Application of Electrodermal Activity Sensors in Transportation Engineering: Opportunities and Challenges

Mohsen Nazemi (presenter), Michael van Eggermond

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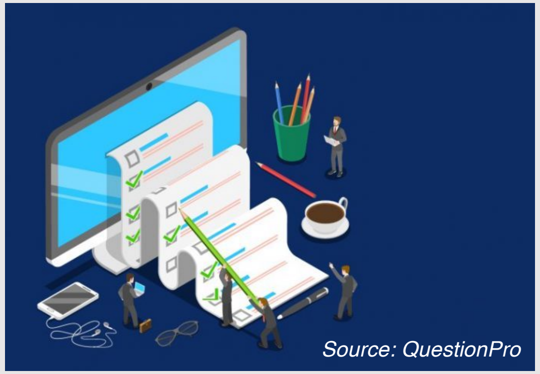
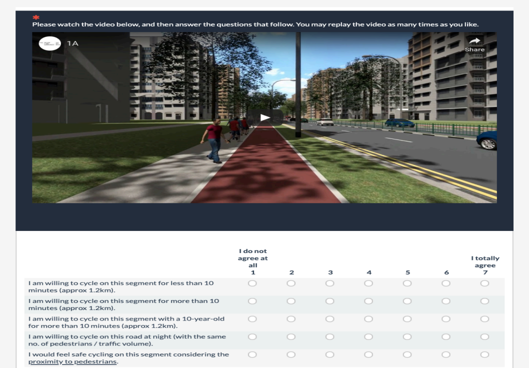

Source: QuestionPro

Survey types

Bicycle road environment surveys[1]:

1. Descriptive: feelings, emotions, and attitudes toward different bicycling environments
2. Comparative: choices of hypothetical alternative bicycling environments
3. Behavioral: Where people should/will ride



Survey limitations

Heavy reliance on respondents' imagination

Different textual or visual cues might lead to different results

Hypothetical biases: overstated / understated opinions (due to misrepresentation of real experiences)

Virtual Reality can help

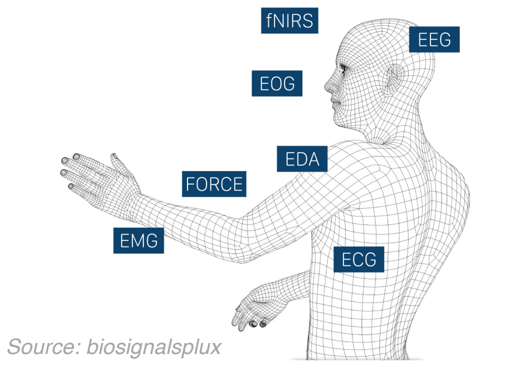
Full control over the experimental manipulation

Enhanced sense of place (eye-level perspective)

Easy variations in design

Replicable scenarios for each participant

Safe controlled environment



Source: biosignalsplux

Physiological measurement as well!

Non-subjective data undistorted by emotion or personal bias

Passive date collection

Non-invasive data collection

Additional behavioural insights beyond self-reported data

1. Fitch, D.T., Handy, S.L., 2018. The Relationship between Experienced and Imagined Bicycling Comfort and Safety. Transportation Research Record 2672, 116–124.

Author (year)	Focus	Who was surveyed?	Perception of . . .	Survey method
Birenboim et al. (2019)	Link	Bicyclists and non-bicyclists	Safety, aesthetics, & enjoyment	Bicycle simulator & VR
Branion-Calles et al. (2019)	City-wide	Bicyclists	Safety	Text
Clark et al. (2019)	Link	Bicyclists and non-bicyclists	Safety & comfort	Images
Caviedes and Figliozzi (2018)	Link & intersection	Bicyclists and non-bicyclists	Stress	Physiological sensors
Fitch and Handy (2018)	Link	Bicyclists and non-bicyclists	Safety & comfort	Video clips & field riding
Ghodrat Abadi and Hurwitz (2018)	Link	Bicyclists and non-bicyclists	Comfort	Rendered images
Griswold et al. (2018)	Link	Bicyclists and non-bicyclists	Safety & comfort	Video clips
Wang and Akar (2018)	Intersection	Bicyclists and non-bicyclists	Safety	Images
Suzuki et al. (2018)	Link & intersection	Bicyclists and non-bicyclists	Safety	Bicycle simulator & VR
Ng et al. (2017)	Intersection	Bicyclists	Safety	Illustration
Boettge et al. (2017)	Link	Bicyclists	Stress	Mental map
Xu et al. (2017)	Link & intersection	Bicyclists and non-bicyclists	Hazard	Bicycle simulator & VR
Lehtonen et al. (2016)	Link	Bicyclists and non-bicyclists	Risk	Video clips
Manton et al. (2016)	City-wide	Bicyclists	Risk	Mental map
Sanders (2016)	Link	Bicyclists and non-bicyclists	Risk	Images
Zeile et al. (2016b)	Link & intersection	Bicyclists and non-bicyclists	Stress	Physiological sensors
Vansteenkiste et al. (2016)	Link & intersection	Bicyclists and non-bicyclists	Hazard	Video clips
Foster et al. (2015)	Link	Bicyclists and non-bicyclists	Comfort	Video clips
McNeil et al. (2015)	Link	Bicyclists and non-bicyclists	Safety & comfort	Rendered images
Chataway et al. (2014)	Link	Bicyclists	Safety	Figures
Dozza and Werneke (2014)	City-wide	Bicyclists	Safety	Instrumented bicycle
Nurul Habib et al. (2014)	City-wide	Bicyclists and non-bicyclists	Safety & comfort	Telephone
Dill and McNeil (2013)	Bicycle facilities	Bicyclists and non-bicyclists	Comfort	Telephone
Jensen (2013)	Intersection	Bicyclists and non-bicyclists	Satisfaction	Video clips
Lawson et al. (2013)	Bicycle facilities	Bicyclists and non-bicyclists	Safety	Text
Sanders and Cooper (2013)	Link & intersection	Bicyclists and non-bicyclists	Safety	Verbal (intercept)
Winters et al. (2012)	Link	Injured bicyclists	Safety	Text
Xing et al. (2010)	City-wide	Bicyclists and non-bicyclists	Safety	Text
Akar and Clifton (2009)	Campus-wide	Bicyclists and non-bicyclists	Safety & bicycle infrastructure	Text
Emond et al. (2009)	City-wide	Bicyclists and non-bicyclists	Safety & comfort	Text
Sener et al. (2009)	Bicycle facilities	Bicyclists	Safety & bicycle facility quality	Text
Møller and Hels (2008)	Roundabout	Bicyclists	Risk and danger	Interview at roundabout
Klobucar and Fricker (2007)	Link	Bicyclists	Safety & discomfort	Video clips
Parkin et al. (2007b)	Link & intersection	Bicyclists and non-bicyclists	Risk	Video clips
Landis et al. (2003)	Intersection	Bicyclists	Safety	Field riding
Leden et al. (2000)	Bicycle crossing	Bicycling experts	Risk	Text
Hughes and Harkey (1999)	Link & curb-side lane	Bicyclists	Risk	Video simulations
Harkey and Stewart (1997)	Link	Bicyclists	Comfort	Video clips
Hughes and Harkey (1997)	Link & curb-side lane	Bicyclists	Risk	Video simulations
Landis et al. (1997)	Link	Bicyclists	Hazards (stress / comfort)	Field riding
Noland and Kunreuther (1995)	Link & intersection	Bicyclists and non-bicyclists	Risk	Text
Sorton and Walsh (1994)	Link	Bicyclists	Stress	Video clips

Source: adopted from Lawson et al. (2013), Table 1.

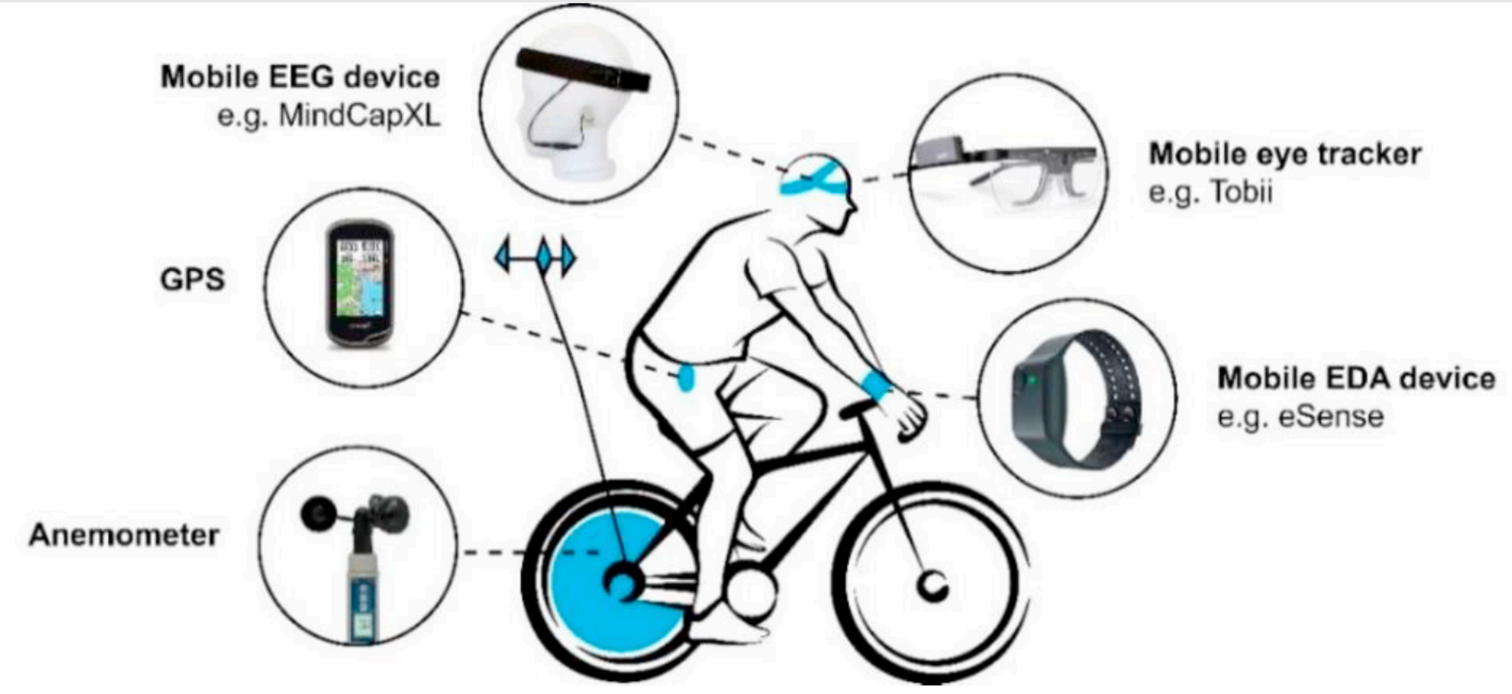
Literature summary

Studying bicyclists' perceived safety

Methods and materials:

- Surveys (representation methods)
  - Telephone
  - Intercept
  - Text
  - Image
  - Illustration
  - Video clip
  - Mental map
- Field studies
  - Equipped bicycle
  - Physiological sensors
- Simulators
  - Video simulation
  - Interactive simulation

Literature summary
Physiological measurements with sensors in bicycle research



Source: Berger, M., Dörrzapf, L., 2018. Sensing comfort in bicycling in addition to travel data. Transportation Research Procedia 32, 524–534.

A range of sensors have been employed to measure bicyclists' comfort in the field.

How **sensitive** physiological sensors are in the field and in the laboratory?

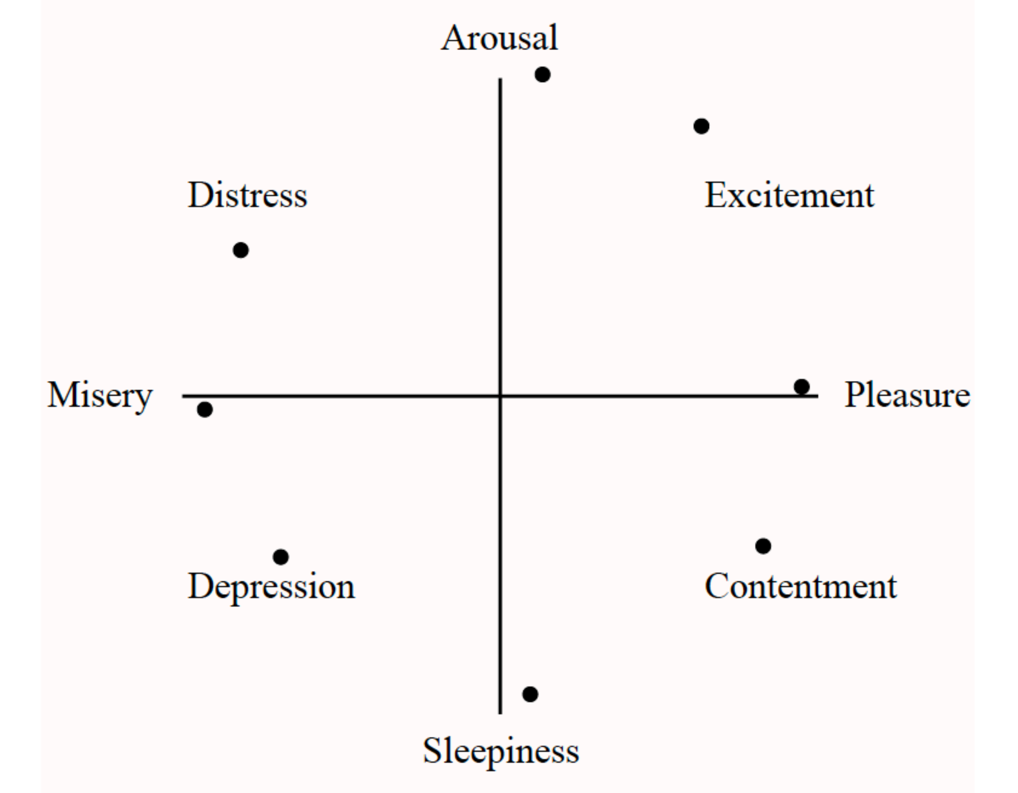
How **reliable** are the measurements?

What is the **influence** of **movement**?

How to **analyse** the data?

Contents

Identifying emotion



Source: Russell (1980), Figure 1.

Circumplex model of emotion:
eight affect concepts in a circular order

Models to **classify** the spectrum of **emotion**

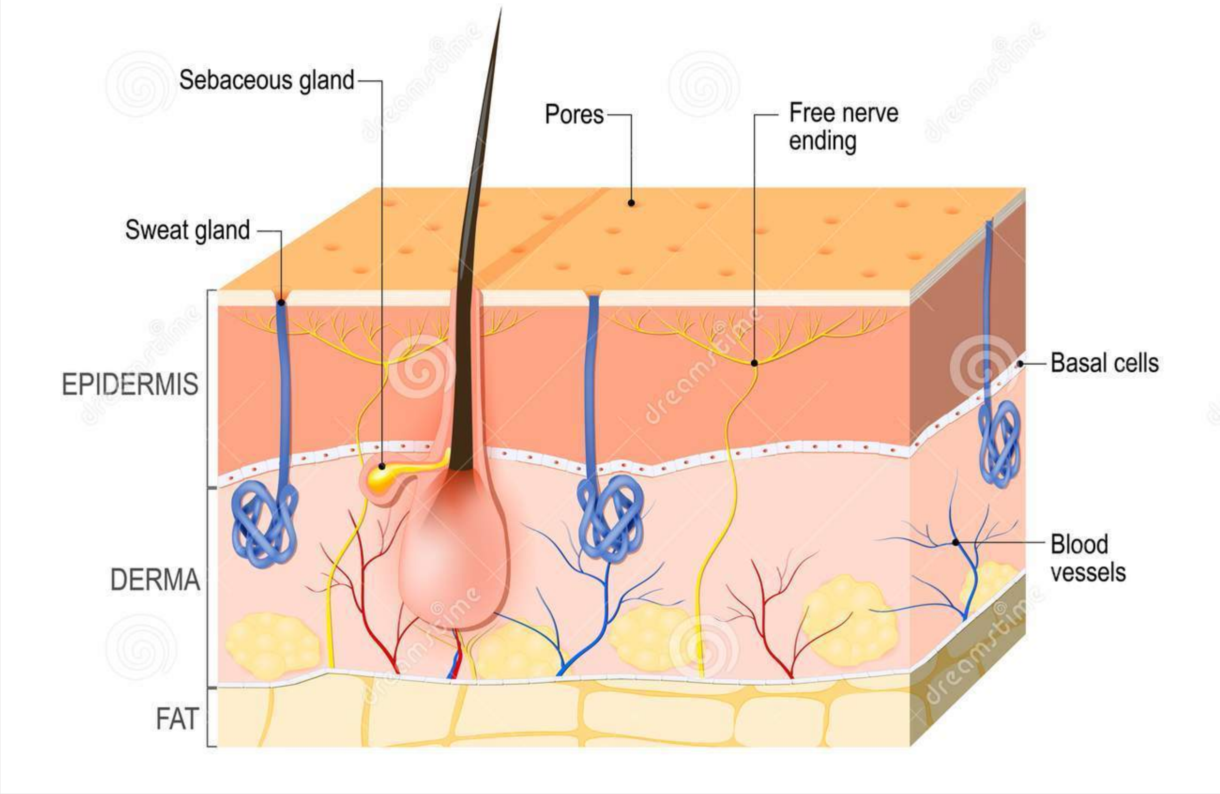
Valence and **arousal** as the two fundamental axes

Ratings to different stimuli by using self-assessment manikins (SAM) **quantify emotional states**, i.e. the amount of valence or arousal.

Level of arousal can be quantified by **EDA sensors**

Stress: a measure of **arousal** with a slightly **negative** valence skew

Electrodermal activity (EDA)



Structure of the skin

Source: 104027700 © Designua Dreamstime.com

Various psychological processes such as **cognitive load** or **stress** activate the sympathetic branch of the nervous system.

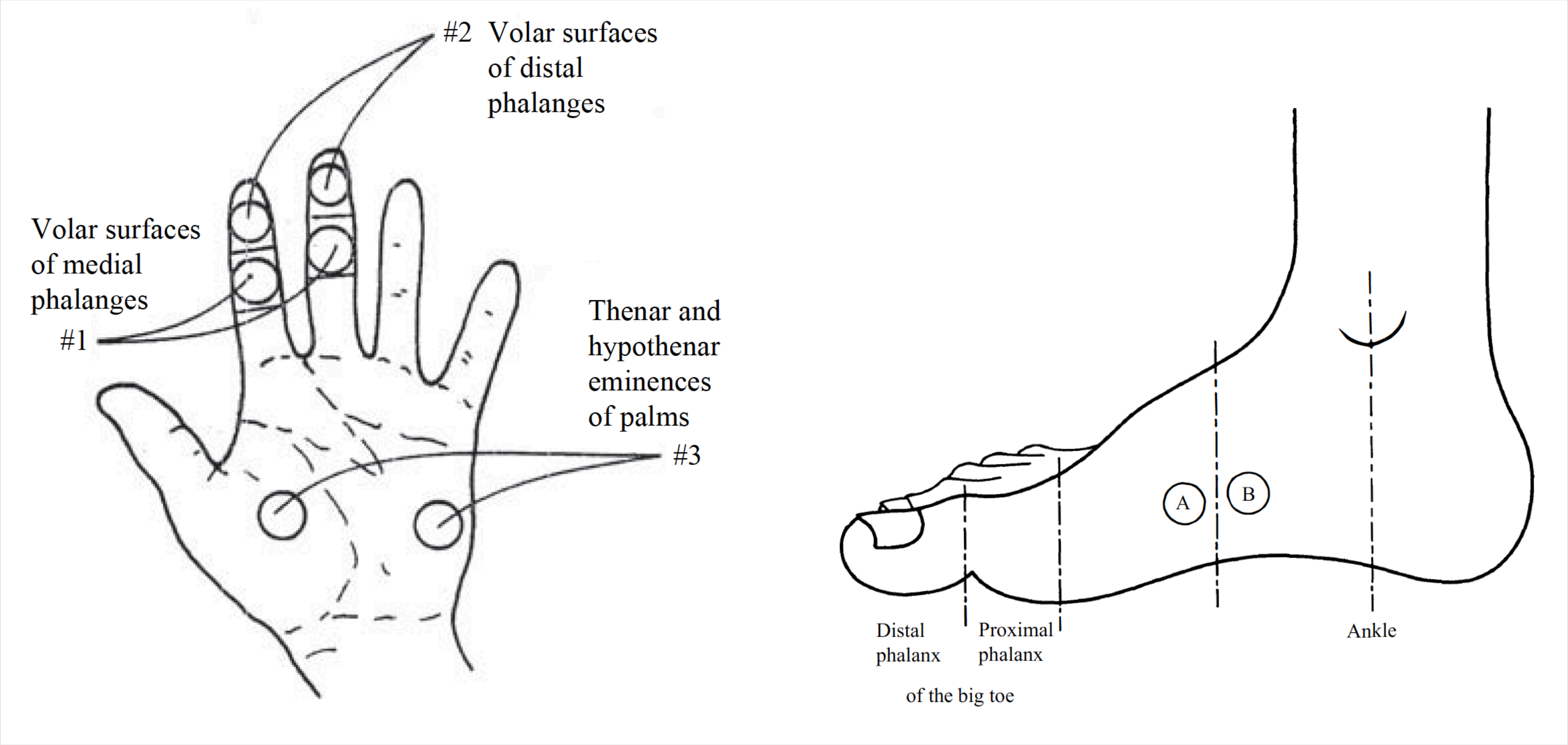
This results in **more sweating** and because sweat is an electrolyte solution, the skin conductivity increases.

Increased skin conductivity in turn can be measured by placing two **electrodes** on the skin and apply a small current.

The amount of current that passes between the electrodes is defined as **skin conductance** (measured in **Micro-Siemens**) and mirrors the underlying **electrodermal activity**

Electrodermal activity (EDA)

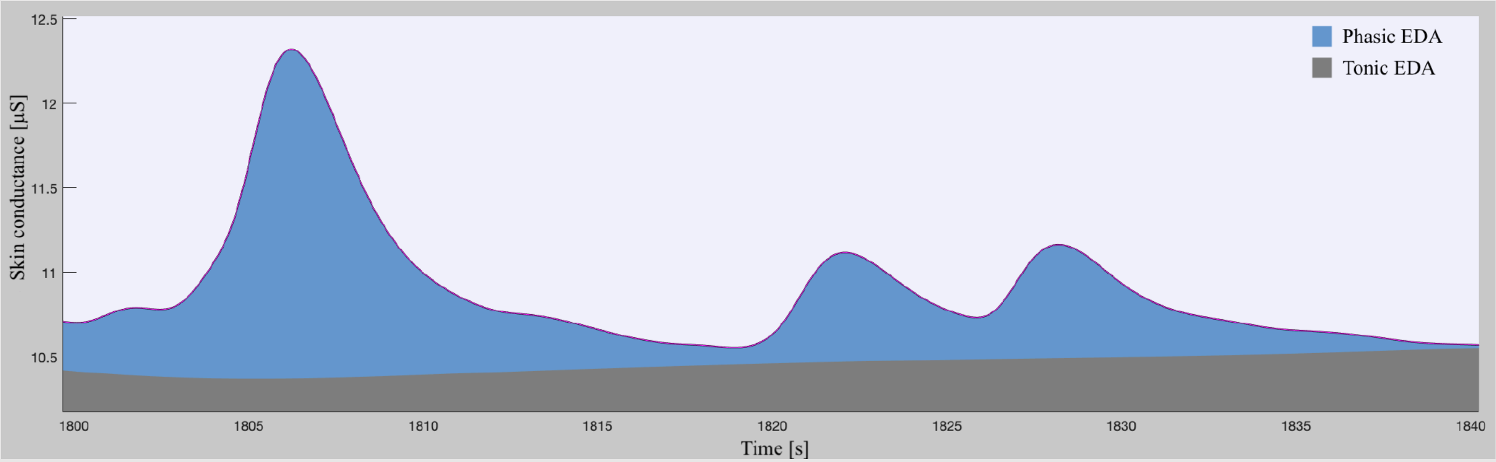
Recommended placement of the electrodes to collect EDA data

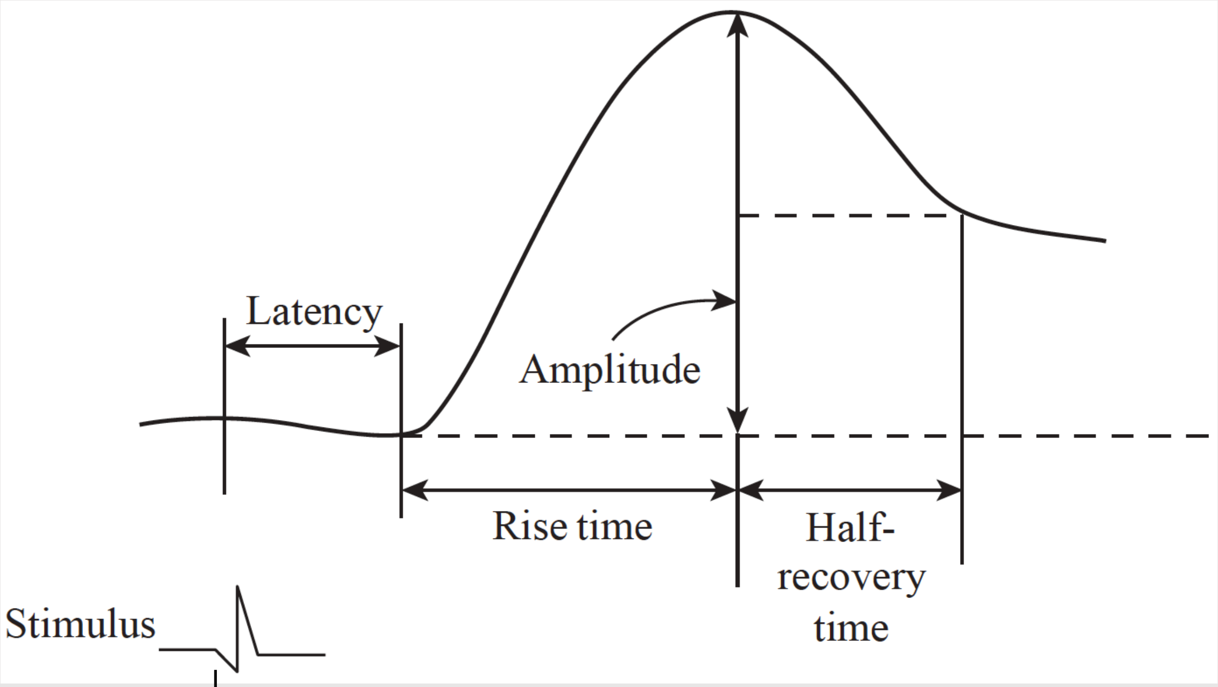


(Left) three recommended electrode placements for recording SC on hand.
(Right) recommended electrode placements for recording SC on foot.

Source:
(Left) adopted from Dawson et al. (2016), Figure 10.3.
(Right) adopted from Boucsein (2012), Figure 2.7.

Skin conductance signal
Stimulus, latency, and arousal





Source:
Dawson et al. (2016), Figure 10.5.

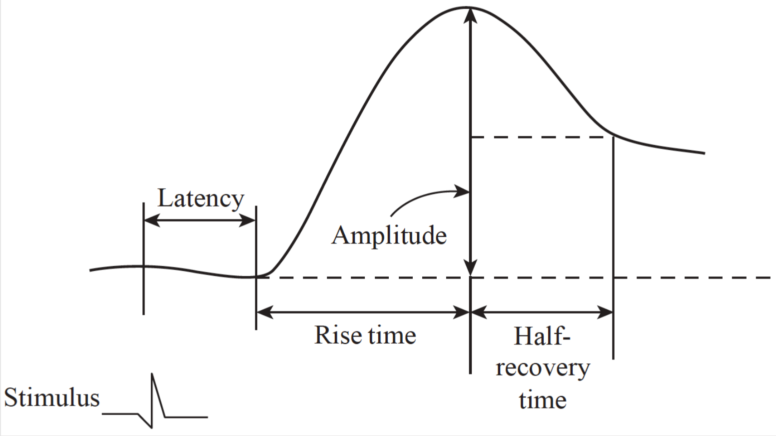
For example: oncoming pedestrian, noise of a bus approaching, etc.

EDA signal is composed of an overall slow drifting signal, called **tonic level**, overlaid by short-term **phasic fluctuations**, called **skin conductance responses** (SCRs)

Response takes place 1 to 4 seconds after the stimulus, called **latency**

Amplitude: phasic increase in SC from SCR onset to its peak (most commonly used measure)

EDA measures
Typical values



Electrodermal measures, definitions, and typical values

Measure	Definition	Typical Values
Skin conductance level (SCL)	Tonic level of electrical conductivity of skin	2–20 µS
Change in SCL	Gradual changes in SCL measured at two or more points in time	1–3 µS
Frequency of NS-SCRs	Number of SCRs in absence of identifiable eliciting stimulus	1–3 per min
SCR amplitude	Phasic increase in conductance shortly following stimulus onset	0.1–1.0 µS
SCR latency	Temporal interval between stimulus onset and SCR initiation	1–3 s
SCR rise time	Temporal interval between SCR initiation and SCR peak	1–3 s
SCR half recovery time	Temporal interval between SCR peak and point of 50% recovery of SCR amplitude	2–10 s
SCR habitation (trials to habituation)	Number of stimulus presentations before two or three trials with no response	2–8 stimulus presentations
SCR habituation (slope)	Rate of change of ER-SCR amplitude	0.01–0.5 µS per trial

Key: SCL, skin conductance level; SCR, skin conductance response; NS-SCR, nonspecific skin conductance response.
Source: Dawson et al. (2016), Table 7.1.

Source: Dawson et al. (2016), Table 7.1.

Values are representative of **healthy young adults**

Parameters that affect the typical EDA measures:

- **Age**, **gender**, and **ethnicity**
- Nature of the eliciting **stimuli**
- Recording **environment** (e.g., season, time of day, temperature, humidity, etc.),
- Recording methodology (constant current or constant voltage)

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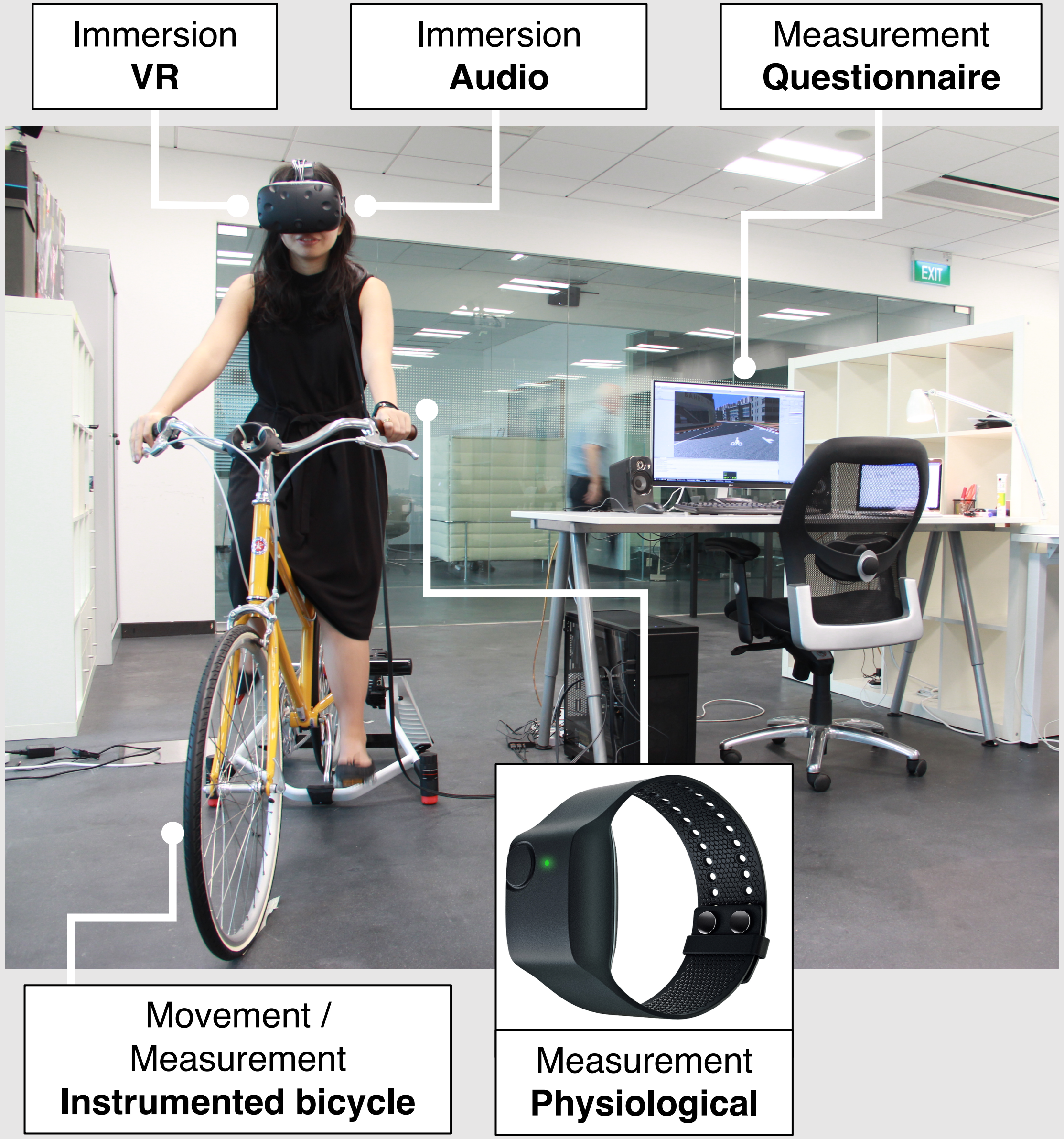


Experiment

Bike to the future

Data sources:

- Questionnaire
- Bicycle simulator
- Physiological sensor

Participants were seated on a bicycle simulator.

Participants could brake and pedal. Steering disabled due to cyber sickness.

Pedalling in VR was synchronized and participants could see their hands on the steering wheel.

EDA Sensor

Source: Imotions.com

EDA sensor and electrodes

Shimmer3 GSR+ sensor

Grabbing the handlebar increased pressure on the electrodes and distorted the signal

The unit was fastened to the arm, two electrodes connected to the inner wrist

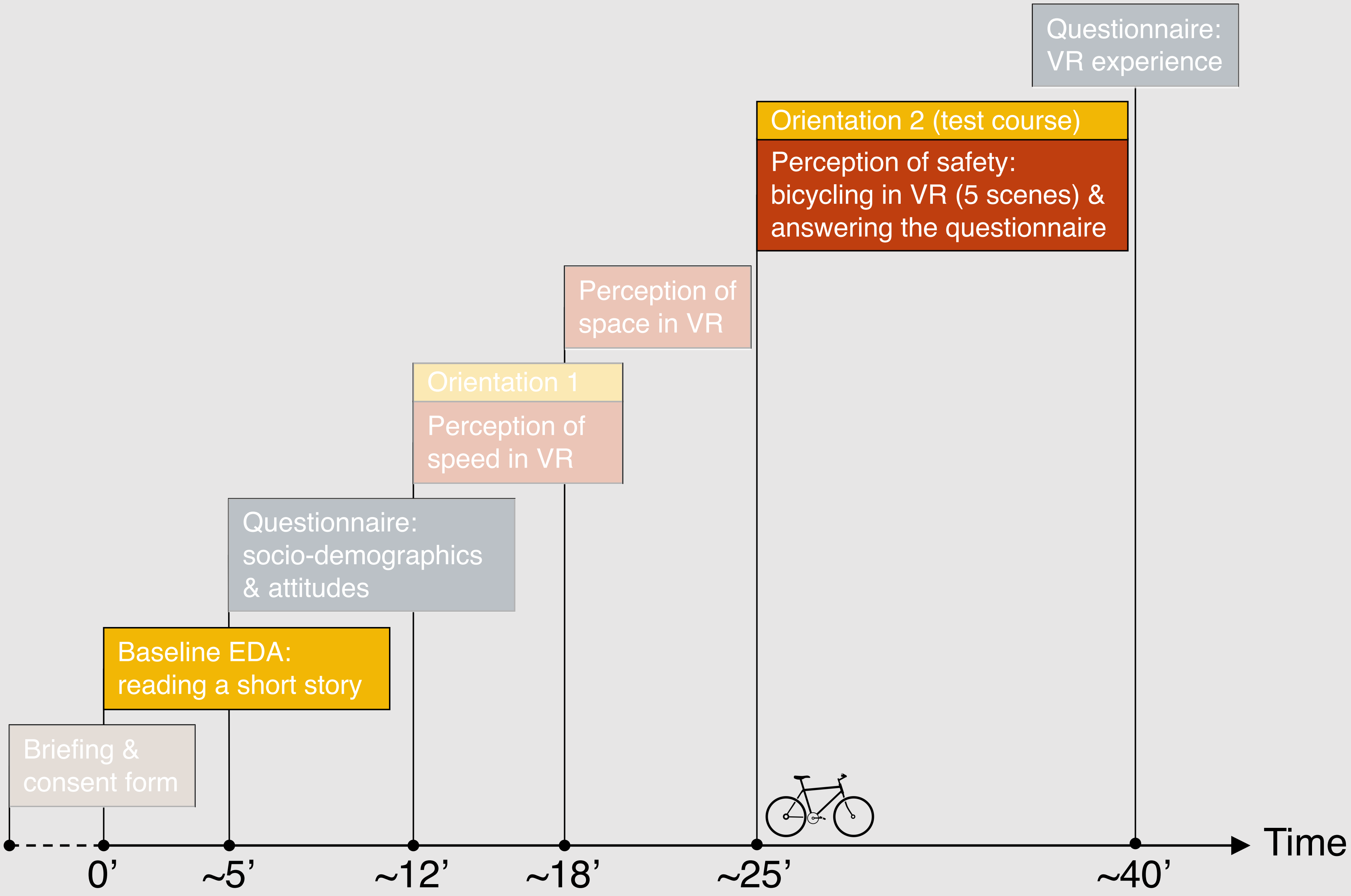
Non-dominant hand, has less movements, avoid artefacts

Brake lever on the left side of the handlebar was taken out to reduce any unnecessary movements due to braking

Sampling rate = 16Hz

Room temperature = 24 °C

Experiment design
Experiment protocol



Baseline EDA:
Participant reads a story

Orientation 1:
Immersion in VR environment (sitting still on the bicycle & there are no other agents)

Orientation 2 (test course):
Bicycling in VR environment (alone with no other agents)

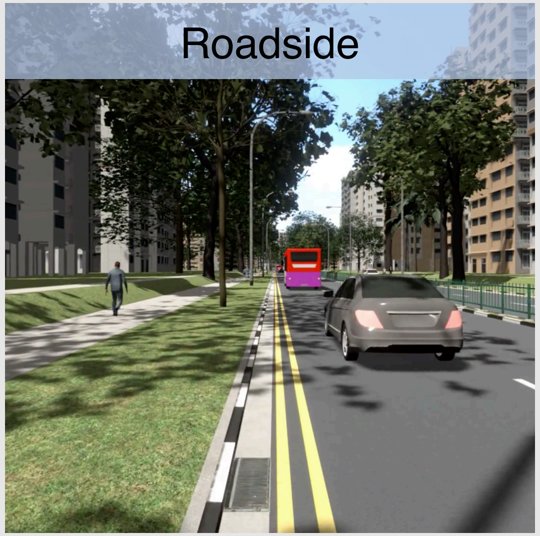
Two different sequences were designed for each part to account for ordering effects

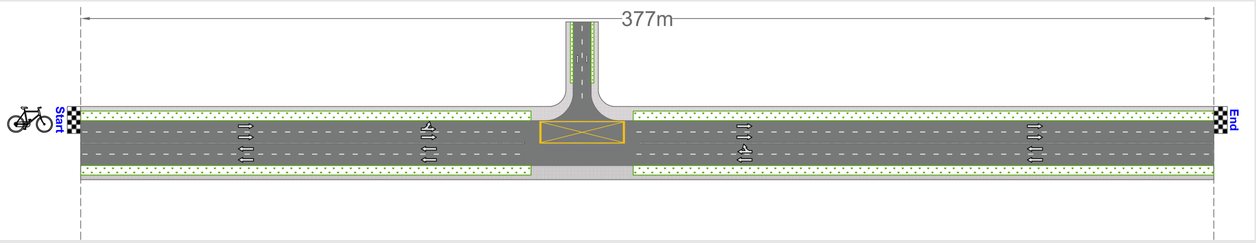
Compensation for 45 minutes
S$15 cash / vouchers

Experiment
Bicycling environments

Five different bicycling environments were designed

All designs were 380m long





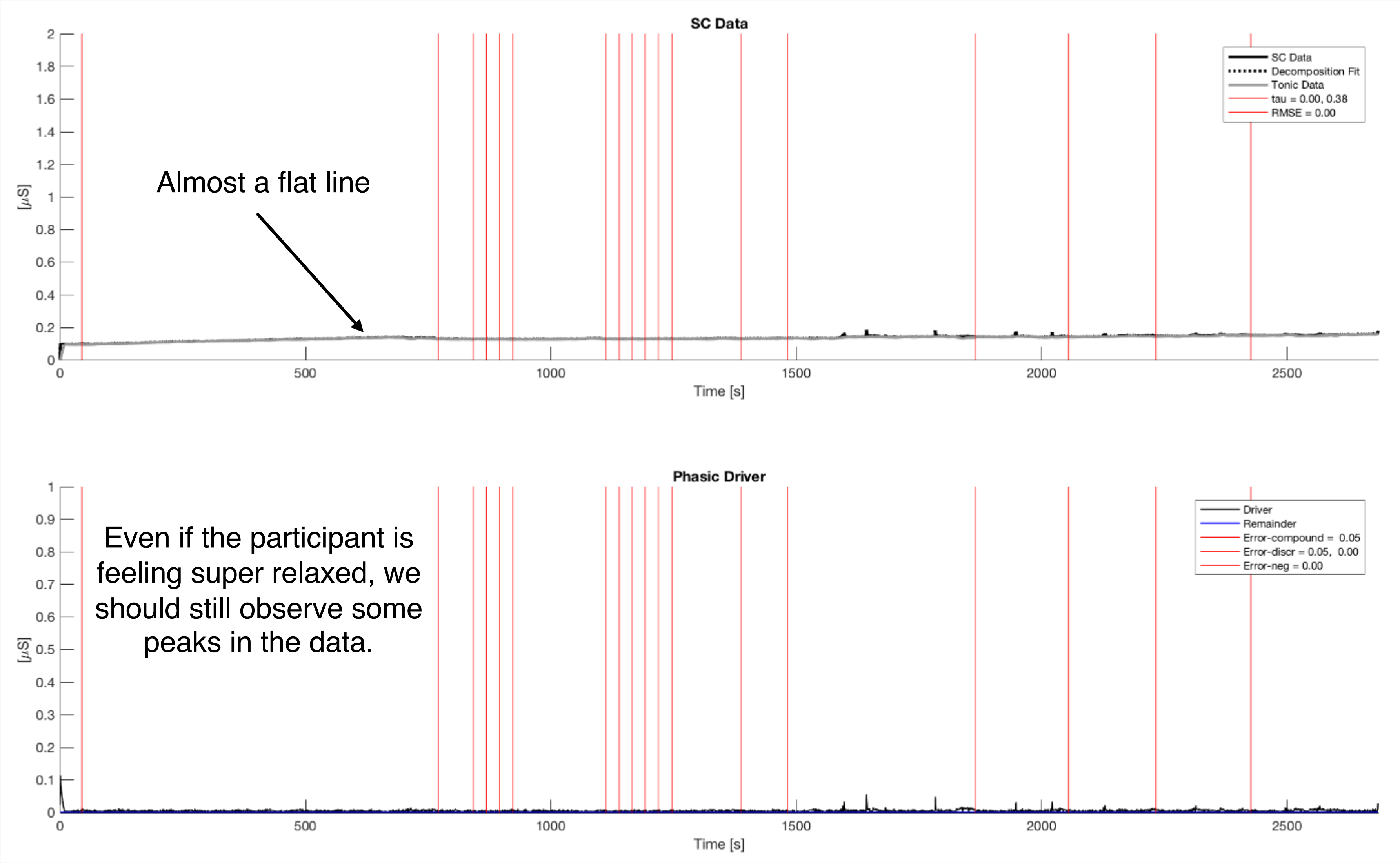
Physiological Sensor
Arousals during bicycling

Visual output indicates how respondents were aroused by **pedestrians**, **intersection**, and **vehicles**.

Contents

Signal processing
Using different sensors

Defective signal: decomposed by **Continuous Decomposition Analysis** (CDA) method[1]



Empatica sensor was used for the first 40 participants; failure rate 38% (Shimmer failure rate was 14%)

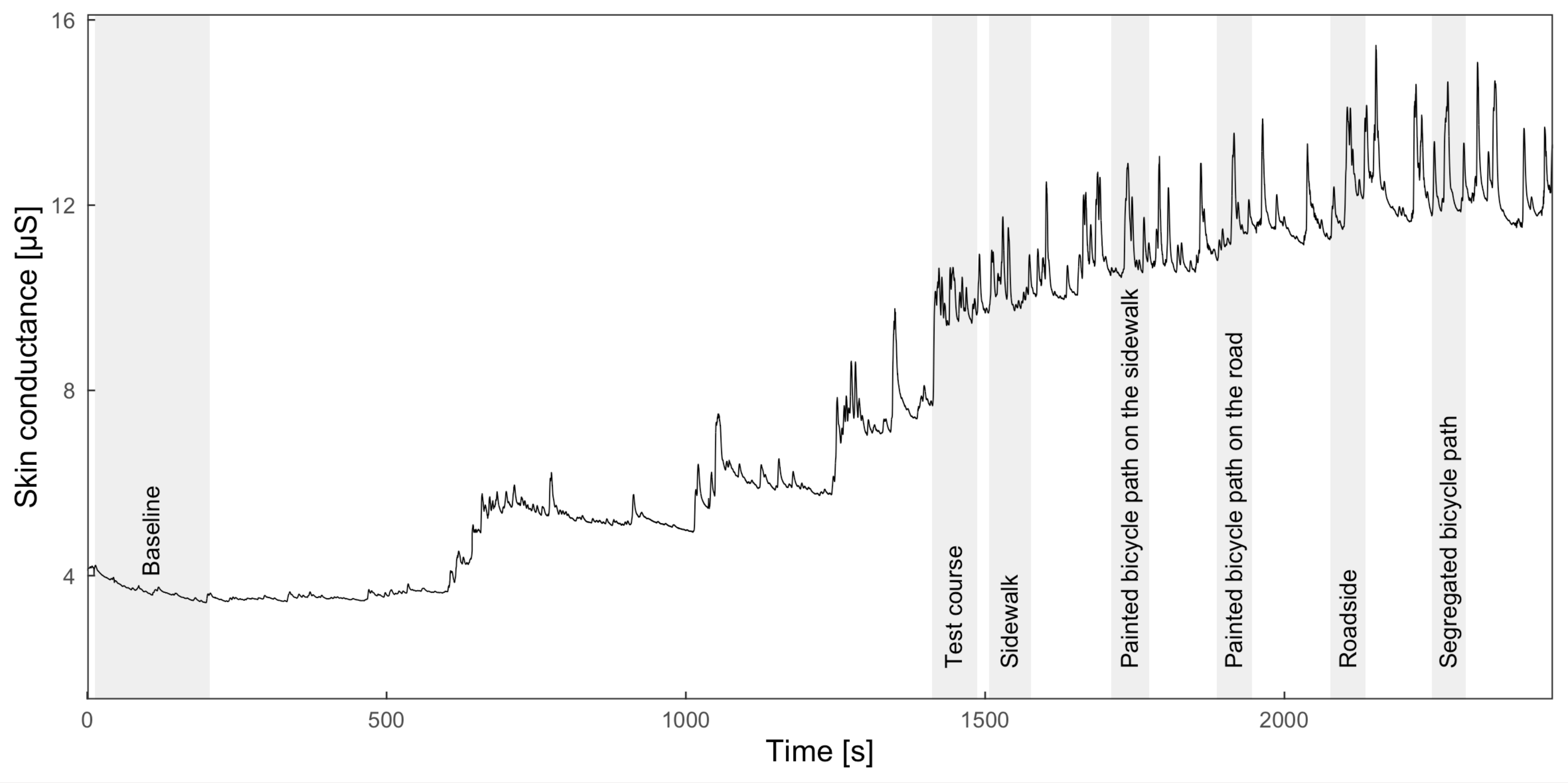
Failure reasons:

- 10% of participants are estimated to be non-responders (hypo-responsive)
- Dry skin type
- Loose electrode connection
- Alcohol/drug/cigarette consumption before the experiment
- The sensor is not sensitive enough

1. Benedek, M., Kaernbach, C., 2010. A continuous measure of phasic electrodermal activity. Journal of Neuroscience Methods 190, 80–91.

Signal processing
Raw data: Shimmer sensor

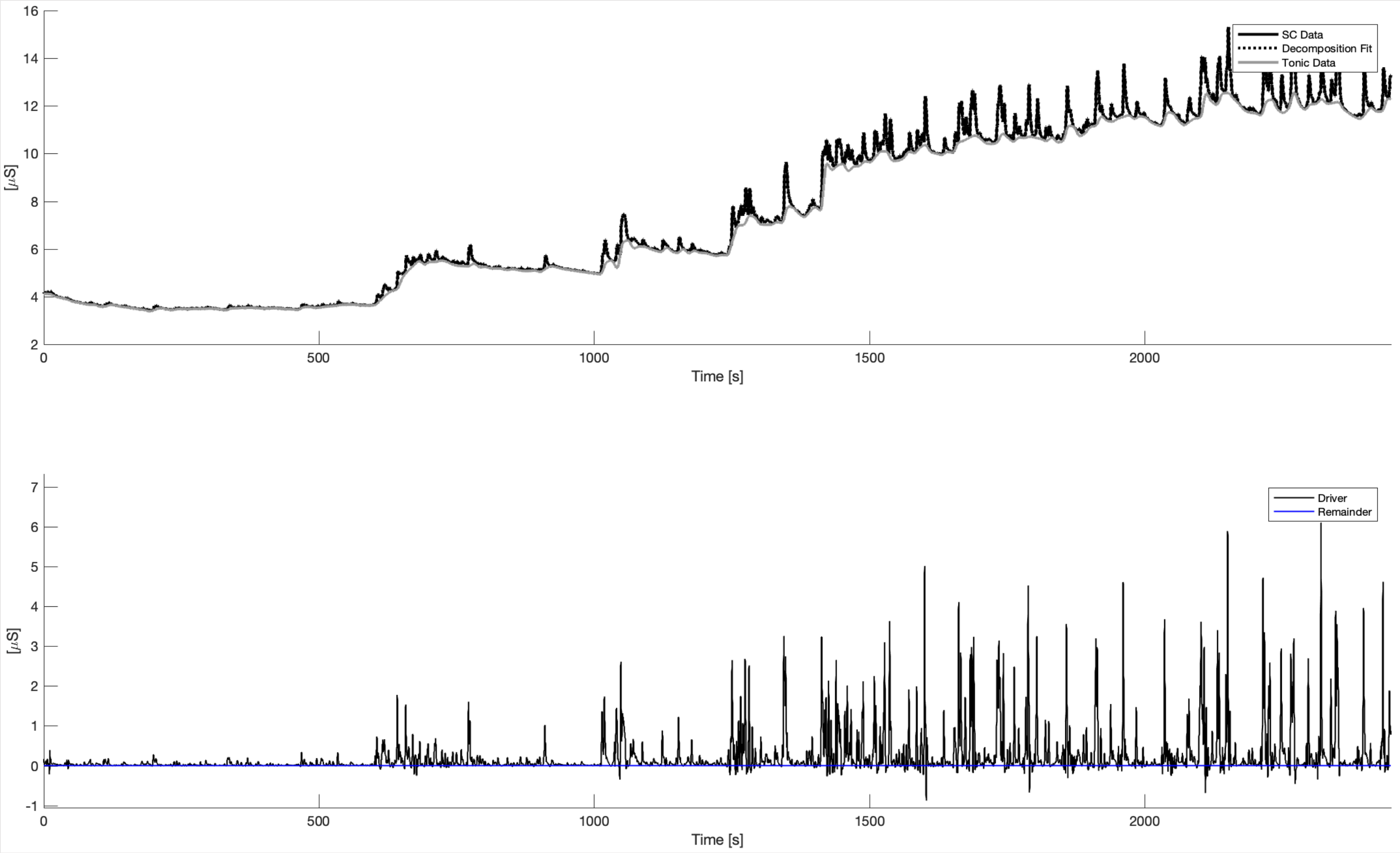
Normal signal



Peaks can be observed throughout the whole signal and at different stages of the experiment.

Signal processing
Raw data: Shimmer sensor

Normal signal (decomposed)



Peaks can be observed throughout the whole signal and at different stages of the experiment.

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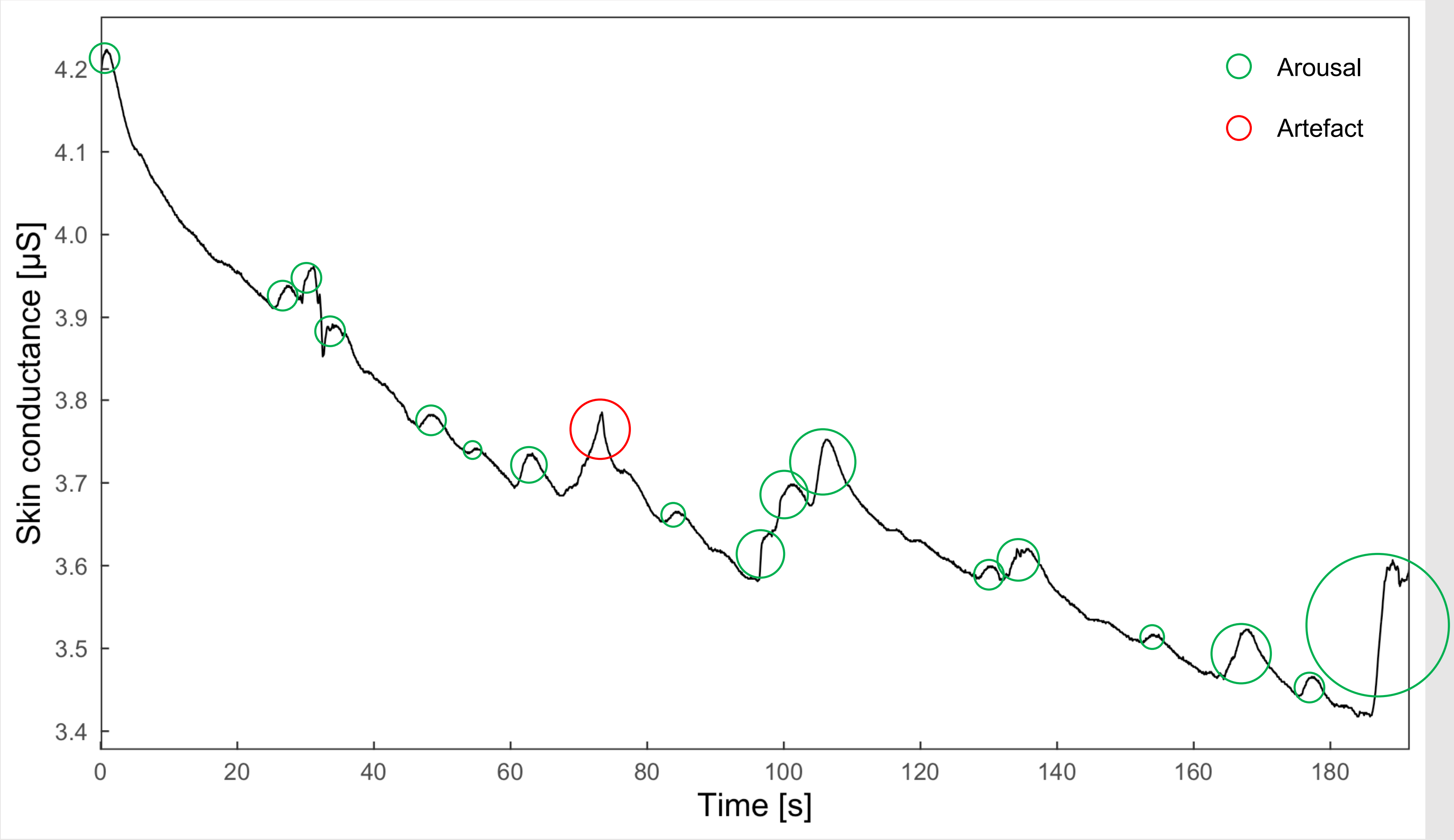
Pre-processing
1. Artefact correction

Raw skin conductance signal during the baseline



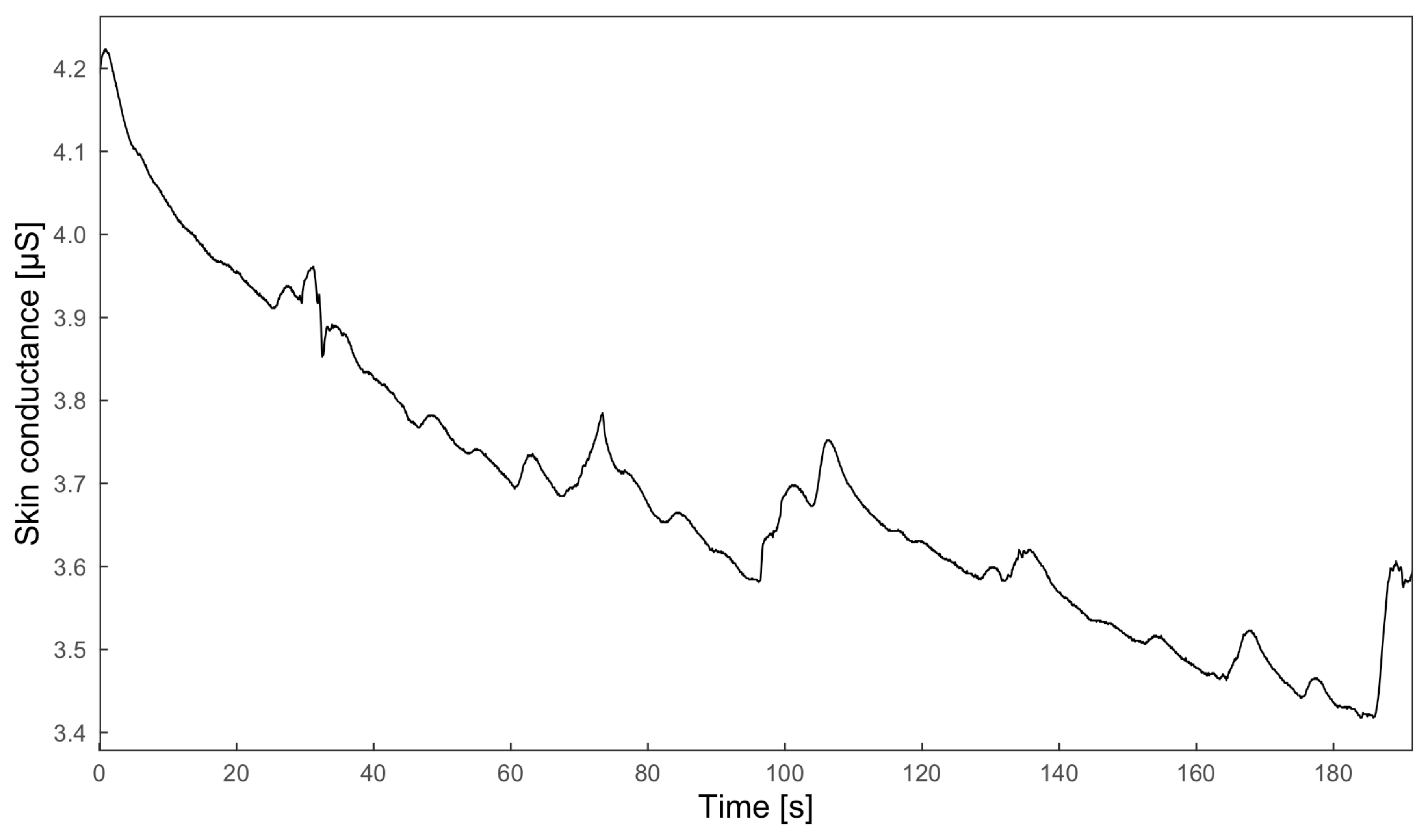
Identifying artefacts by visual inspection and correcting them manually

Artefacts have sharp slopes and sharp angles on the peak

Artefact reasons:
- Hand movement
- Wearing and taking off the head-mounted display
- Movement of electrodes on the wrist

Pre-processing
2. Smoothing

Raw skin conductance signal during the baseline



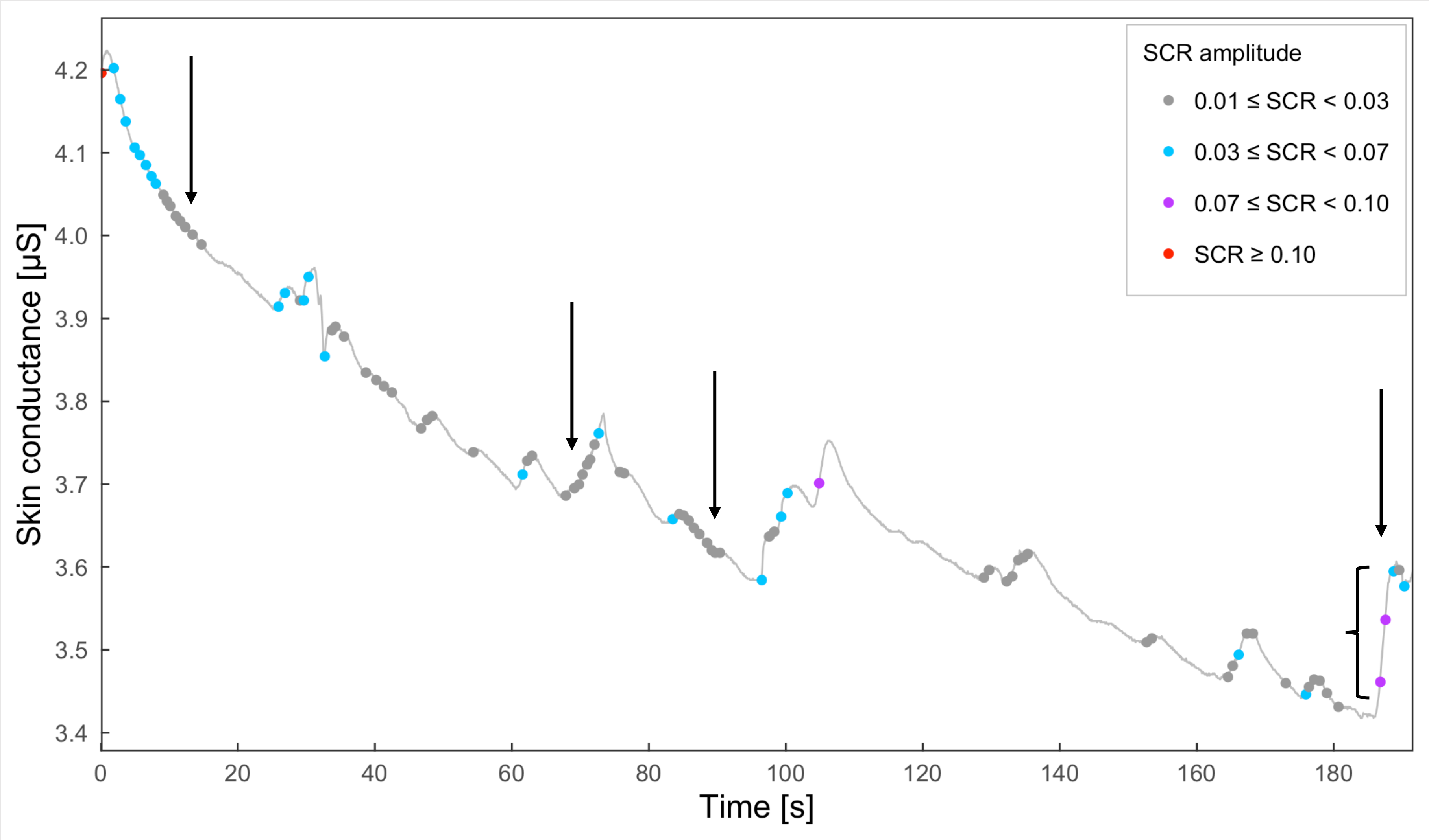
Raw skin conductance signal has a lot of shakes which might be identified as small arousals

Smoothing is critical when number of SCRs (nSCR) is used as a performance measure

Data collection frequency = 16Hz

Pre-processing
2. Smoothing

Not smoothed signal



Not smoothing will result in:

- Too many small SCR's
- SCR's are not strong enough

This can result in erroneous conclusions of the effect of different treatments

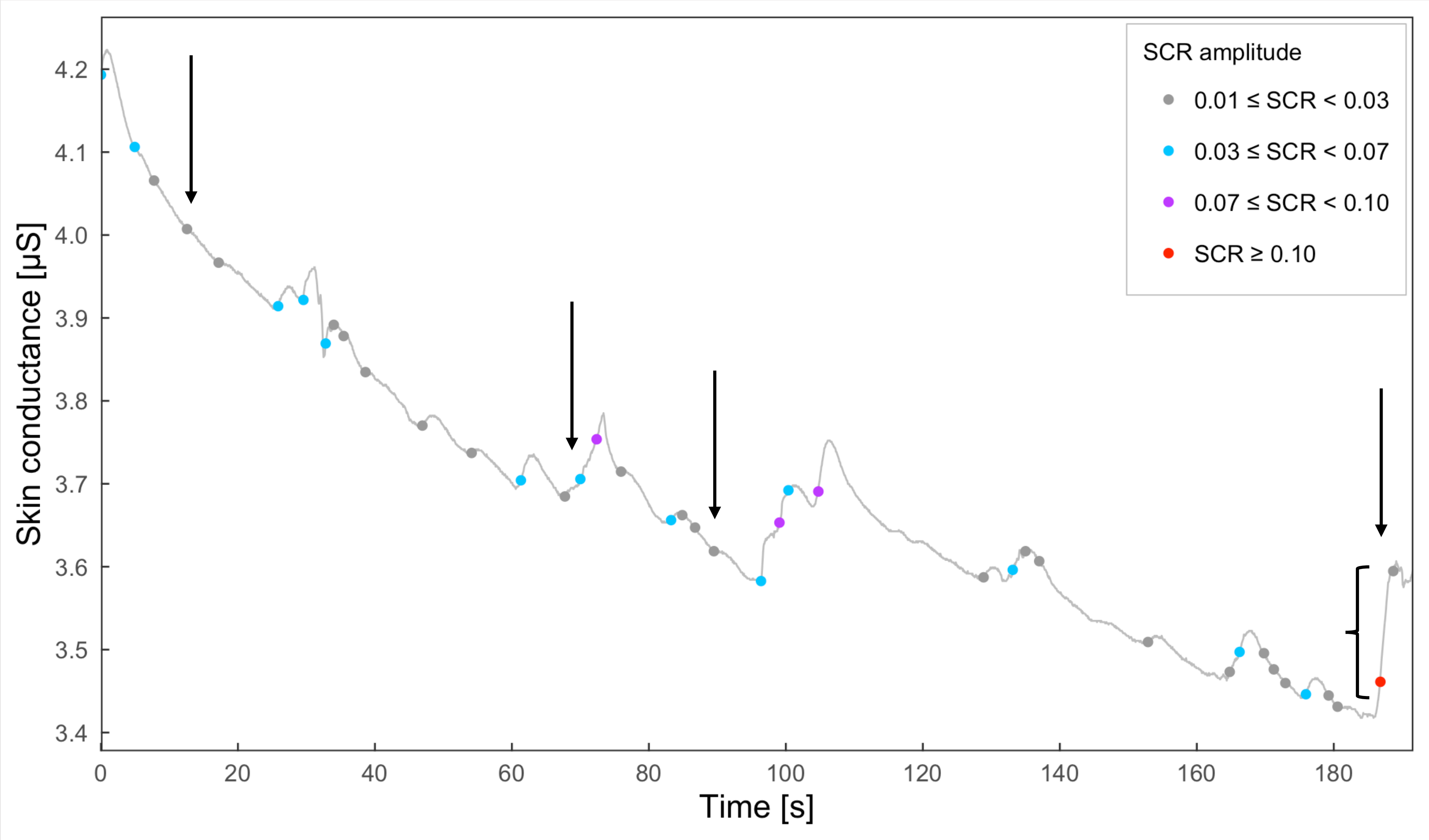
SCR threshold = 0.01

Long and non-stationary signal → Gaussian filter

Small SCRs got removed or, they turned into bigger SCRs

Pre-processing
2. Smoothing

Smoothing window = 48



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Long and non-stationary signal → Gaussian filter

Small SCRs got removed or, they turned into bigger SCRs

Pre-processing
2. Smoothing

Effect of smoothing window size on the measurements

Measurement	No smoothing	Gauss $w = 16$	Gauss $w = 32$	Gauss $w = 48$	Gauss $w = 64$
nSCR	1363	1015	786	611	519
(change %) *		(-25.5)	(-42.3)	(-55.2)	(-61.9)
Marginal change % †			-16.8	-12.9	-6.7
SCR mean	0.15	0.18	0.21	0.25	0.27
(change %) *		(20.0)	(40.0)	(66.7)	(80.0)
Marginal change % †			20.0	26.7	13.3

* Change rows indicate the amount of variation in the measurements due to the window size, compared to the not smoothed data.

† Marginal change rows show the amount of change compared to the previous status of the data which is presented in the column on the left.

Sensitivity analysis for the window size of the Gauss method

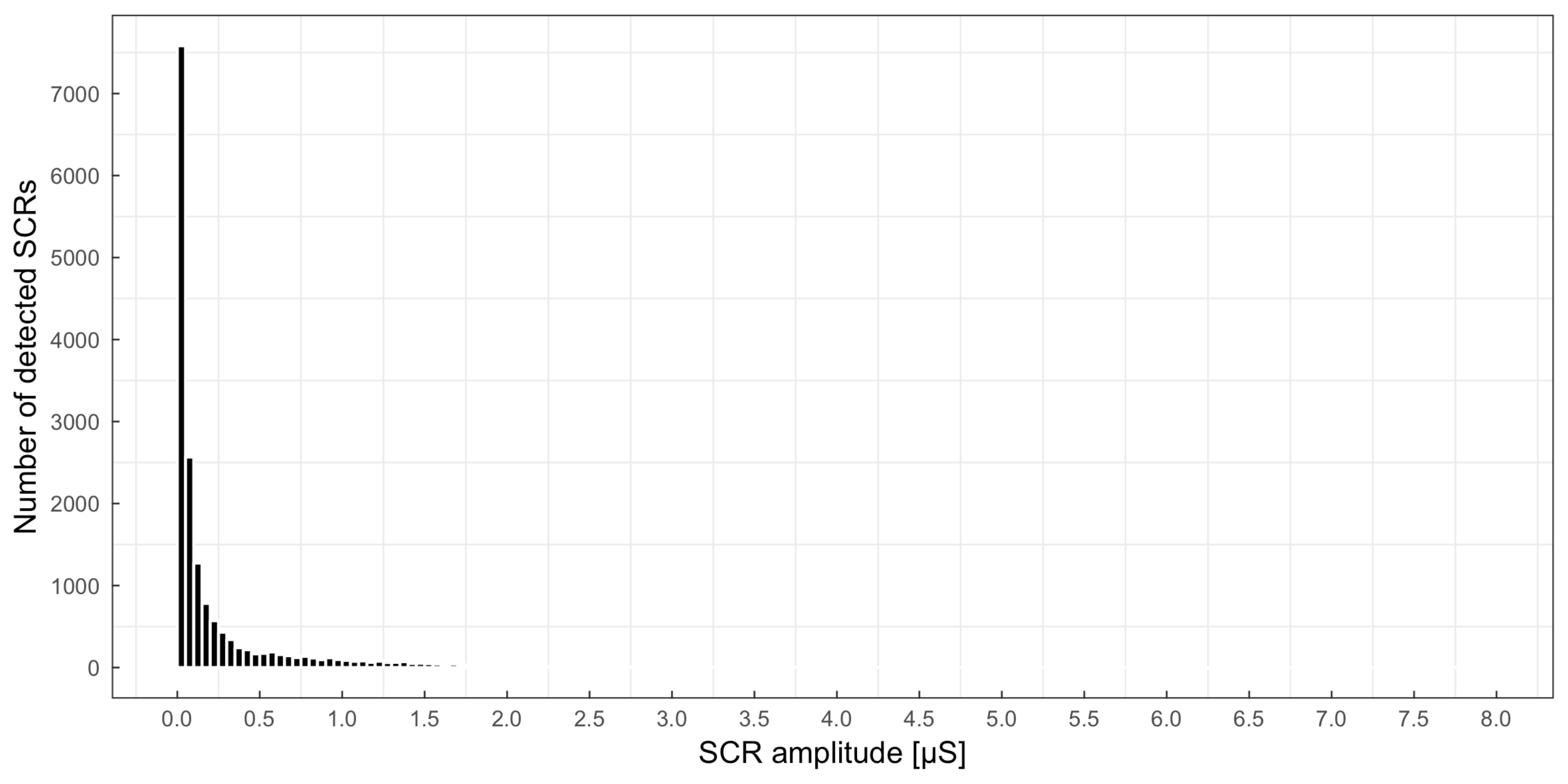
Increasing the window size from 16 to 32, 48, and 64 to observe the changes incrementally

Visual inspection of the results revealed that a window size of 48 performed better in identifying SCRs

Absolute changes and marginal changes also shows how window size 48 outperformed the rest

Post-processing
1. SCR threshold

Histogram of detected SCRs for all participants at all stages of the experiment



Usually SCRs greater than **0.01 μS** are reported

The majority of detected SCRs fell between 0.01 μS and 0.05 μS

Due to the **dynamic** nature of the experiment that involved **physical activity** and **body movements**, the **0.03 μS** was selected as the threshold for statistical analysis, which is also the recommended threshold by Braithwaite et al. (2013)[1]

Visual inspection of the detected SCRs also verified this threshold

1. Braithwaite, J.J., Watson, D.G., Jones, R., Rowe, M., 2013. A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments. Psychophysiology 49, 1017–1034.

Post-processing
2. Variance reduction

Transformation of measurements due to **inter-individual variations** in **nSCR** and **response range**[1]:

- **Standardize** SCRs
- **Transform** normally distributed z scores to **T scores** (*M* = 50, *SD* = 10) to drop out the minus signs

Standardised SCRs

$$z_{ik} = \frac{SCR_{ik} - \overline{SCR_i}}{s_i}$$

z_{ik} = kth SCR standardised value for individual i,
SCR_{ik} = kth raw SCR score for individual i,
$\overline{SCR_i}$ = mean of all SCRs for individual i, and
s_i = standard deviation of all SCRs.

T transformation

$$T_{ik} = 50 + 10\, z_{ik}$$

T_{ik} = kth SCR T score for individual i, and
z_{ik} = kth SCR standardised value for individual i.

1. Ben-Shakhar, G., 1985. Standardization within individuals: A simple method to neutralize individual differences in skin conductance. Psychophysiology 22, 292–299.

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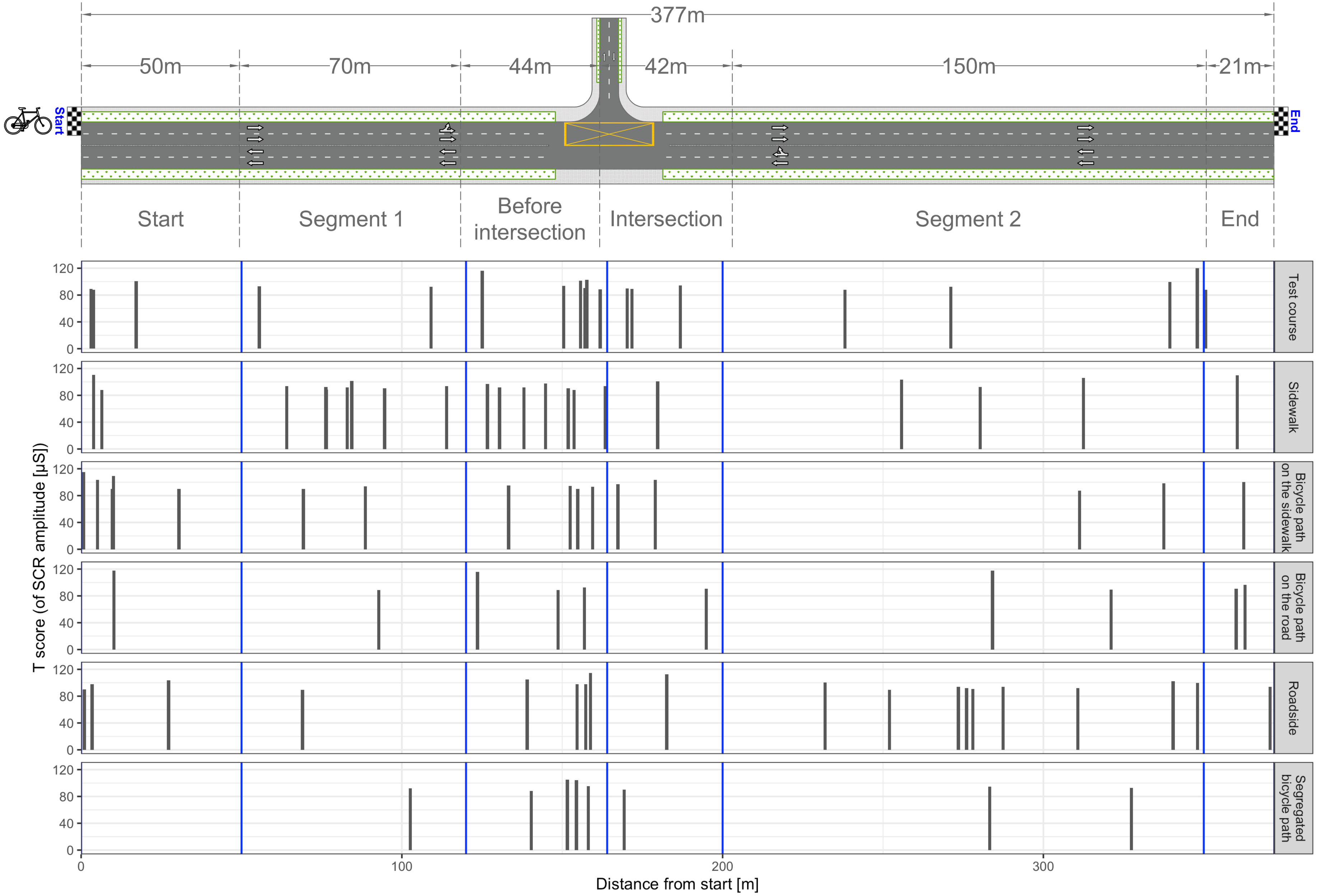
T SCORES ≥ 99TH PERCENTILE



Results

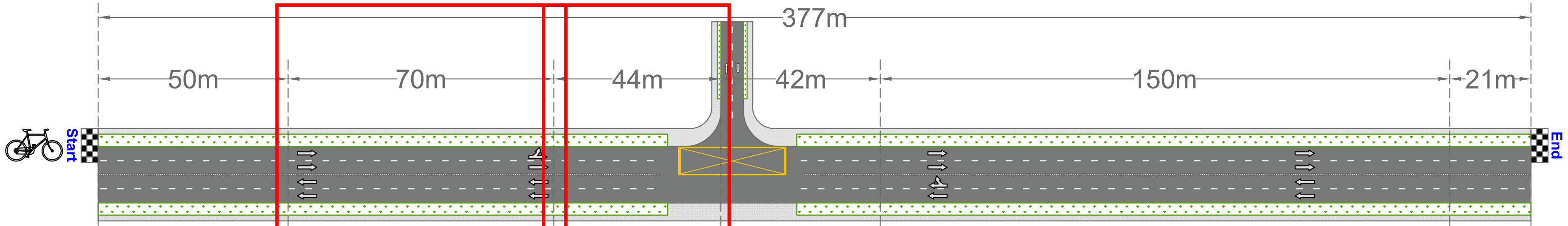
Aggregate level

The location of the Identified SCRs for 89 participants (T scores)

Figure shows only **the top one percentile T scores** for better clarity.

These SCRs can be due to different stimulus;

- Presence of pedestrians, vehicles, etc. next to the bicyclist in VR,
- Stress of crossing an intersection,
- Excitement of being immersed in a new scene or passing the finish line, and
- Other non-specific SCRs due to unknown stimuli.



High arousal – Low arousal

	Start	Segment 1	Before intersection	Intersection	Segment 2
Test course	52.23 (10.38)	49.83 (9.19)	53.58 (12.88)	51.01 (11.10)	50.88 (10.14)
Sidewalk	51.22 (10.76)	51.51 (11.60)	52.99 (12.21)	51.46 (10.20)	50.4 (9.56)
Painted sidewalk	49.64 (10.72)	48.93 (8.08)	52.30 (11.07)	52.96 (11.93)	49.32 (8.85)
Painted road	48.85 (9.40)	47.75 (7.19)	53.89 (11.69)	49.33 (8.92)	50.70 (9.85)
Roadside	50.12 (10.51)	48.57 (8.21)	55.11 (13.31)	51.38 (11.03)	51.01 (10.60)
Segregated	49.75 (9.04)	47.84 (7.39)	54.64 (12.87)	52.58 (11.14)	50.22 (9.22)

Physiological Sensor
Aggregate level

Mean SCR amplitudes of 89 participants for each segment were calculated.

Higher arousals were detected **before** the **intersection**.

Considering the **habituation** effect, **segment 1** might best represent the **net effect of a bicycling environment** on the arousal level of the bicyclists.

Considering segment 1, **painted bicycle path on the road** and **segregated bicycle path** were found to be the least stressful environments while **sidewalk bicycling** found to be the most stressful one.

Physiological Sensor
Comparison of mean SCRs

Regression results (mixed effects model) for
T scores of detected SCRs in different segments

Coefficients	SCR T score		
	Estimate	t-value	Sign.
Intercept	48.98	171.81	***
Segment			
Start	0.98	2.56	*
Segment 1 (reference)	–	–	–
Before intersection	4.78	11.50	***
Intersection	2.52	5.23	***
Segment 2	1.33	3.84	***
End	1.78	3.28	**
Adjusted rho-square	0.008		

Sign. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Environment-level analysis did not show any significant differences in T scores between different bicycling environments.

Segment-based analysis showed that the segment **before intersection** had been the most stressful segment.

Contents

Summary & conclusions

Innovation

At the **intersection** of **transportation engineering** and **psychophysiology**, this study explored whether **bicyclists' stress** level can be captured from their physiological responses by means of the passively recorded EDA of the participants.

This research also investigated the **opportunities** and **challenges** associated with the application of **EDA sensors** in **mobile** settings.

New inspiration

EDA sensors provide **new insights** on the participants' **emotional arousal**, in addition to the self-reported results, at a **higher level of granularity**.

EDA sensors obtain real-time measurements at the order of **seconds**.

EDA measurement can be employed to **avoid** the cognitive **biases** inherent to **self-reports**.

EDA measurements can be **combined** with other data sources to **consolidate results**.

Room for improvement

Data **collection**, **cleaning**, and **processing** requires many steps and requires (sometimes arbitrary) choices.

Transparency: These steps should be mentioned and the impact on results should be evaluated.

Pre-processing

1. Artefact correction
2. Smoothing

Post-processing

1. SCR threshold
2. Variance reduction

Remaining questions

Looking into other EDA metrics such as **integrated SCR**, which accounts for the **duration** of SCR

Incorporating the physiological responses of the participants to model their **choice behaviour**

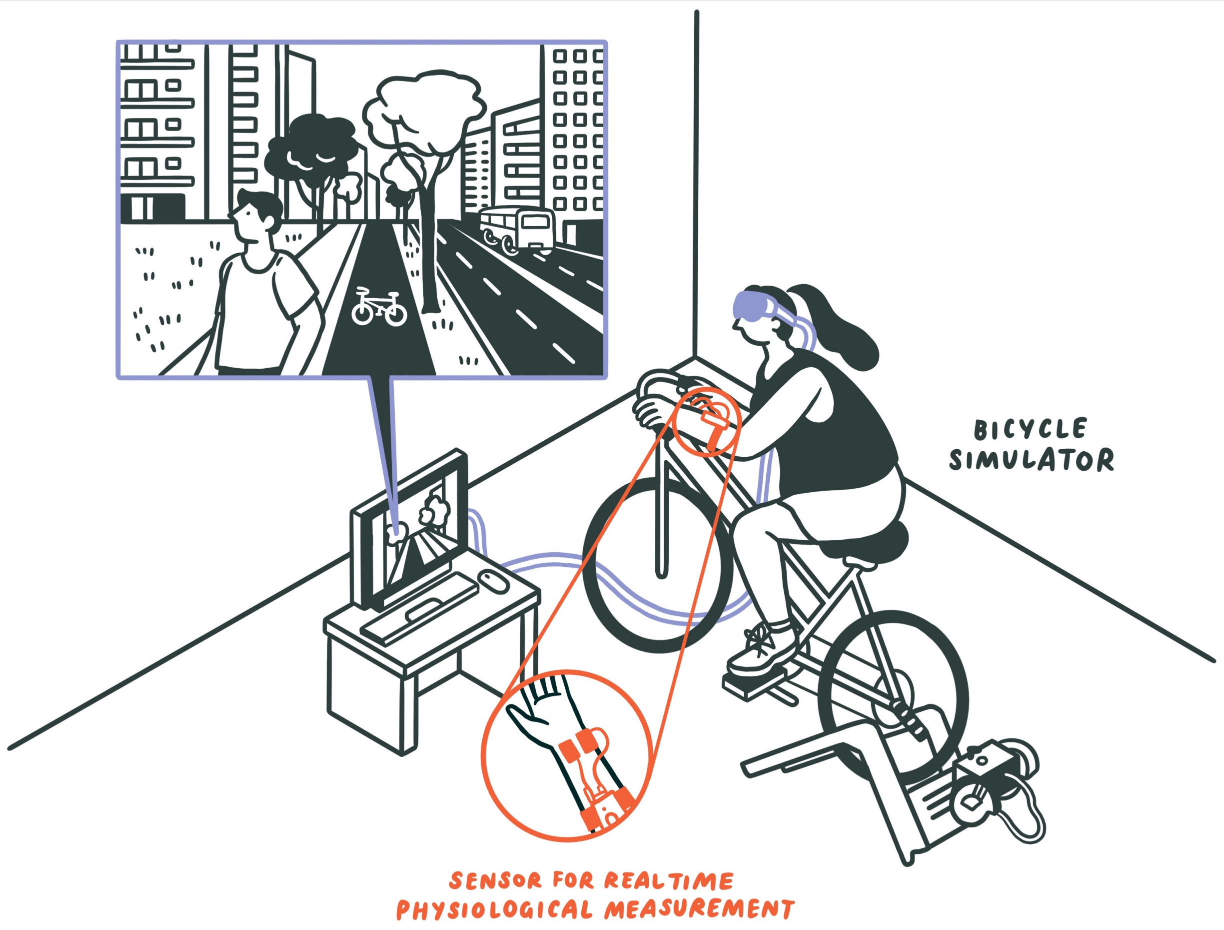
Panel data & SCR T scores

df_coice_2

	participant_id_seq	treatment	willingness_more_10	gender	age_group	min_plos	m_speed	m_norm_brake	m_T_SCR_segment_1
1	100_seq1	painted_road	7	Female	25 to 34	1	22.454	[illegible]	43.548
2	100_seq1	painted_sidewalk	7	Female	25 to 34	7	21.935	[illegible]	45.116
3	100_seq1	road	1	Female	25 to 34	1	18.067	[illegible]	45.408
4	100_seq1	segregated	7	Female	25 to 34	7	24.068	[illegible]	54.338
5	100_seq1	sidewalk	7	Female	25 to 34	1	14.634	[illegible]	49.718
6	101_seq1	painted_road	5	Female	35 to 44	5	21.296	[illegible]	45.131
7	101_seq1	painted_sidewalk	7	Female	35 to 44	6	19.353	[illegible]	43.621
8	101_seq1	road	1	Female	35 to 44	1	20.261	[illegible]	42.852
9	101_seq1	segregated	7	Female	35 to 44	7	21.612	[illegible]	49.744
10	101_seq1	sidewalk	4	Female	35 to 44	5	14.383	[illegible]	65.050
11	102_seq1	painted_road	6	Male	25 to 34	5	22.164	[illegible]	49.280
12	102_seq1	painted_sidewalk	7	Male	25 to 34	6	20.735	[illegible]	45.713
13	102_seq1	road	1	Male	25 to 34	1	26.325	[illegible]	43.536
14	102_seq1	segregated	7	Male	25 to 34	7	25.494	[illegible]	75.713
15	102_seq1	sidewalk	5	Male	25 to 34	1	10.883	[illegible]	56.093
16	103_seq1	painted_road	5	Female	25 to 34	2	17.048	[illegible]	47.973
17	103_seq1	painted_sidewalk	5	Female	25 to 34	3	17.234	[illegible]	45.937
18	103_seq1	road	3	Female	25 to 34	1	19.674	[illegible]	47.115
19	103_seq1	segregated	7	Female	25 to 34	6	21.520	[illegible]	43.875
20	103_seq1	sidewalk	2	Female	25 to 34	2	18.804	[illegible]	46.036
21	104_seq1	painted_road	6	Male	55 to 65	5	19.986	[illegible]	58.114
22	104_seq1	painted_sidewalk	7	Male	55 to 65	6	18.938	[illegible]	48.410
23	104_seq1	road	2	Male	55 to 65	2	15.770	[illegible]	57.698
24	104_seq1	segregated	7	Male	55 to 65	7	19.618	[illegible]	44.807
25	104_seq1	sidewalk	3	Male	55 to 65	4	12.101	[illegible]	50.844
26	105_seq1	painted_road	6	Male	25 to 34	2	25.157	[illegible]	43.959
27	105_seq1	painted_sidewalk	3	Male	25 to 34	3	17.517	[illegible]	49.022
28	105_seq1	road	2	Male	25 to 34	1	21.816	[illegible]	[illegible]
29	105_seq1	segregated	7	Male	25 to 34	7	24.915	[illegible]	44.785
30	105_seq1	sidewalk	3	Male	25 to 34	2	15.910	[illegible]	[illegible]
31	106_seq1	painted_road	4	Male	25 to 34	4	12.488	[illegible]	[illegible]
32	106_seq1	painted_sidewalk	7	Male	25 to 34	7	11.087	[illegible]	[illegible]
33	106_seq1	road	2	Male	25 to 34	2	13.981	[illegible]	[illegible]
34	106_seq1	segregated	7	Male	25 to 34	7	13.253	[illegible]	[illegible]
35	106_seq1	sidewalk	7	Male	25 to 34	7	11.106	[illegible]	[illegible]

Showing 1 to 36 of 750 entries, 9 total columns

Thank you
for your attention



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