

International Steering Committee for Transport Survey Conferences

Sensing comfort in bicycling in addition to travel data

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Abstract

Bicycling is a key component of sustainable mobility. This paper gives an insight into the importance of bicycle-friendliness, also known as “bikeability” and its qualitative components like perception and emotions of the riders. The research applies a multi-methodical framework on bicycling aiming to identify stressful events on a bicycle ride. The goal was to test new bio-physiological sensors (like EDA device, eye tracker etc.) to develop a methodology on how sensor technologies can be integrated in the data collection processes and to discuss their practicability. The experiences in this field can help to foster a long-term integration of sensor technology into travel survey methodologies and further into transportation planning.

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1. Introduction

Trends all over Europe show that bicycling is enjoying increasing popularity. Besides social, environmental and recreational value, bicycling is the key component of sustainable mobility (Oosterhuis 2016). The bicycling-friendliness or “bikeability” is often illustrated in an index where infrastructural or environmental components are mathematically weighted to make different cycling infrastructures comparable (Krenn et al. 2015). Bikeability indices include mostly objective and quantitative aspects of cycling like distance, topography etc. However, new gadgets and sensor technologies like smartbands, smartwatches, eye tracker etc. allow to track the human perception through bio-physiological parameters e.g. electroencephalography (EEG), electrodermal activity (EDA) and eye movements.

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These sensors also enable the identification of comfort deficiency and events that increase bicyclers' stress levels and offer additional data in travel surveys (Zeile et al. 2016, Dörrzapf et al. 2015).

2. Methodology

The approach applies a multi-methodical framework aiming to identify stressful events on bicycle rides. It is embedded into a multiple case-design (two case studies within a varying set of experiments). The data collection combines different data sources (e.g. GPS, eye-tracking, traffic, weather) which will be described in more detail in the two case studies (see chapter 4.2.-4.4.). Pre- and/or post-questionnaires as well as mental maps help to validate the findings during the ride and to compare the measured with the stated results.

Over the years, case studies have evolved as a research design, representing a useful tool for investigating the application of different methods in (transportation) planning. This method is especially useful for testing theoretical models and tools by using them in real-world situations and field tests (Yin 2014). Case study design is the adequate choice when it comes to test and validate different sensor technologies in a delimited urban area. The sample size of case studies is rather small. As it is a multiple-case design, the methods differ within the case studies and are appropriately selected. Case studies do not lead to representative results, especially in terms of sampling size and bicycle rides under real-world conditions (e.g. weather change), but an "improved understanding of complex human issues is more important than generalizability of results" (Marshall 1996, p. 523).

3. Background

3.1. Bikeability – objective methods to measure bicycle-friendliness

The attractiveness of bicycling is equated with the term "bikeability" (Krenn et al. 2015, Winters et al. 2011, Wahlgren 2011). Bikeability is "the bicycle-friendliness of urban environments [...] with the underlying objective to compare areas and point out parts that are most in need for improvement" (Krabbenborg 2015, p. IX). However, bikeability also "refers to the comfort and convenience of an entire bikeway-network for accessing important destinations" (Lowry et al. 2012, p. 5). Comfort seems to be one of the key factors when improving the experience of cyclists and it is often understood as the opposite of "stress" (Blanc & Figliozzi 2016). There is a lack in literature concerning bikeability assessment and how to define comfort in relation to bicycling.

However, literature and research in the field of bikeability especially with a focus on qualitative aspects are rare (Krabbenborg 2015). Previous studies on bikeability mainly investigate the influence of certain routes (duration, curves, bridges etc.) and the infrastructure (residential streets or main connection, cycle path or cycling tracks etc.).

Nevertheless, there is still a mismatch between the objective and perceived environment, which leads to mixed findings of the relationship between the travel behavior and built environment studies (Ma & Dill 2015, Van Acker et al. 2013). "[I]t is difficult to objectively define and measure bikeability. A good bicycling environment may mean different environmental attributes for different people and/or for different bicycling purposes" (Ma & Dill 2015, p. 303). This mismatch between the objective and perceived environment can be overcome by a more human-centered approach.

3.2. Measuring bikeability – new methods

The research field of bikeability experiences a methodical reevaluation by taking the human perception more into consideration. The research project "Urban Emotion" refers to the subjective perception of urban space and tries to shape planning processes (Zeile et al. 2016). These research projects share the opinion that the involvement of human perception can lead to a better acceptance and identification with the built environment. The research from Furth et al. also refers to stress while bicycling (Level of Traffic stress) by classifying bicycling facilities into route segments (Furth et al. 2012). In addition, the mapping of experiences through geo-web services (Manton et al. 2016, Snizek 2015) can capture bikeability, but is often inaccurate and fails in usability when the biker is on his/her way. Collecting GPS data especially by the cyclist him/herself via smartphone app is more feasible and can be seen as a new method in travel surveys. For example, the app "BikeCitizens" (www.bikecitizen.at) enables the rider to track bicycle routes,

which can be aggregated and displayed anonymously in heat maps (Pühringer 2017). However, these methods neglect the human point of view. New wearables like smartbands, smartwatches, eye tracker etc. can track the human perception through bio-physiological parameters and provide additional data in travel surveys (Zeile et al. 2016, Dörrzapf et al. 2015).

Specifically, smartbands for EDA are used to measure the skin conductance level (SCL) (an electrical potential between two points of skin contact and the resulting current flow between them) together with skin temperature to create insights into the emotional state of cyclists and pedestrians. “According to emotion researchers, when a negative experience occurs, the skin conductivity increases and the measured skin temperature decreases” (da Silva et al. 2014). Besides EDA, also EEG is used in this context. The idea is that EEG provides “good observational data of variability in mental status” (Subhani et al. 2011) and therefore data on emotions and stress. However, it still lacks reliability and is difficult to use in a non-laboratory environment. Currently EDA seems to be the most reliable parameter to derive emotions, which has been proven in several field tests and case studies (Zeile et al. 2016).

Mobile eye trackers allow recording the entire visual perception of the user. It is possible to capture the eye movement and viewing direction during a bike trip (Amstad et al. 2015). Emotions of the cyclist can be quantified by detecting increased eye movements, which are visualized in gaze patterns (de Lemos et al 2008).

3.3. Technologies and tools

The technologies and tools (see table 1) can gather reported and sensed data. As reported data is based on participants’ statements, there is always a high risk of distortion of perception and gaps in memory. In contrast, sensed data is objective and helps to overcome these challenges.

Table 1. Overview of traditional, recent and new methods and technology in bikeability surveys (adapted from Widmer et al. 2016; Kanjo et al. 2015) (bold font: technologies and data relevant for the following case studies) (✓=relevant)

Technologies and tools		Travel behaviour	Spatial context	Environmental influences (e.g. weather)	Identification of stressful events, risks	Identification of events with high attention	Data (examples)	Reported data	Sensor data
Traditional	Questionnaire	✓	✓	✓			Travel data, opinions , emotions	✓	
	Photo/ Camera recording	✓	✓	✓			Critical spots , traffic load, noises, interaction with other road users	✓	
	(Virtual) maps			✓	✓	✓	Individual perception of public space (mental maps)	✓	
Recent	GPS, GSM	✓					Start and end points of stages, speeds, routes		✓
	Social Media (e.g. Twitter)						Emotions, opinions, frequented places	✓	
New	Mobil eye tracker		✓			✓	Data on eye movement in space and time, visual focus and fixation		✓
	Mobile EDA devices (e.g. smartband, -watch)			✓	✓		Physiological data (skin condundance and pulse as stress indicators)		✓
	Mobile EEG devices					✓	Physiological data (brain waves and brain signals), blinking		✓
	Bike sensors (anemometer, cadence sensor, braking force sensor etc.)	✓	✓	✓			Meteorological data, data on bicycle behaviour		✓

Traditional methods of collecting data on travel behavior can be enriched by integrating new sensor technologies, which are summarized above (table 1). These methods include, among others, observation, counting, video recording and more qualitative approaches like interviews. Besides technologies like GPS tracking and crowdsourcing of social media data emerging as new data collection tools, there are other new methods (eye tracking, EDA, EEG), which include the human perception and emotion into the data collection process (Widmer et al. 2016, Kanjo et al. 2015). However, a comprehensive integration of the human perception into the data collection process has not yet been achieved. The new methods are tested and discussed in the following case studies as a first step.

4. Case studies on bikeability and sensors

4.1. The set-up of the case studies

In the two case studies, the aim was to detect bikeability by applying a multi-method approach. The main question was: Can new sensor technologies capture objective, valid and reliable data to determine what makes cycling stressful?

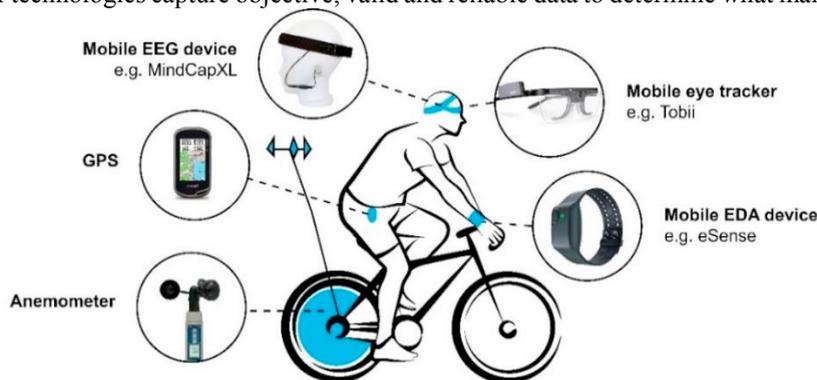


Figure 1: Overview of recent and new technologies applied in the two case studies

The integration of sensor technologies such as EDA device (eSense Skin Response), EEG device (MindCap XL), eye tracker (TobiiGlasses) into the methodology of collecting travel data was a major goal (see figure 1). The methods were applied in different phases of the cases studies: Whereas traditional methods (e.g. questionnaires) were mainly used in the pre-and post-phase, recent and new methods were applied during the bicycle ride. These methods allow tracking the human perception under real-world conditions, whereby bio-physiological parameters, help to identify stressful events on the trip and provide additional data in travel surveys. Furthermore, the bicycle can be equipped with other sensors e.g. anemometer for wind speed and wind direction data (see case study 1, chapter 4.2.).

Case study	phase	Traditional			Recent	New			
		Questionnaire	Observation	(Virtual) maps	GPS	Mobile EDA device	Mobile EEG device	Mobile Eye tracker	Special sensors
1 "Wind in the wheels"	Pre-phase	✓	✓						
	Test phase				✓	✓	(✓)	(✓)	✓
	Post-phase			✓					
2 "No trespass-ing!"	Pre-phase		✓						
	Test phase				✓	✓		✓	
	Post-phase	✓		✓					

Table 2: Methods applied in the two case studies (✓=applied). Notes: In () are methods which were planned in the beginning of the field test. After a couple of test rides, it became clear that the method was not appropriate to answer the research question or failed in the technical application e.g. no data, hardware/ software failures.

The research design in the case studies was structured in three phases where different methods were applied. In the pre-phase (before the test ride), mostly questionnaires and observations were carried out. During the rides, GPS and the other sensors collected the (bio-physiological) data and afterwards (post-test) mental maps and questionnaires helped to verify the results.

4.2. Case study 1: Wind in the wheels

The following case study "Wind in the wheels" (Bergmann/Kalisch/Schaub/Schett 2017) investigates the influence of wind on the subjective perception of cyclists. The question was how various wind forces and changing wind directions effect the perception and well-being of athletic and non-athletic cyclists. Logically it was assumed that in

the case of headwind, the cyclists’ experiences are negative, and in case of tailwind the cyclists’ perceptions are positive. It is assumed that the wind direction has more influence on the comfort of the cyclists than the wind force.

Research area and participants

For the selection of the research area, the aspect of wind certainly was important. By carrying out the tests in typically windy locations, the risk of test rides without wind could be minimized. In addition, it was important to select rather quiet streets, in order to minimize distractions and other stressful situations for the participants.

The test track along the Danube Canal runs between the Roßauer Lände underground station and the Aspern Bridge in Vienna. Since there is no car traffic on the Danube Canal, there was no distraction by motorized traffic or road signs. Moreover, on the test days, the Danube Canal was unfrequented due to bad weather conditions.

In Aspern Nord a course in the form of a rectangle was selected, in order to be able to record wind conditions from all directions. It was assumed that the wind direction does not change significantly during the duration of a test ride. There was little traffic on the route.

Table 3: Overview research area of case study 1

Research area	<p>Danube Canal, Vienna Bike lane in 2 directions, one direction is known for strong wind (south-north) Duration: 15-20 min., length: 5 km</p> 	<p>Aspern Nord, Vienna New development area in Vienna, route in form of a rectangle, in order to be able to record wind from all directions Duration: 20-25 min., length: 6 km</p> 
	<p>Participants: 11 (5 x ♀, 6 x ♂) Average age: 22,7</p>	

Methods and approach

Before the bicycle ride, observations were made and participants answered a questionnaire about their fitness level and bicycling behavior. As it was obvious because of the anemometer that the ride was dealing with wind conditions while cycling, the participants were instructed to bicycle as they would in daily life. During the ride, the EDA device (Mindfield eSense) collected the data on skin conductance level, which is measured in μ Siemens and is the inverse of electrical resistance. The 2D-anemometer measured the wind conditions on the ride and was attached to the bike. The participants were asked to draw a cognitive wind map after the ride.

Results

Almost all the participants agreed that the wind on the Danube Canal was stressful. On the way back there was a clear headwind, which was felt to be negative and detrimental to the comfort of bicycling, which is shown in the EDA data, even if only 4 out of 11 mentioned the headwind as negative in the mental maps. This can also be linked to the stronger and weaker gusts of wind during the bicycle rides. The test persons felt the headwind when reversing, which was immediately perceived as a negative contrast to the previously pleasant backwind, so 7 out of 11 participants marked a “hot spot” at the turning point.

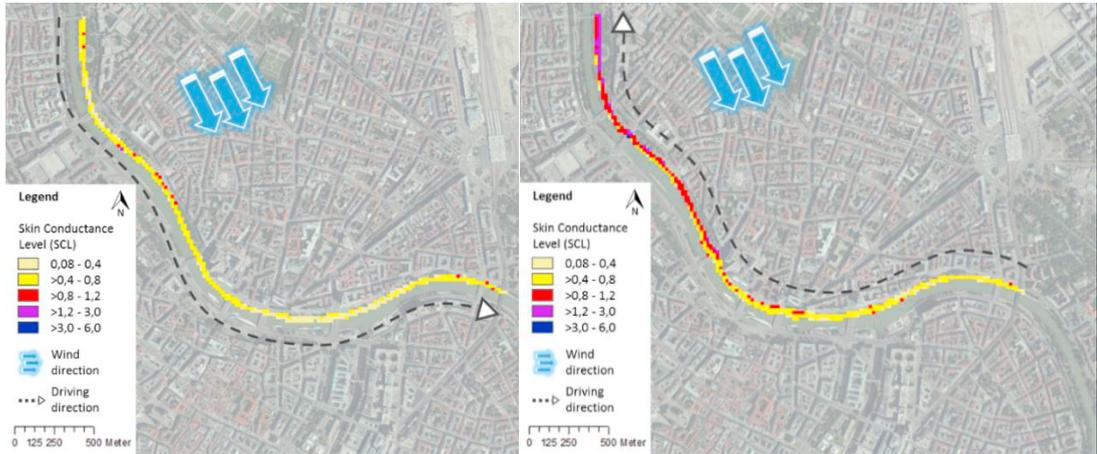


Figure 2: Skin conductance on outward (left) and backward trip (right) (red and violet indicates stressful events)

By analyzing the EDA data, it can be shown that there was almost no increase in the skin conductance during the outward route under backwind, which implies that the participants were relaxed on average (see figure 2). On the return journey, the skin conductivity values rise significantly halfway, which can be interpreted as stress. However, it is not certain that this stress is caused by wind. It is even more likely that the level will rise towards the end, because the participant had to invest more effort and therefore produced more sweat, which is reflected in the skin conductance level.

The results from the second field test show a similar pattern. Due to the rectangular shape of the test field, it is possible to get wind from all directions (head, tail and side wind from left and right). The mental maps drawn by the participants show that tailwind was received positively, while the headwind as well as the side wind are perceived as negative. This is also reflected in the skin conductance level (see figure 3) of average athletic participants.

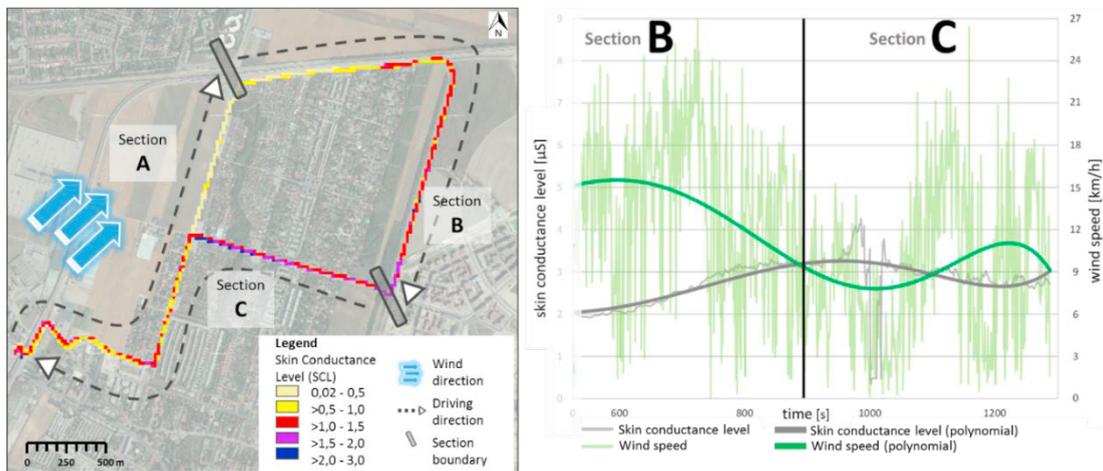


Figure 3: Skin conductance of average athletic participants (left) and example of skin conductance level of average athletic participants in relation to wind speed (right)

During back wind, the skin conductance continuously decreases and then rises in the section with side- and headwind (shown as polynomial trendline). Comparing this data with the wind speed, it becomes obvious that especially at the end of section B and C the wind direction (see figure 3 and 4) actually has less influence on the

comfort of the biker. It can be assumed referring to the mental map that the side wind was actually more stressful than the strong headwind.

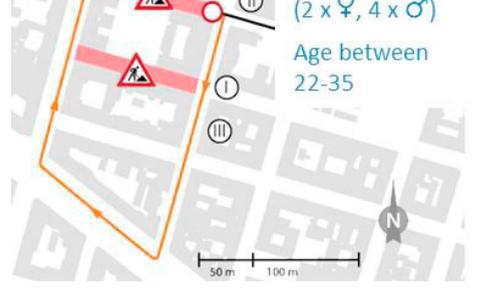
4.3. Case Study 2: No trespassing!

In cities, there are numerous construction sites, which can also affect bicycle traffic infrastructure. This occurs more frequently during the summer months, as the weather makes it easier to carry out major renovations or alterations. Construction sites collide with the then increased numbers of cyclists and can limit the accessibility of the cycling infrastructure. This case study “No trespassing!” (Berger/Brunner/Kern/Steiner 2017) examines the impairments caused by construction sites and the resulting human perception of changes in connectivity through roadblocks, narrowed streets and diversions.

Research area and participants

In order to carry out the research, it was necessary to identify different roads in Vienna, in which current maintenance sites can be found.

Table 4: Overview research area of case study 2

Research areas	Lazarettgasse, Vienna	Lessinggasse, Vienna
	<p>Quiet neighborhood area, mixed traffic lanes, diversion of the route through another street</p> <p>Participants: 8 (2 x ♀, 6 x ♂)</p> <p>Age between 22-35</p> 	<p>Building refurbishment, therefore street blocking of 2 sides, cycling against the one-way regulation allowed</p> <p>Participants: 6 (2 x ♀, 4 x ♂)</p> <p>Age between 22-35</p> 

The streets were selected using three different criteria including temporary impairment (continuity of a bicycle track is temporarily impaired by a construction site and is guided via a diversion system); frequencies (high number of cyclists should be visible in the observation and road function (road should be used primarily by everyday-cyclists).

Methods and approaches

The previous observation was very important to get a first idea of how cyclists react to the construction site and use the diversion. A mix of different methods (see table 2) was applied. The eye tracker seemed to be essential to detect cyclists' viewing direction and the resulting route choices. There was no information about the construction site or diversion given to the participants, only the start and end of the route was shown on a map. After the ride, the participants were asked to fill out a semi-structured questionnaire including mobility behavior concerning cycling, personal information and special incidents on their rides.

Results

From the eye tracking data, it could be seen that cyclists' eyes usually focused on the construction site in the Lazarettgasse early on.



Figure 4 Example eye tracking results Lazarettgasse from participant no. 5 (heatmap left) and example eye tracking results Lessinggasse from participant no. 3 (heatmap right)

The example (see figure 4) shows that the signposts were only briefly spotted and the participant tried to analyze the alternative route options, or identify potential obstacles, but mostly fixed on the intersection.

In general, the cyclists reduced the speed approaching the construction site, in order to check the possibilities for route selection. Differences in behavior of the participants could be noticed: Some cyclists examined the restricted route concerning its navigability, accompanied by a certain deceleration of the speed; others slowed down only slightly, and clearly fixed on the signposts.

In figure 6, the participant no. 3 looked back and forth between left and right while slowing down. This implies problems in wayfinding. The participant also focused on signposts, which only indicated a roadblock. At the Lessinggasse the correct diversion was not used by any of the test persons, but there were no signposts at all to guide the cyclist to the diversion road. However, the diversion was quite unsafe for cyclists as there are higher traffic volumes, more road lanes and tram rails.

The junction before the respective diversion was a substantial focal hot spot in both field tests. Starting from this point the diversion begins and the cyclist has to make a decision which route to take. It often came to a standstill, as the signposts were unclear or badly recognizable. The overall results could lead to recommendations regarding how and where to signpost construction sites for a better orientation of cyclists. In addition, the diversion has to be chosen and examined carefully to prevent danger of the cyclists.

5. Reflection on methods

The methods applied in these case studies are well established in laboratory environments. The transfer to a real-world setting acquires a differentiated discussion and reflection of the research criteria objectivity, reliability and validity. The validity is more important than the reliability, and this again exceeds the objectivity (Diekmann 2007). In context of bio-physiological data, the objectivity is given through the measurement by instruments and these “are inherently better shielded from both subject bias and experimenter bias than are either reported measures or measures based on behavior observations” (Meehan et al 2002). A reliable measure is one that returns the same result each and every time. Validity determines whether the research truly measures what it was intended to measure (Schnell et al. 2014).

The eye tracker is very useful when it comes to visualize the eye movement and gaze patterns – mostly used for monitors. The objectivity of the application should be given through the device itself, the standardized instruction for the riders, as well as the minimization of influences in the surrounding area (e.g. other cyclists, changing weather conditions) (ibid.). The analysis software for the gaze data provided by TobiiGlasses should guarantee the objectivity of data interpretation. The reliability in data acquisition by eye-tracking is essentially determined by the accuracy and precision of the technology. Nevertheless, the real-world conditions must be considered as the technology was designed for indoor tests on monitors. For example, since the cyclists are in motion, it takes the eye tracker time to record the surrounding, which results in fewer fixation points. The assessment of the validity of the method is difficult, since there are no precisely determinable parameters available and the validity can be related to different aspects: With regard to the use case, the validity consists of how well it is possible to grasp the riders’ activities as precisely as possible while bicycling on construction sites. This means assessing to what extent the measured fixation frequencies and durations (e.g. of signpostings) are valid indicators for the related behavior of the cyclist (Esau & Fletscher 2018). For this purpose, questionnaires have to be included in the evaluation, which have shown some clear similarities.

Stationary EEG and EDA are physiological measurements, which are an established practice in closed laboratory settings (Döring & Bortz 2016). Due to the real-world conditions of the use cases, the objectivity of the process is a challenge, as it is not fully possible to standardize the test situation. In context of the skin conductivity, the values can increase because of physical exercise and the produced sweat. The positioning of the electrodes at the fingers was also difficult as they detached while cycling. A sensor located directly on the wrist (e.g. smartband in Zeile et al. 2016) would be more practical. However, to guarantee the objectivity of analysis and interpretation, it is important to involve medical or psychological expertise and knowledge – especially assessing the raw data and identifying artefacts. In context of the validity, two questions arise: Does the instrument measure what it is supposed to measure and how can the researcher assure that the sensed data is not influenced by other triggers (e.g. thoughts, surrounding noises)? This challenge can be operationalized in questionnaires so the validity of the physiological measures can be established by investigating how well the physiological reactions correlate with one or more of the questionnaire-based measures. Even if reliability is given through the accuracy of the technology, “[o]ne potential source of unreliability is attributable not to the measuring instrument but to the changing nature of the process being measured” (Muckler & Seven 1992). Reliability assumes that the process remains relatively stable over time, which is – even if external influences are minimized in the use cases- not completely given in a real-world setting (ibid).

Although the number of participants in the two case studies seems low, it offered an interpretation tendency and initiated further discussions. The results would have been more statistically robust with a larger sampling size, as it decreases the margin of error. Additionally, random sampling guarantees the representativeness.

6. Conclusion and outlook

This paper presents the results of two case studies in which bikeability was assessed with different focal points by using a combination of traditional, recent and new methods. Traditional methods offer results on qualitative assessments, but are often prone to false statements due to selective perception of participants. In contrast, GPS proved to be useful for retracing the route choices of the cyclist, but it does not allow getting deeper information about his or her motives and perception of the route. The new methods described in this paper move the human perspective more into the center of research. Further, it allows verifying results or statements from qualitative methods, which often underlie the subjective influences of participants (e.g. incorrect answers in questionnaires) or of researchers (e.g. interpretation of qualitative statements). Data from new methods support the identification of stressful events, which can be further used to initiate discussions. The results can be considered as a source of information to help improving (bicycle) transportation planning. However, there are still open research questions, which need further clarification. Especially the transfer of the sensing data into a bikeability index and the process of integration into planning practice needs further research. Additionally, how can the researcher guarantee that the data analysis is fully objective, reliable and valid? How can sensing methods complement traditional methods in travel surveys to achieve comprehensive and robust assessments of bikeability? What are the costs and benefits of sensing methods compared to methods used so far? Which value do the results of sensing methods have as a basis for planning? How can it be assured that the data is handled correctly also against the background of data privacy and ethics?

Consequently, there is a need for further research - especially in the field of data synchronization, interpretation and usability of sensor technologies to enable better use in travel surveys. Technologies for bio-physiological data sensing continue to develop further and researchers are eagerly awaiting sensors, which fit their research demands in a better way. There is certainly a need to unite expertise from different fields – especially cooperation with experts like psychologists or sport physicians. Even if the results of the case studies have to be interpreted with caution, it presents a first step towards integrating the collection of bio-physiological data into the methodology of travel surveys.

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