# A Naturalistic Analysis of Objective and Perceived Urban Bicyclist Comfort


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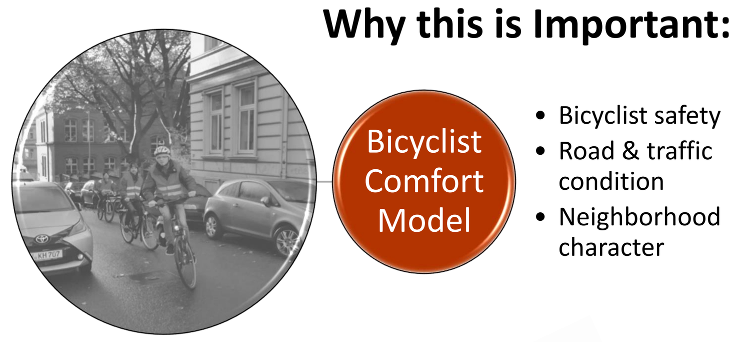
## Abstract


Examining bicyclist comfort is important because increasing the subjective well-being of those using this mode has the potential for long-term utilization, which could have positive effects on the environment and public health. The growing body of research focused on understanding this remains limited. Previous research has only started to assess bicycling comfort in real-time using wearable sensors, and few have accounted for micro-scale streetscape factors such as viewable area and urban form. The current research addresses these gaps. Focusing on an urban neighborhood in Wuppertal, Germany, we harnessed participants with wearable and bicycle mounted sensors to measure bicyclist comfort and the travel environment in real-time, with the goal of understanding where and why it was reduced. We captured micro-scale isovist and topological properties of each streetscape using Space Syntax and accounted for other known bicycling mode-choice factors such as: slope, land-use, road type, and urban density. The perceived and objective variables were first examined using descriptive statistics and geo-visualization techniques in a geographic information system (GIS). The final methodological approach used was a hierarchical regression model, where the dependent variable was average heart-rate per street. Expectantly, our preliminary results showed that streetscapes which were pedestrian friendly and allowed for an even distribution of viewable space positively impacted bicycling comfort, while the increase in the angularity of street intersections had the inverse effect. The findings validate the use of wearable sensors for measuring bicycling comfort, and stress the importance of visibility in designing streetscapes that encourage active transportation modes.

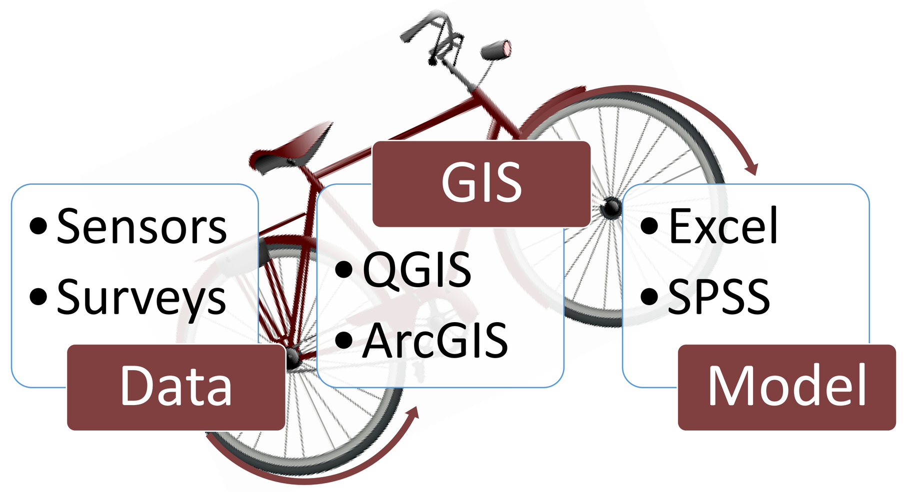

### Why this is Important:




- Bicyclist safety
- Road & traffic condition
- Neighborhood character

Increasing bicyclist mode share is vital in creating a healthy and vibrant urban environment

### Processes:



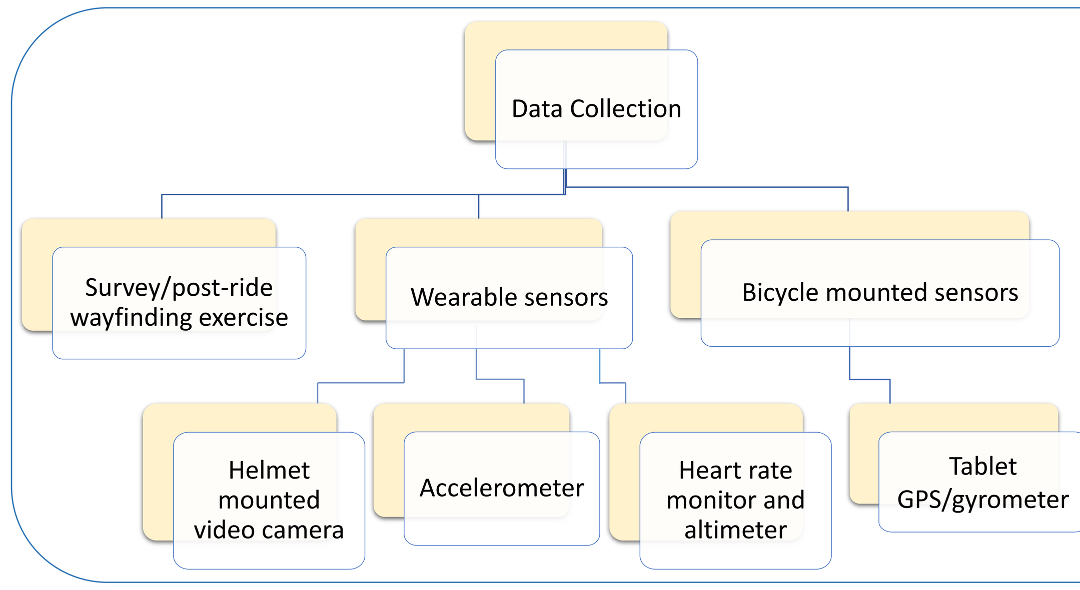

Data collection was performed in both the pre-processing and post-processing phases of the study. Multiple researchers reviewed video data from the same participant for quality control. QGIS and ArcGIS were used in tandem to correct errant GPS points. A spatial join of points to lines was used and timestamp data was used to verify that points were correctly assigned to the nearest polyline. The majority of data management is done during the post-processing phase.

## Research Goals

The goal of our research is to ultimately quantify what factors determine the comfort level for bicyclists on any given roadway. Improving comfort level by addressing concerns with factors that directly affect the measured heart rate of participants will ultimately lead to a greater infrastructure investment for facilities that support bicycle use. Our study area was Wuppertal, Germany. Wuppertal's streets are not designed to support bicyclist facilities. The town lies in a valley with hills on both sides and a river dissecting the city. Terrain in this area makes the city difficult to navigate by bicycle and there is a lack of bicycle lanes, racks for parking, and signage directly applying to bicycles. We affixed volunteer participants with sensors that measure their heart rate, cameras, and bicycles outfitted with sensors that track their geographic location, vibrations, and elevation. The idea is that participants would be shown the general location of two target destinations in order to see how people made their way and determined their routes.

Wuppertal is a city of 350,000 people in an area roughly 168 km². The study area encompassed a small fraction of the overall city, an area of about 1.1 km². The study site is ideal as there are a variety of land use types, changes in elevation, traffic counts, speed limits, road widths and visibilities.

## Data Collection and Methodology

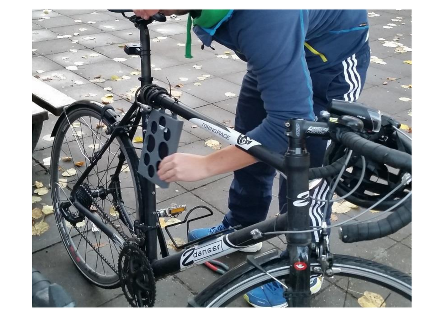



Sensor

Garmin VivoSmart® HR
Barometric altimeter
Heart rate monitor
Accelerometer
GPS

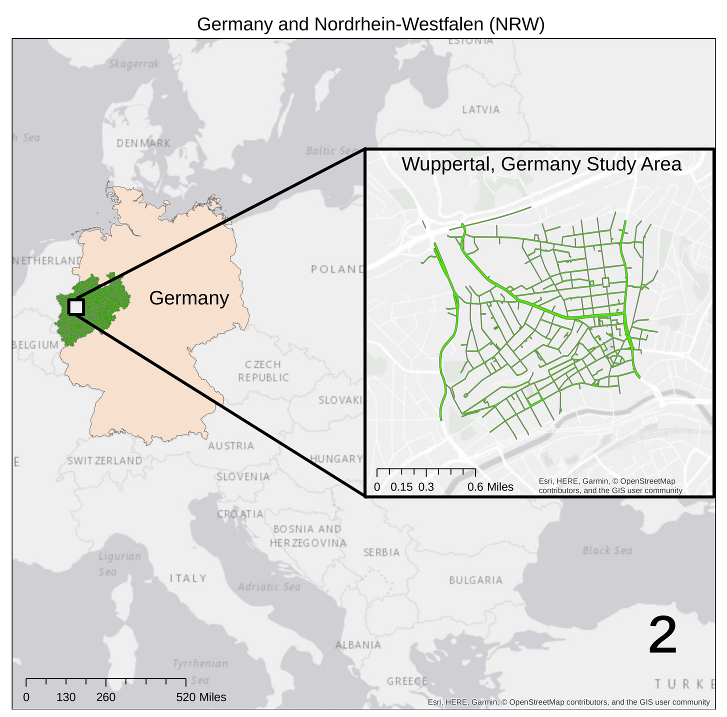
Equipment


Custom made bicycle apparatus for data collection tablet (left, and data collection app (right)



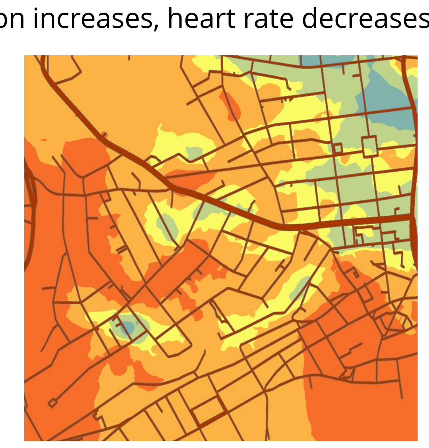
Custom tablet mount affixed to bicycle

## Data

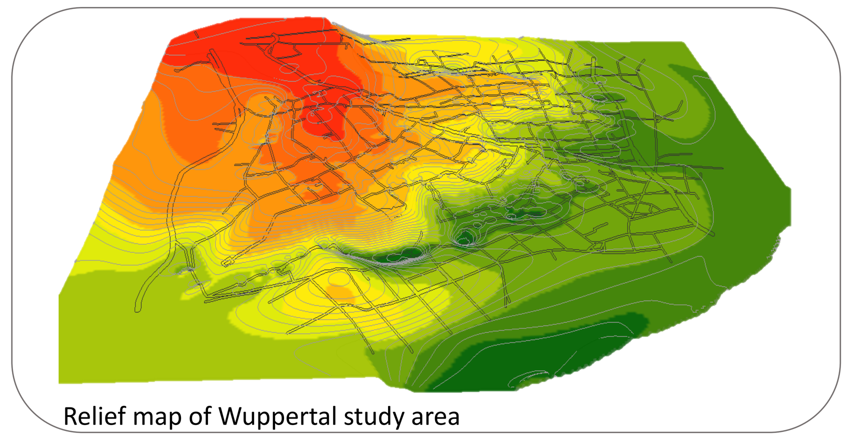



Simple graphic referencing direction for participants.

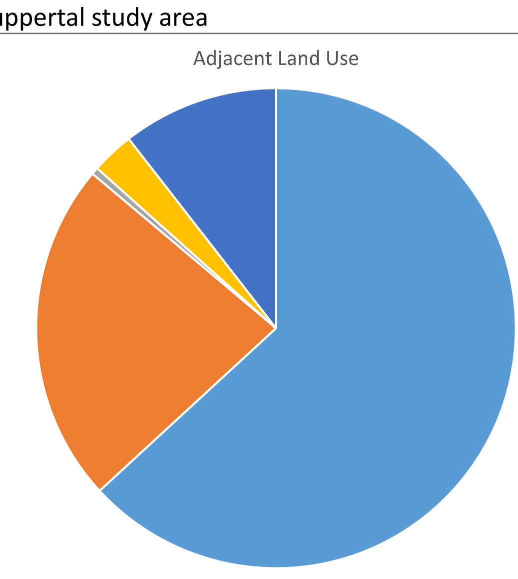
The study was performed during October of 2016, meaning that the majority of leaves have fallen and that visibility may be improved over when the trees are fully leafed. The fallen leaves may hide bumps on the roadways, leading to higher gyrometer readings and possibly elevated stress levels. This study could be replicated across a couple of seasons to account for changes in visibility and traffic patterns. There aren't many urban trees in Wuppertal. From Table 2, we see that there is a weak negative correlation between trees and heart rate. As tree concentration increases, heart rate decreases slightly.



Inverse Distance Weighting yields a raster of areas that experience high average heart rates (orange) and low average heart rates (blue)



Relief map of Wuppertal study area

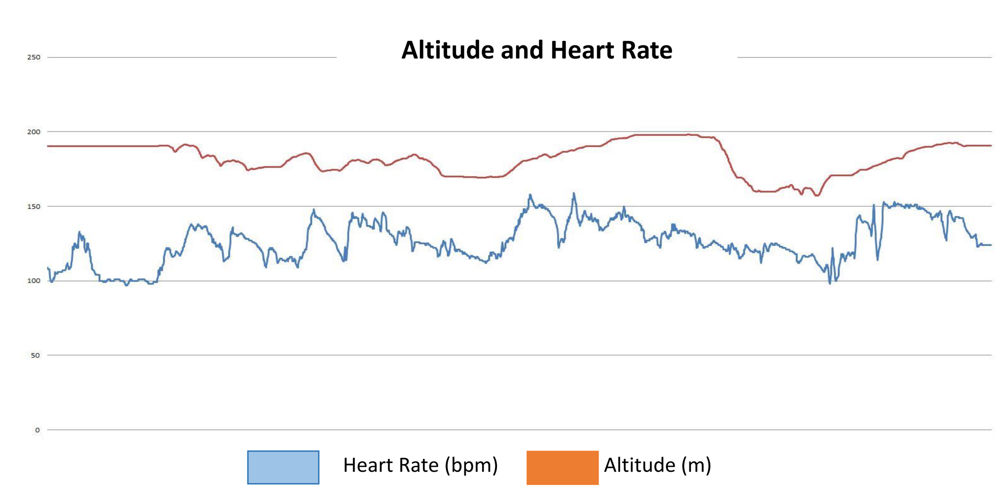



There are a mix of land uses in the study area with the majority being residential.

The streets of Wuppertal feature few to no bike lanes and racks for parking bicycles

There are varying concentrations of urban trees in Wuppertal. The may restrict vision on the western side of the study area where slope is high. It may be hard to see and more stressful to ride in that area as a result of tree density.

| Table 1. Variable definitions and descriptive statistics | | | |
|---|---|---|---|
| **Variables** | **Definition** | **Data Type** | **Mean** |
| **Dependent variable** | | | |
| Heart Rate | Heartbeats per minute | Continuous | 115.73 |
| **Explanatory variables** | | | |
| Visibility | | | |
| Angular depth | Quantity of visible steps around a radius | Continuous | 3.30 |
| Mean depth | Quantity of visible steps that are needed to reach one node to another | Continuous | 6.32 |
| **Urban design** | | | |
| Integration | Average depth of a space to all spaces in the system (ranges from most to least integrated) | Continuous | 2.30 |
| Connectivity | The quantity of immediate neighbors that are directly connected to a space | Continuous | 205.39 |
| ***Roadway character*** | | | |
| Slope | Unit rate of altitude increase | Continuous | 4.49 |
| Vibration | Units per second obtained from a accelerometer | Continuous | 2.41 |
| Road surface quality | Subjective assessment based on: cobblestone, asphalt (good) and asphalt (poor) | Categorical | n/a |
| Speed limit | Posted speed limit per road | Categorical | n/a |
| Approaching automobiles | Proportion of approaching cars | Continuous | .69 |
| Passing automobiles | Proportion of passing cars | Continuous | .34 |
| Stationary traffic | Parked cars averaged across participant videos | Continuous | 10.5 |
| Bicycle facility | Presence of facility type (lane, signage, or rack) per road segment | Categorical | n/a |
| Roadway bicycle space | Distance (meters) allowed for bicycling | Categorical | n/a |
| Roadway type | Government road classification type | Categorical | n/a |
| ***Environment*** | | | |
| Land-use | Land use type along street | Categorical | n/a |
| Road density | Interpolated (IDW) road density per kilometer. Indicator of urban density | Continuous | n/a |



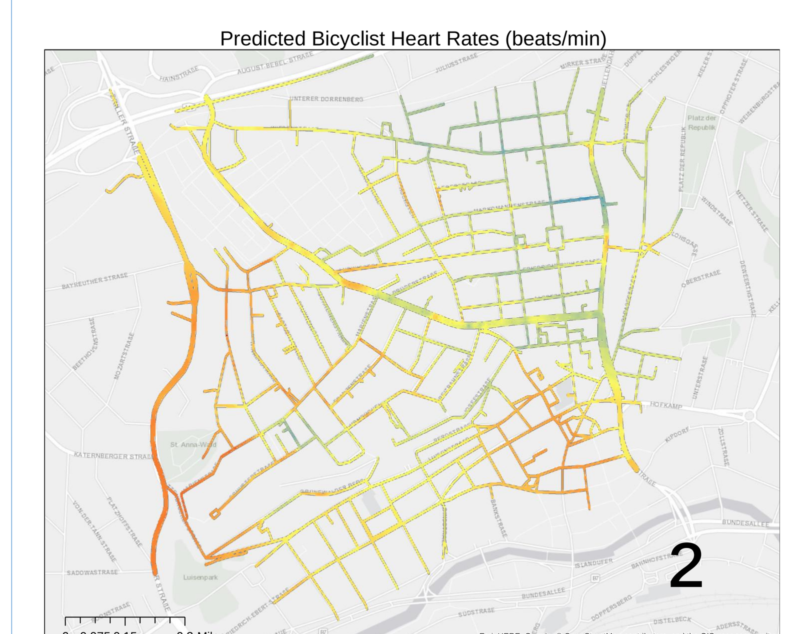

Heart rates and measured altitudes can be compared like this for each participant. Here the average among all participants for both values are shown.

## Results


**Table 2. Pearson product - moment correlation coefficient for select independent variables (n = 8,539)**

| | Heart rate (bpm) | Angular Depth | Mean Depth | Integra-tion | Connec-tivity | Controll-ability | Slope | DCI | Comfort index | Passing autos | Parked autos | Mixed land-use | Bicycle Signage | Tree Density | Road density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Heartrate (bpm)** | 1 | | | | | | | | | | | | | | |
| **Angular Depth** | **.088** | 1 | | | | | | | | | | | | | |
| **Mean Depth** | **.116** | **.816** | 1 | | | | | | | | | | | | |
| **Integration** | **-.141** | **-.753** | **-.877** | 1 | | | | | | | | | | | |
| **Connectivity** | **-0.002** | **-.647** | **-.672** | **.798** | 1 | | | | | | | | | | |
| **Controllability** | **.208** | **.110** | **.224** | **-.153** | **.310** | 1 | | | | | | | | | |
| **Slope** | **.138** | **.145** | **.059** | **-.148** | **-.152** | **.076** | 1 | | | | | | | | |
| **DCI** | **-.137** | **-.122** | **-.110** | **.081** | -0.021 | **-.217** | 0.020 | 1 | | | | | | | |
| **Comfort index** | **-.082** | **.068** | **-.072** | -0.002 | **-.122** | **-.185** | **.162** | **.538** | 1 | | | | | | |
| **Auto passing** | **.029** | **-.457** | **-.337** | .292 | **.492** | **.273** | **.053** | **-.056** | **-.136** | 1 | | | | | |
| **Parked autos** | **.288** | **.233** | **.230** | **-.250** | **-.224** | **.113** | **.083** | **-.237** | **-.243** | **-.167** | 1 | | | | |
| **Mixed land-use** | **-.121** | **-.457** | **-.274** | **.348** | **.438** | **.108** | **-.256** | **.048** | **-.159** | **.268** | **-.221** | 1 | | | |
| **Bicycle Signage** | -0.010 | 0.010 | 0.017 | **-.032** | **-.037** | -0.021 | -0.008 | **.033** | -0.006 | **-.029** | **-.054** | **-.033** | 1 | | |
| **Tree Density** | **-.363** | **.236** | .410 | **-.254** | **-.231** | -.024* | **-.296** | **-.057** | **-.071** | **-.217** | **-.071** | **.261** | -0.003 | 1 | |
| **Road density** | **-.187** | **-.474** | -.578 | **.532** | **.353** | **-.253** | -0.021 | **.248** | **.191** | **.170** | **-.364** | **.021*** | **.045** | **-.216** | 1 |

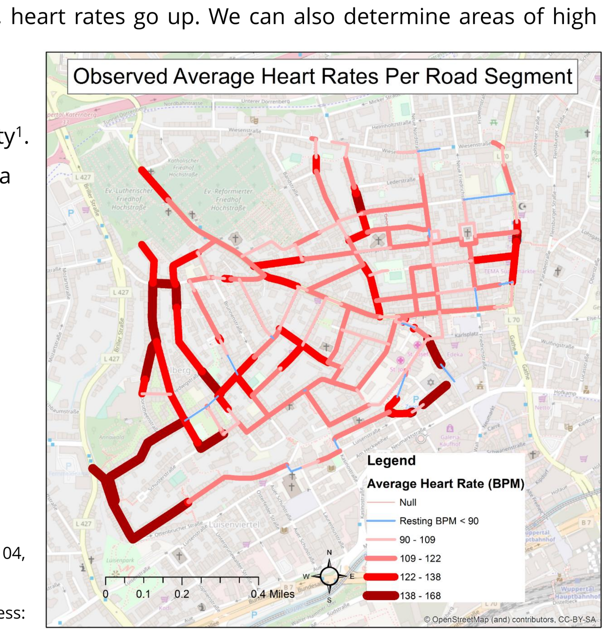
**Bold colors indicate significance at the 0.01 or 0.05 level**




We can see in the map to the left that given the isometric visibility values based on connectivity and the mean depth values associated with each street segments yields high predicted heart rates in areas with diminished visibility. There are certain wide streets with low predicted heart rates that were found to have higher average heart rates due to other factors such as increased traffic and slope. To clarify, mean depth is calculated by assigning a depth value to each space according to how many spaces it is away from the original space, summing these values and dividing by the number of spaces in the system less one (the original space)[2].

## Conclusions

After analyzing the data from our 27 participants, we can see that the association with connectivity and heart rates are highly negatively correlated. This means that as connectivity goes down, heart rates go up. We can also determine areas of high observed heart rate, as shown in the map to the right. The roads that are symbolized in the thickest red have average heart rates that meet or exceed the CDC's guidelines for intense physical activity[1]. As shown in the correlation table above, these high heart rates are a Result of high volumes or passing cars, and connectivity issues. The experience of riding in Wuppertal confirms that streets with high slopes, no bicycle lanes and drivers who can be aggressive towards cyclists are major factors in how perceivably comfortable streets are for cyclists. Any modern vibrant city should look into increasing infrastructure support for bicycles as a means to solve transportation and health issues in the future.




## References


[1]Target Heart Rate and Estimated Maximum Heart Rate. (2015, August 10). Retrieved April 04, 2018, from https://www.cdc.gov/physicalactivity/basics/measuring/heartrate.htm

[2]Hillier, B. & Hanson, J. (1984), The Social Logic of Space, Cambridge University Press: Cambridge. pp. 108