantly more overtaking manoeuvres triggered stress than at smaller overtaking-distances.

No stress-triggering overtaking events were recorded for overtaking events at distances above200 cm. However, the overtaking distances of the stress-triggering overtaking events above150 cm reveal that 13 overtaking events with a distance of 160 cm, 170 cm, and 180 cm were stress-triggering in certain cases (proportionately 15 %, 16 %, and 21 % of the overtaking events at these distances, respectively). These values indicate that, in these instances, the distance of 150 cm is insufficient or that perhaps other environmental parameters are responsible for the stress. 7 % of the overtaking events were thus still assessed as causing stress at overtaking distances greater than 160 cm.

Overtaking distances have a very large influence on the occurrence of stress among cyclists when overtaking by motor vehicle traffic. A statistically significant relationship between overtaking distance and the

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frequency of stress-inducing overtaking was found for all distances below 160 cm. This relationship is most pronounced for overtaking distances less than 130 cm. However, overtaking events that did not have a stress-triggering effect also occurred below 130 cm and, at the same time, stress-triggering overtaking events occurred for overtaking events at a distance of more than 160 cm. These peculiarities are to be regarded as statistical outliers.

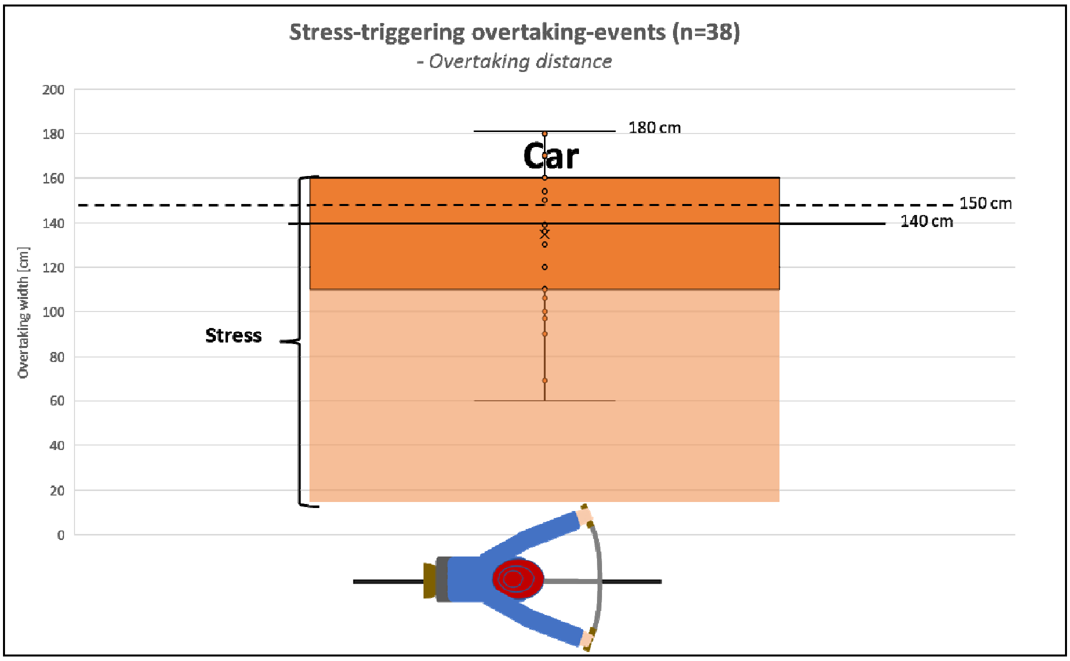

Fig. 4: stress-triggering overtaking-events depending on distance

Other environmental parameters did not provide any detectable influences on stress in the study: the influence of extra bicycle traffic guidance on the road such as protective lanes and bicycle lanes had no influence on stress occurrence. Also the difference between motor vehicle speeds of 50 or 30 km/h showed no influence in this study. However, these findings should not be considered definitive due to the small sample size.

5 DISCUSSION OF LOW-STRESS OVERTAKING INTERACTIONS INVOLVING BIKE AND CAR TRAFFIC

The present study shows that overtaking by motor vehicle traffic of cyclists has a measurable effect on objectively measurable subjective safety cyclists. Stressors such as crossing at 42% and overtaking vehicles at 28% occurred most frequently in the study. Stressors were measured in 17% of detected overtaking events. Thus, according to this study, motor vehicle overtaking events have a high influence on the occurrence of stress among bicyclists within urban areas.

The results show that the overtaking distance plays a decisive role: The larger the distance, the less stress was measured in motor vehicle overtaking events. Up to a value of 160 cm, a statistically relevant positive correlation was found between the small overtaking distances and the number of stress moments that occurred. For overtaking distances of less than 100 cm, the proportion of overtaking events causing stress was 38%, for distances between 100 and 149 cm it was 21%, and for overtaking distances between 150 and 199 cm it was only 15%.

In summary, the overtaking distances in overtaking events by motor vehicle traffic are most related to stress occurrences for cyclists. The overtaking distance of 150 cm regulated by, for example, the German Road Traffic Regulations (StVO) can therefore be seen as a sensible starting point for providing cyclists with sufficient subjective safety space. No negative or positive effect on the occurrence of stress among cyclists could be attributed to the environmental parameters of route type, bicycle traffic guidance type, maximum permitted speed for motor vehicle traffic, constricting elements in the right lane edge, and heavy traffic.

Measures should be taken to increase overtaking distances.Cyclists should be proclaimed to be respected on urban roads. The appropriate behavior of motor vehicle drivers should be encouraged through campaigns and notices. Some cities and states already launched campaigns to address the failure of motor vehicle traffic to maintain the minimum overtaking distances with cyclists. In countries such as Switzerland, campaigns actively attempt to attract more attention to the issue of cyclist overtaking (Brenn 2021). The aim of these campaigns is to raise awareness of the current rules on minimum overtaking distance and to increase considerate behavior between motor vehicle traffic and bicycles. The long-term effects of these campaigns on overtaking are not yet foreseeable.

Another thing that derives from the study is that bicycle infrastructure must be built that promotes sufficient overtaking distances. In particular, sufficiently-large, on-roadbicycle facility widths of at least 1.85 m are important. If there is insufficient space for wide bike infrastructure, it should be checked whether mixed traffic on the roadway at low speed, possibly supported by pictogram sequences, present possible solutions. In some cases, a solution may be to prohibit overtaking of single-lane vehicles.

It is recommended to conduct further studies of this kind on a larger scale to make even more quantifiable statements. Additional factors, such as the influence of heavy traffic or the guidance of bicycle traffic on protected lanes on cyclist stress during motor vehicle overtaking events could be made. In addition, a further study should be conducted on the stress perception of cyclists when motor vehicles are following behind in order to be able to exclude potential stress occurrences for cyclists.

This research makes an important contribution towards determining the subjective feeling of safety of cyclists through an objectively-measurable method and therefore better understand the subjective safety of cycling. The statistical relevance of the overtaking distances with cycling traffic contributes to the so-far only partial implementation of minimum overtaking distance regulations and ultimately increases the subjective safety of cycling and promotes cycling in general.

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