

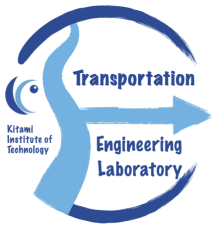


European Road Profile Users' Group 2023  
*Better use of data and smarter analysis*

# Human-centered Evaluation of Expressway Surfaces Focusing on Mental Stress of Road Users with Biosignals

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October 25, 2023@Athens, Greece



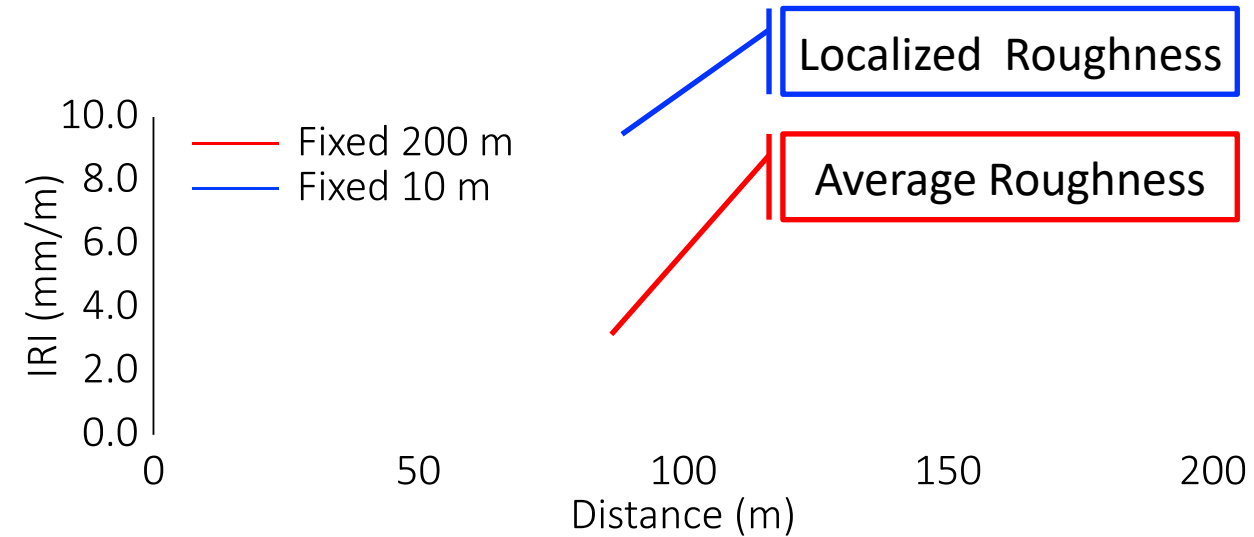
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# Introduction

Roughness Control Criteria  
for Expressways in Japan (NEXCO):

## International Roughness Index (IRI)

- ✓ Fixed interval of 200m  $\leq$  3.5mm/m  
Average roughness level
- ✓ Fixed interval of 10m  $\leq$  8.0mm/m  
Localized roughness level



An Example of IRI-based Surface Evaluation in NEXCO

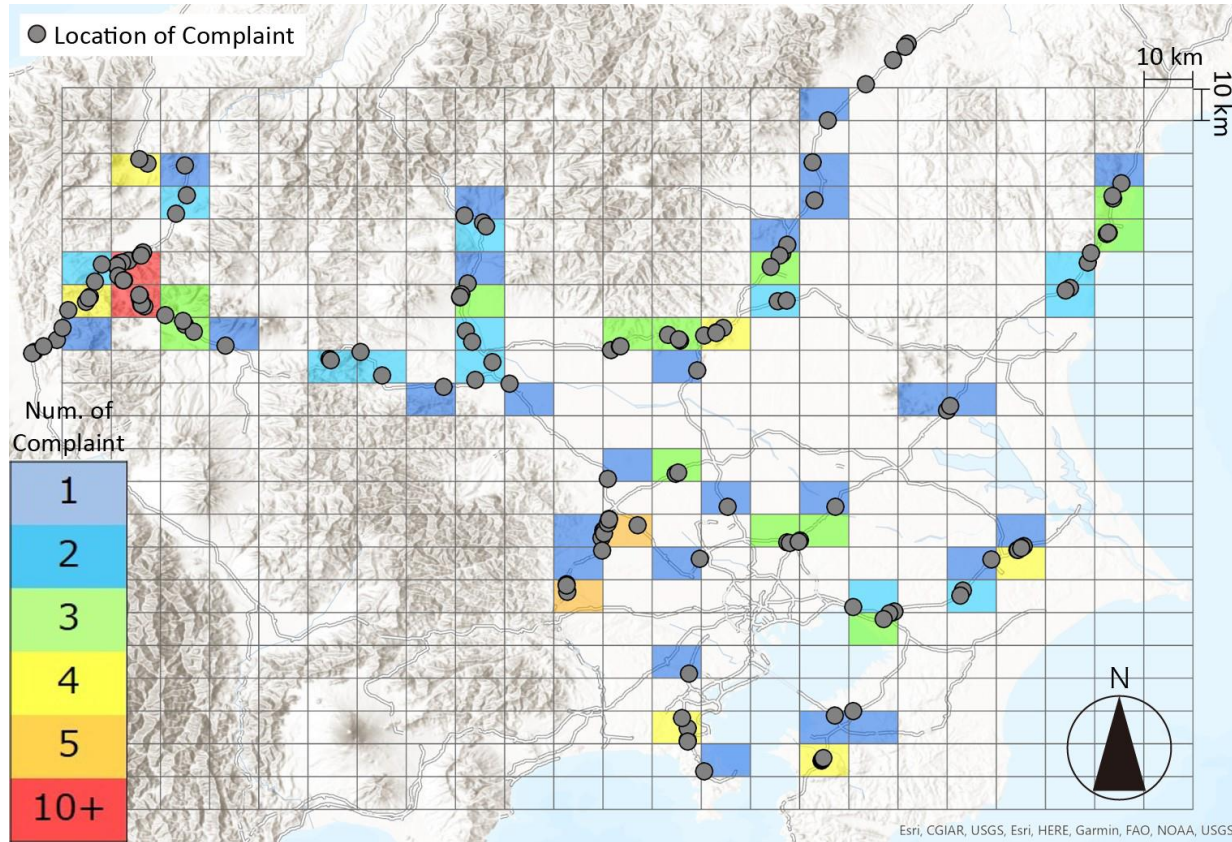
**Localized Roughness:**

Trigger for maintenance

**Average Roughness:**

Trigger for rehabilitation

# Motivation



Distribution of Complaints in FY2021

User Demand for Ride Quality Improvement:

**100+ User Complaints**

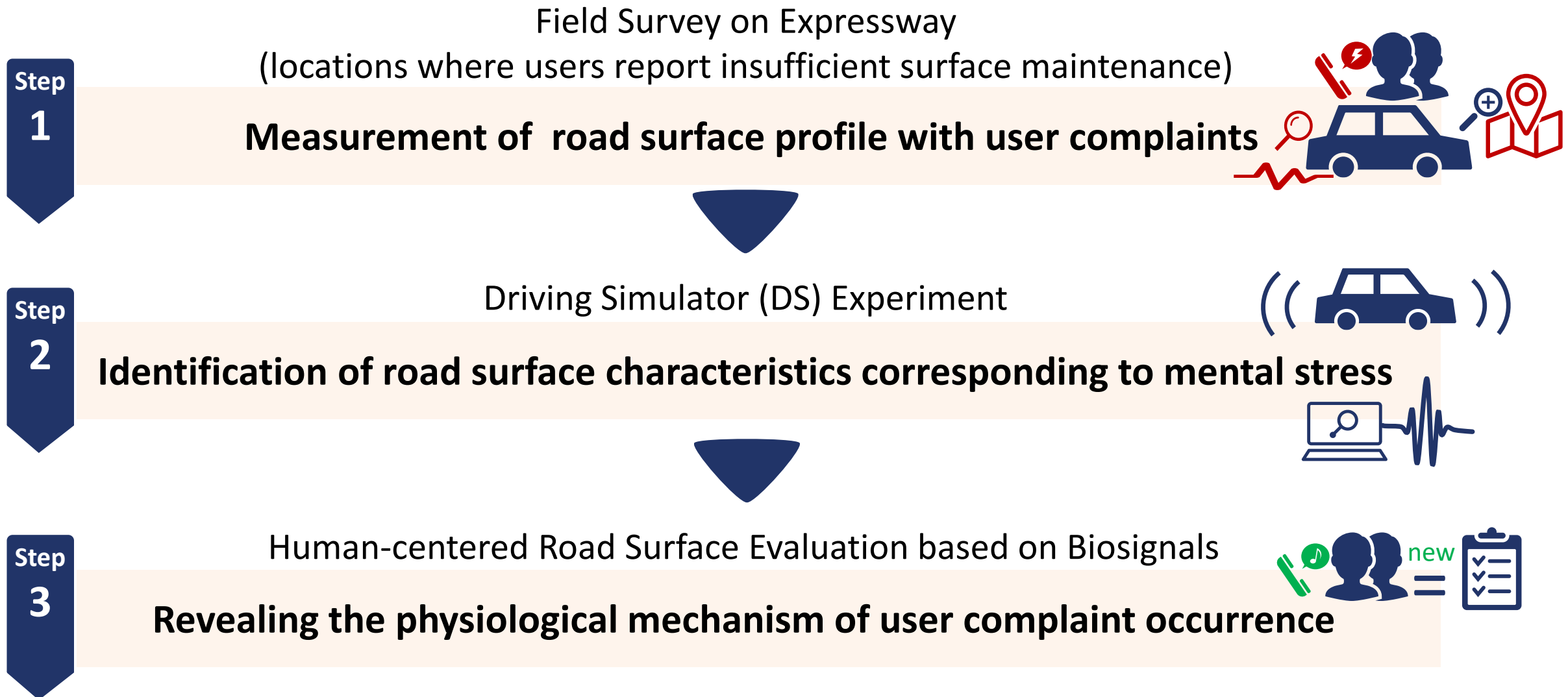
(NEXCO East, Kanto Branch, FY2021)

A lot of complaints were recorded even though the **IRIs were under control threshold**



**Gap between users' rating and maintenance criterion**

# Research Purpose and Flow



# Field Survey

Measurement of road surface profile with user complaints



Complaint

Within 1 month

Confirm the Report

Geographical Analysis with GIS

- Location (Geographical Coordinate and KP)
- Contents of the Complaint

Field Survey



Vehicle used in the survey

Vehicle Motion

- Gyro Sensor
- Acceleration
- Coordinate



Physiological Information

- ECG, EDA
- Heart Rate
- Skin Conductance



Surface Condition

- Mobile Profilometer
- Surface Profile
- IRI



Front Image

- GoPro MAX
- Surface Image
- Roadside Condition



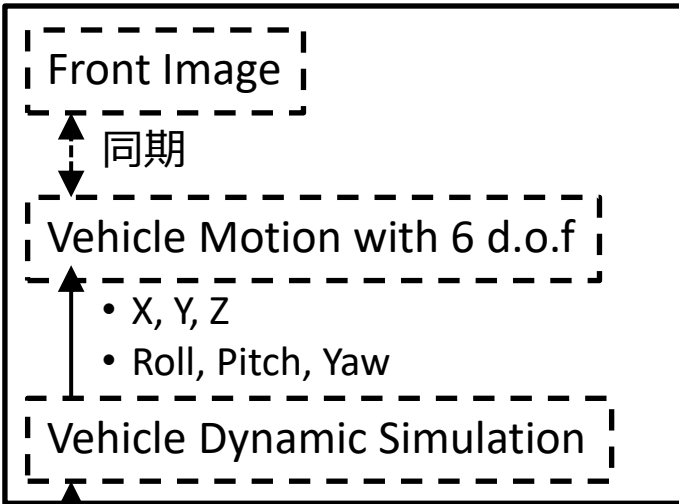
Diagnostic Observation

- Visual & Sensory Rating
- Distress Condition
- Diagnostic Rating

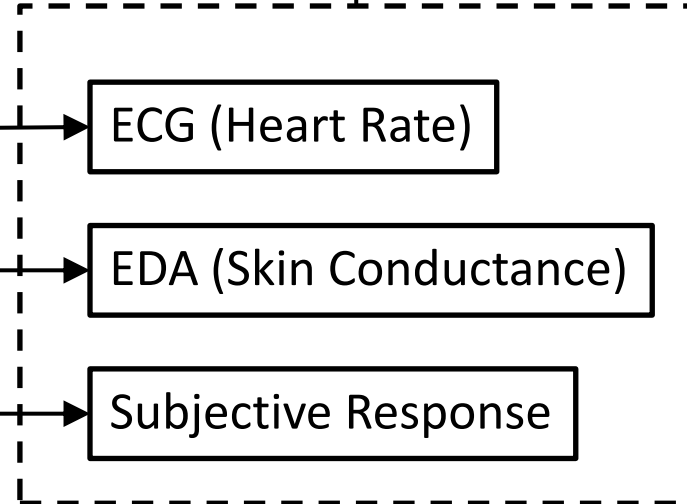
Diagnosis	Level
1	Low
1.5	Moderate
2	
2.5	High
3	

# DS Experiment

## Motion-base DS (KITDS)

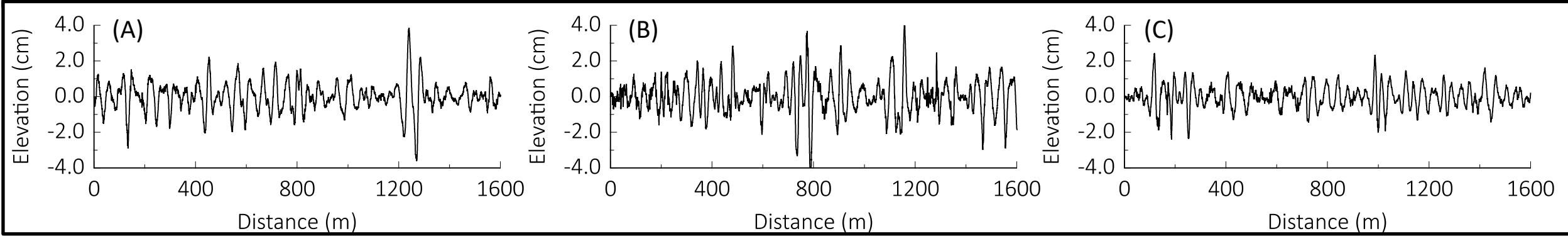


Human-centered Evaluation

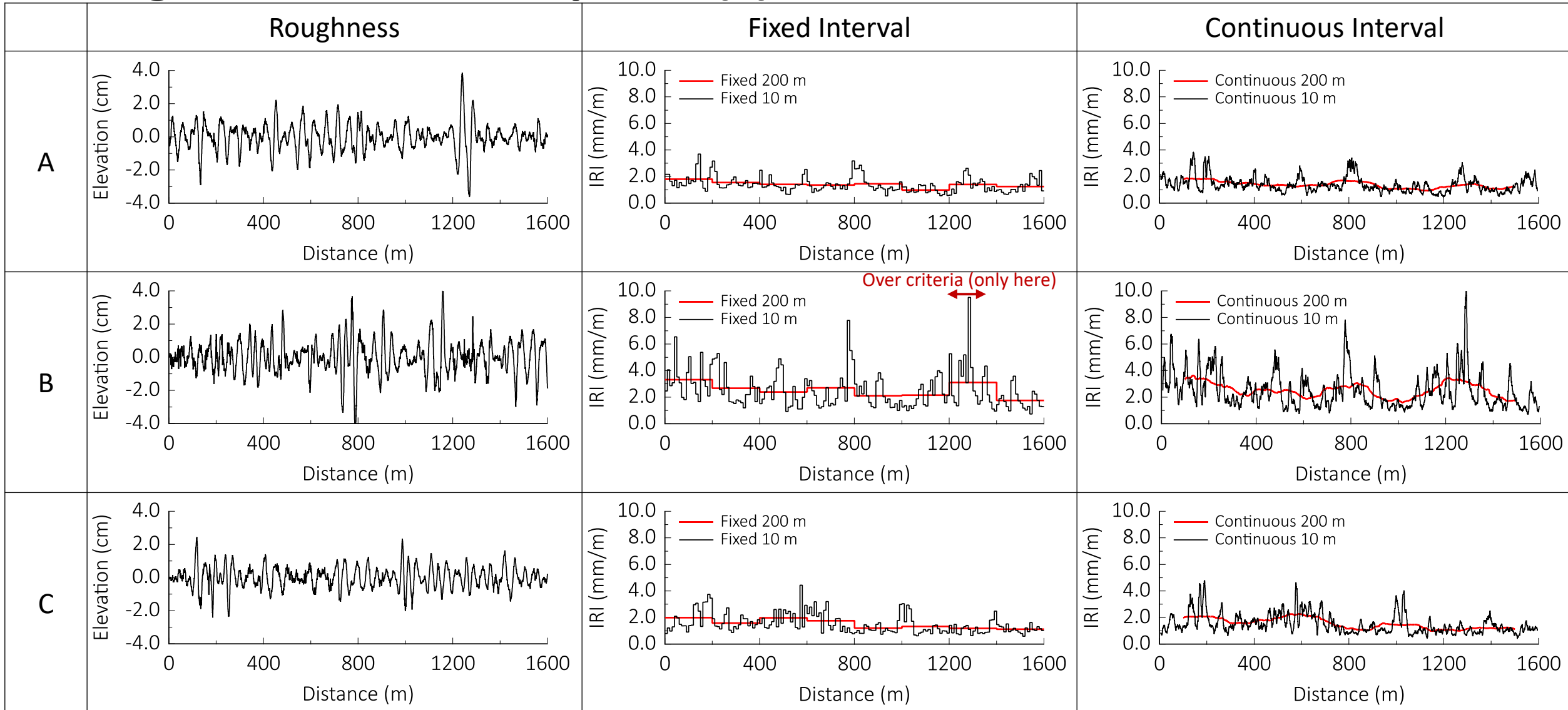


Roughness of just after Complaint

KITDS can reproduce mm scale surface profile for the evaluation of riding safety and comfort



# Roughness with Complaint(s)



# Driving Scenario

(1) Vehicle Speed: 80km/h (constant without driving operation)

(2) Surface Condition: 10 surfaces given randomly

- Test Surface (A/B/C) } Combined
- Control Surface (a/b/c) }
- Reference Surface ( $IRI_{Fix}(200)=1.7\text{mm/m}$ ; average of in-service expressways)

Control Surface

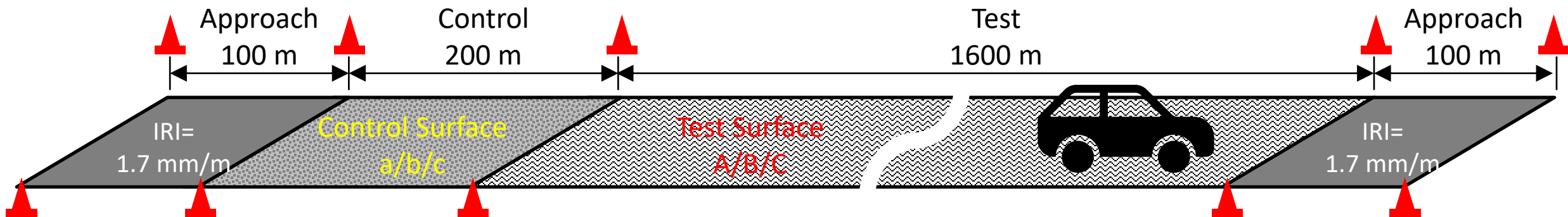
a.  $IRI_{Fix}(200) = 1.0 \text{ mm/m}$ : New

b.  $IRI_{Fix}(200) = 2.7 \text{ mm/m}$ : 50% uncomfortable

c.  $IRI_{Fix}(200) = 3.5 \text{ mm/m}$ : Criterion

(3) Duration: 1.5-2.0 min/run, 16.5-22.0 min/participant

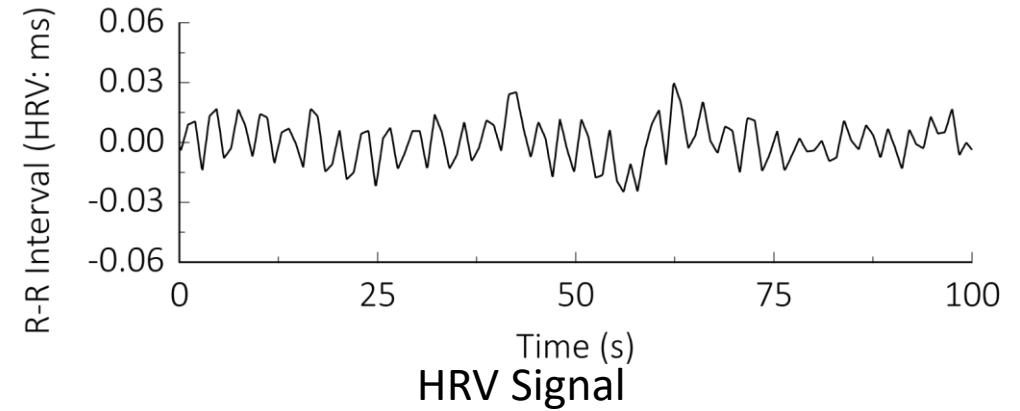
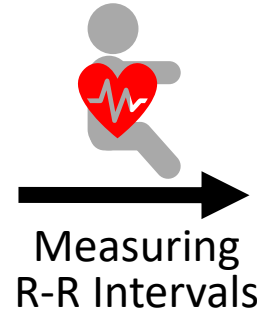
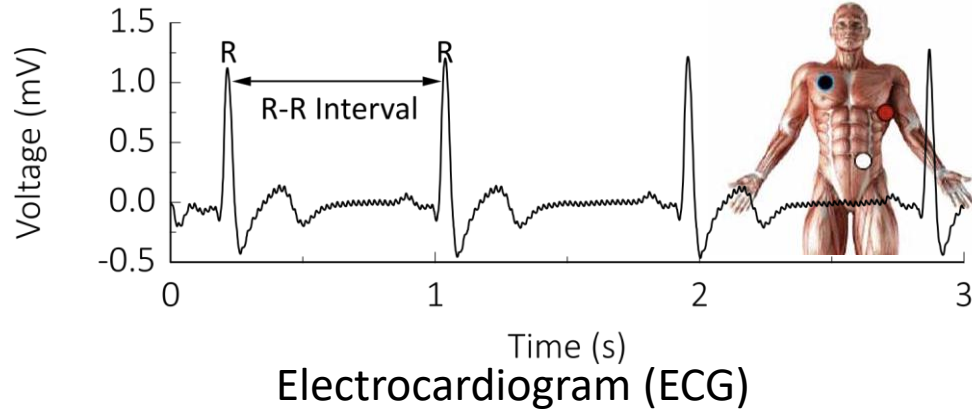
(4) Participants: 6 students (average of 22.7 years old) and 11 practitioners (average of 35.3 years old)





# Biosignals

A measure of autonomic nervous system on stress and relaxation

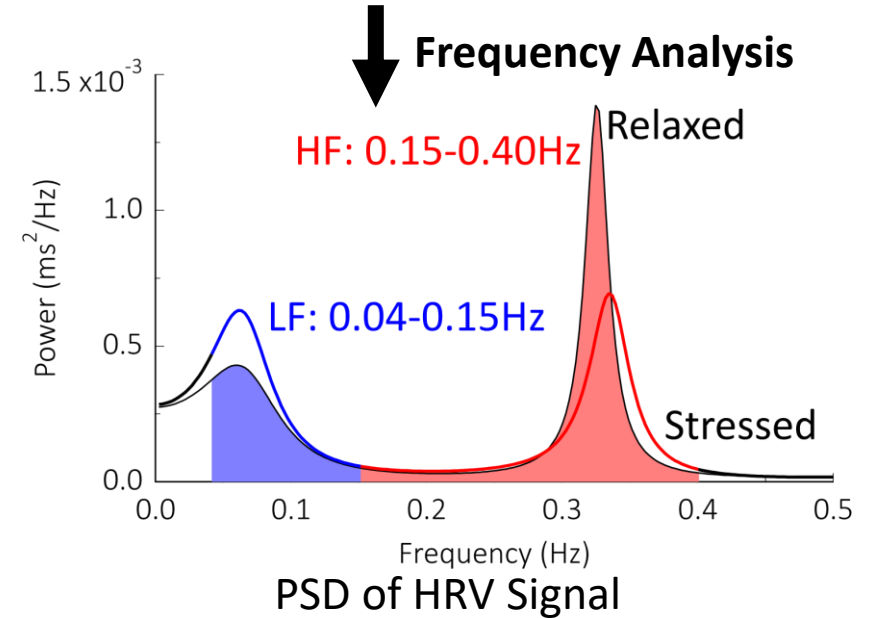


**Low HRV**

- Fight-or-Flight
- High Stress and Fatigue
- Easily Exhausted
- Health Issues

**High HRV**

- Rest and Relax
- Low Stress and Fatigue
- Better Physical Performance
- Improve Cognitive Performance

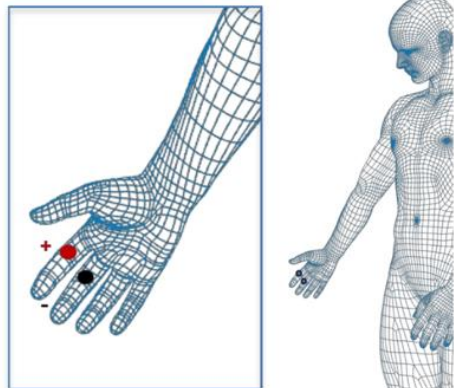
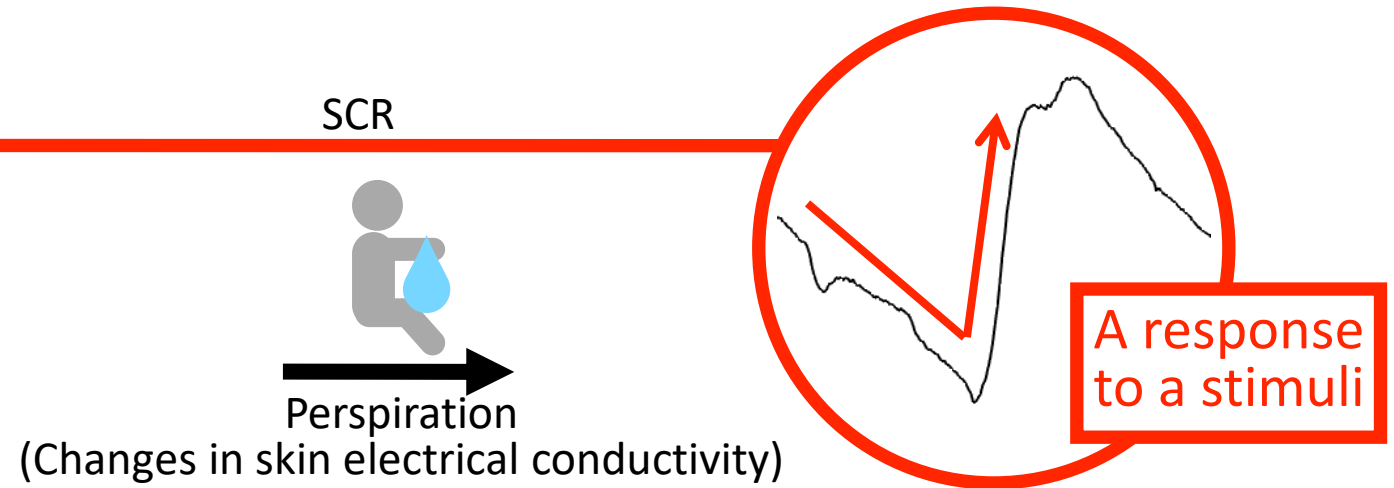
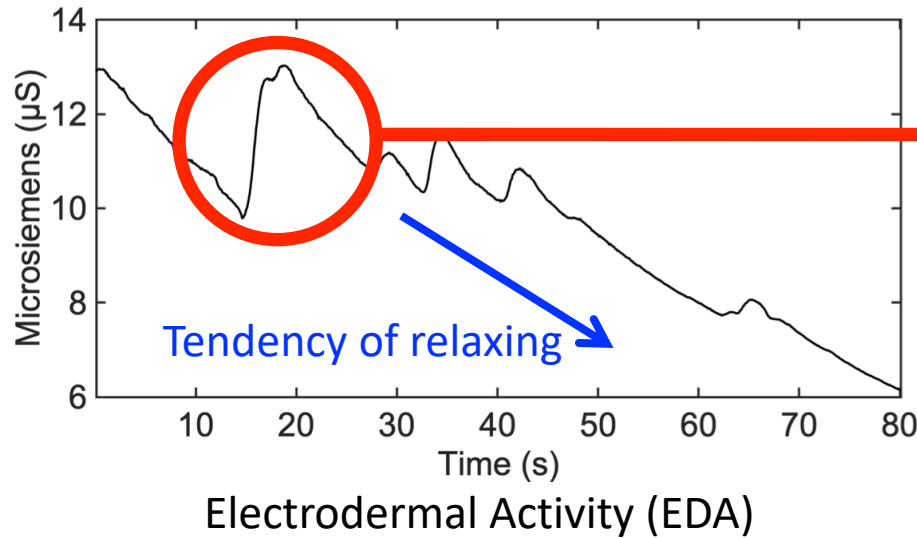


LF/HF: ↗ HF: ↘

LF/HF: ↘ HF: ↗

# Biosignals

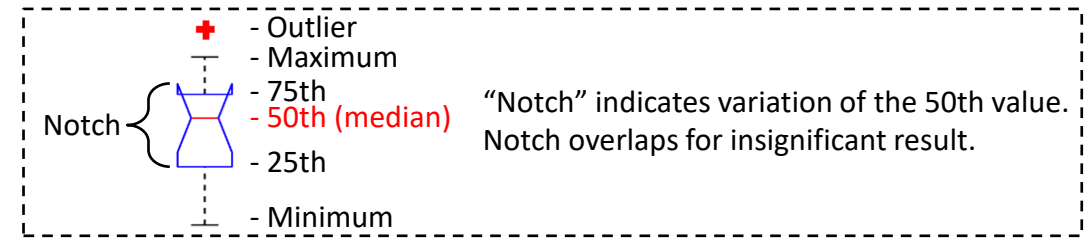
A measure of autonomic nervous system on stress and relaxation



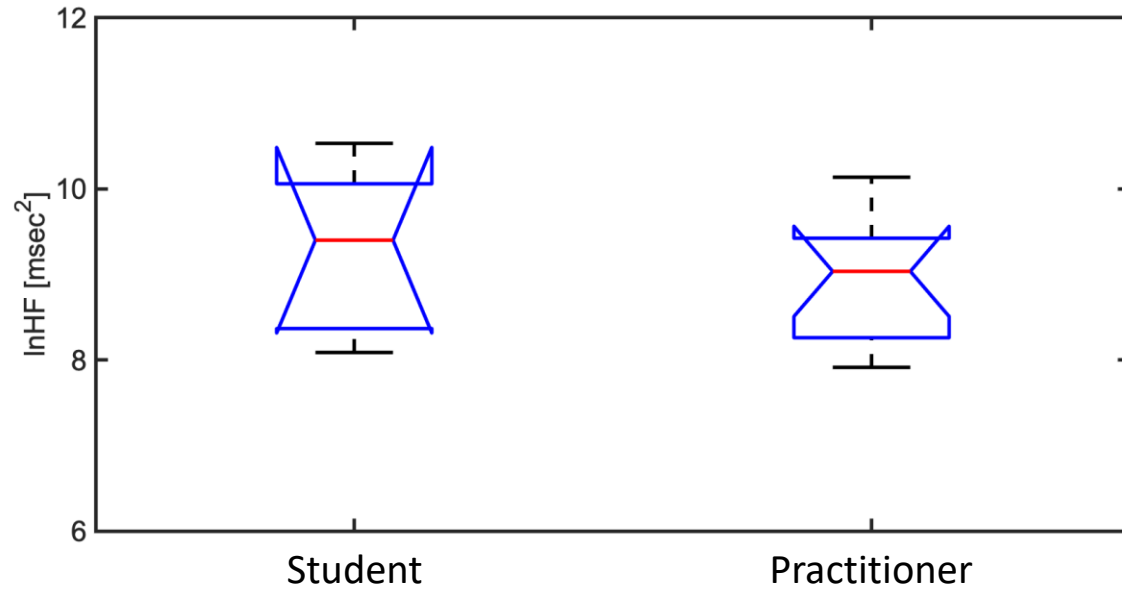
**SCR Appear**  
**Transient Increase**  
 Emotional arousal  
 Stress increase

**SCR Disappear**  
**Gentle Decrease**  
 Relaxing

# Validation of DS Experiment

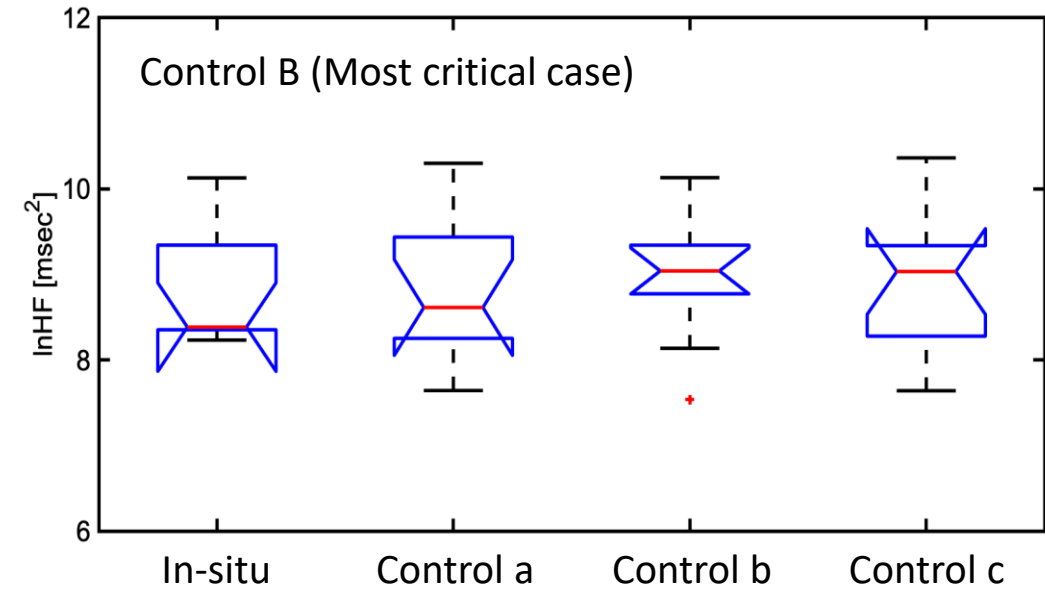


Difference of Participants



Source	SS	DF	MS	F	p
Participant	0.559	1	0.55986	0.89	0.3599
Error	10.0893	16	0.63024		
Total	10.6437	17			

Difference between DS and Real Vehicle

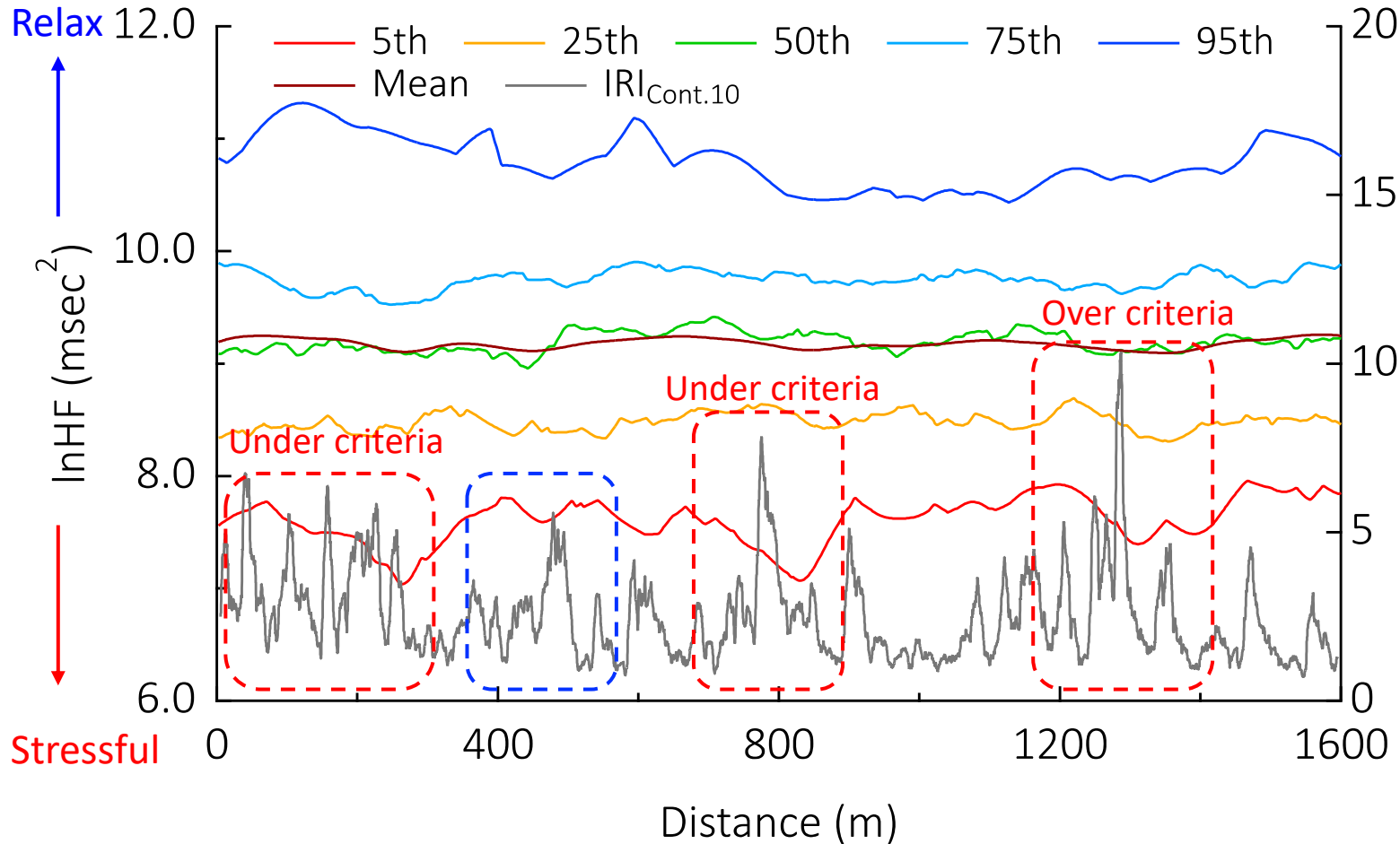


Source	SS	DF	MS	F	p
Surface	0.1903	3	0.06344	0.11	0.9533
Error	21.7526	38	0.57249		
Total	21.9449	41			

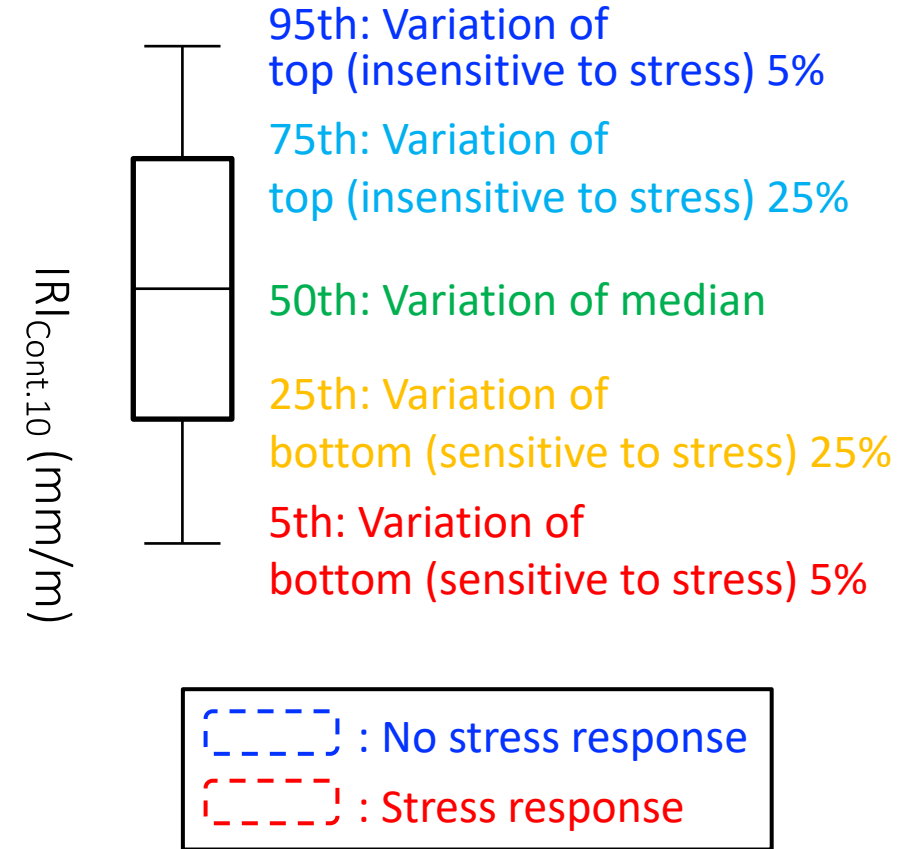
No significant difference has been observed

# Results

Relationship between IRI and Heart Rate Variability (HRV)



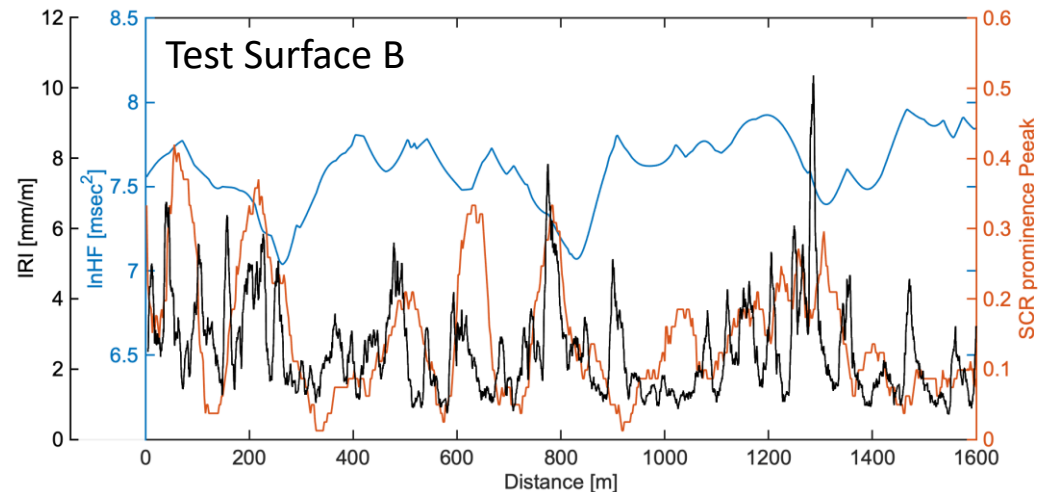
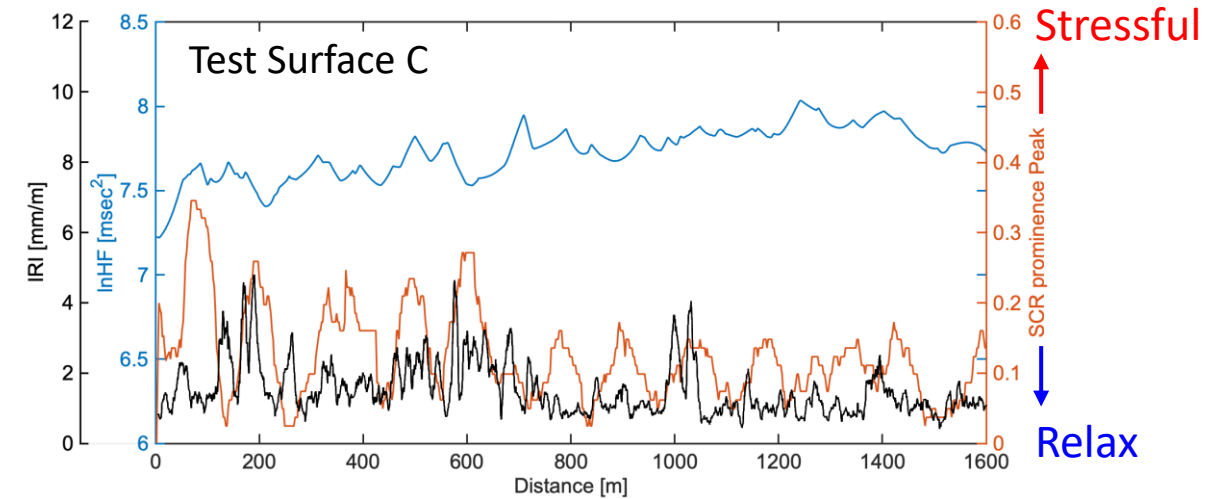
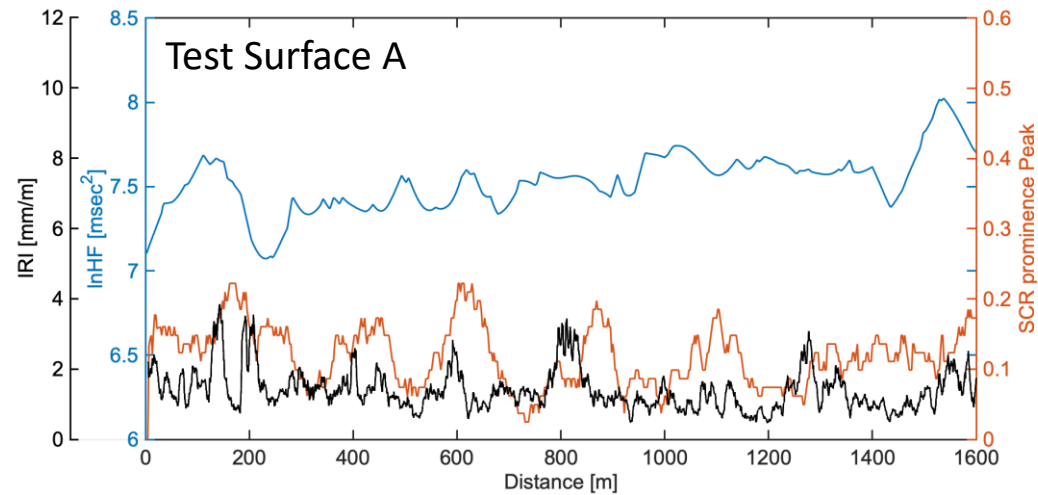
Mental stress changes in HRV for Test Surface B (Most critical case)



Level of Mental stress reflected in HRV can be inconsistent with degree of IRI.

# Results

## Relationship between IRI and Skin Conductance Response (SCR)

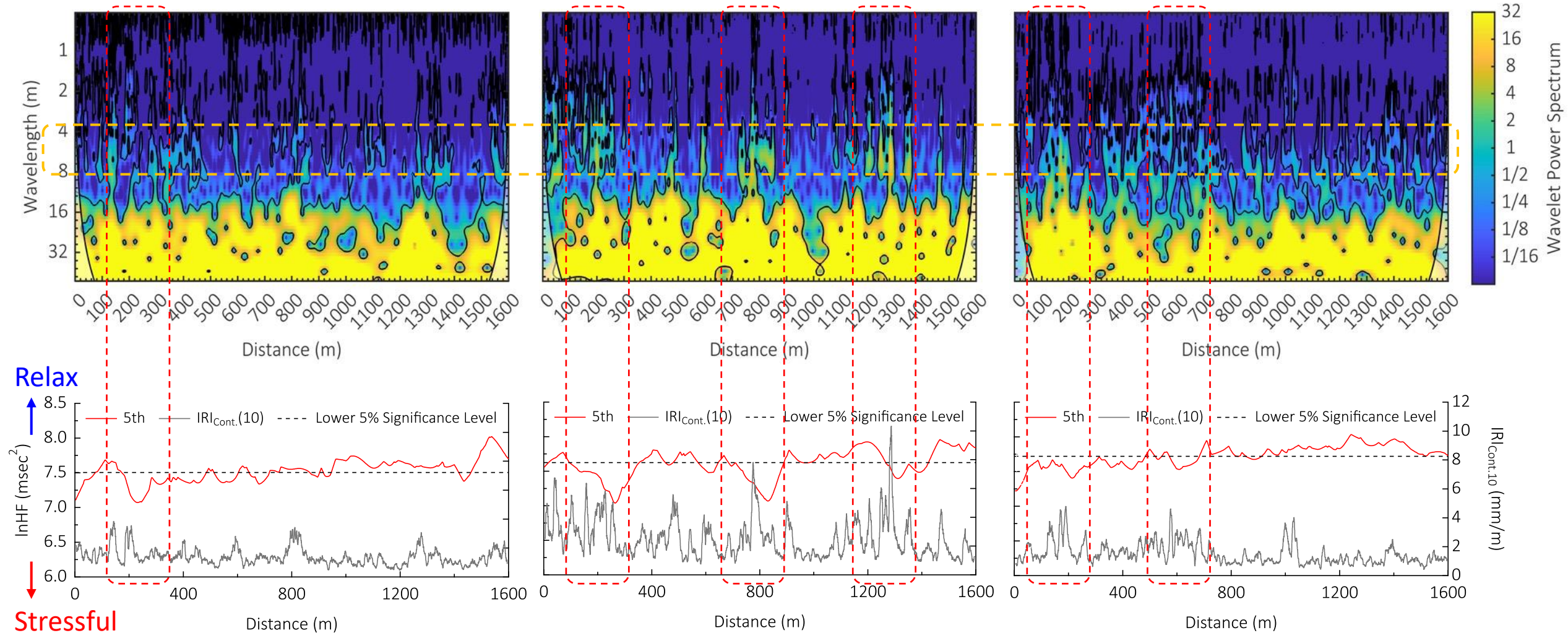


- SCR responds to surface irregularities
- Frequency of SCR is consistent with localized roughness fluctuation
- Roughness fluctuations causing the reduction of HF of HRV lead to the increase of SCR frequency
- Mental stress increase with occurrence of SCR and decreasing HF at the same time

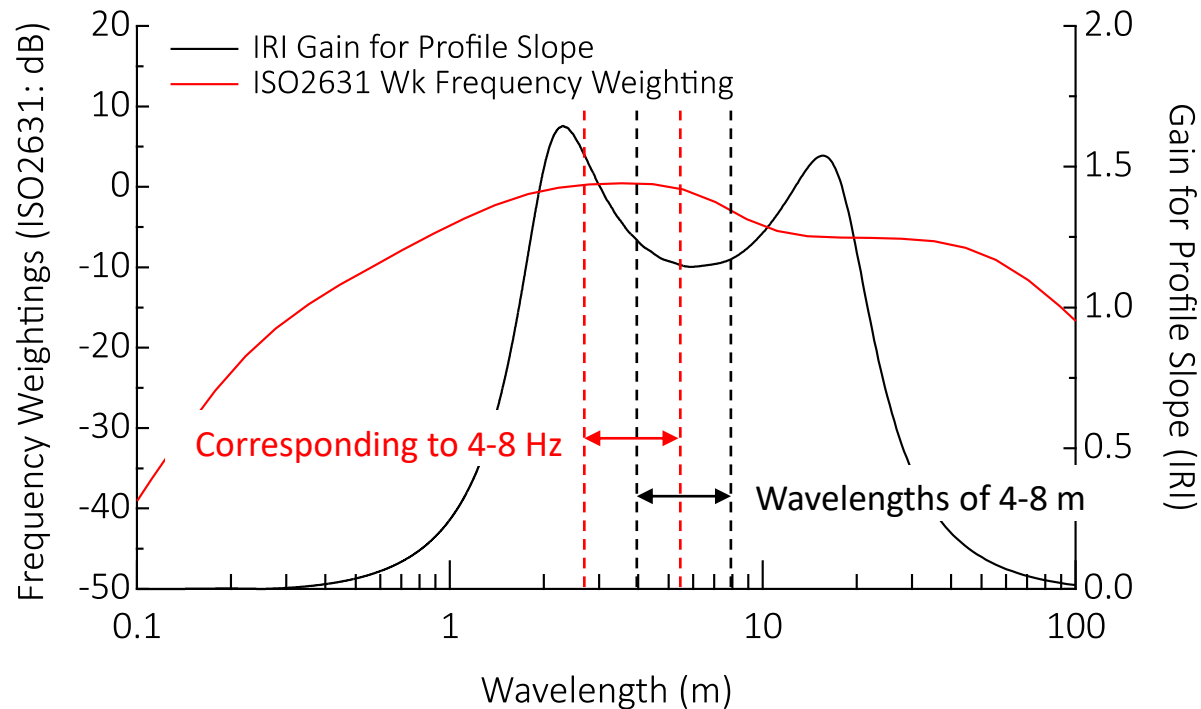
# Results

## Wavelet Analysis of Profile

Mental stress increases with increasing profile component including wavelengths ranging from 4 to 8 m even though the IRI value is less than criteria



# Discussion



Response of the QC Model and Sensitivity of Whole Body Vibration

Sensitive frequency for whole body vibration : 4-8Hz

-> Corresponding wavelengths 2.8-5.6 m at 80 km/h

## Mechanism of User Complaint Occurrence

(1) Profile components including wavelengths ranging from 4 to 8 m which are insensitive in IRI induce vehicle vibration sensitive to human body at 80 km/h.



(2) Mental stress can be observed in 5% of sensitive participants against localized roughness consisted of the wavelength of 4-8 m.



(3) Complaints can be raised for surfaces stimulating mental stress significantly which is hard to be evaluated with IRI.

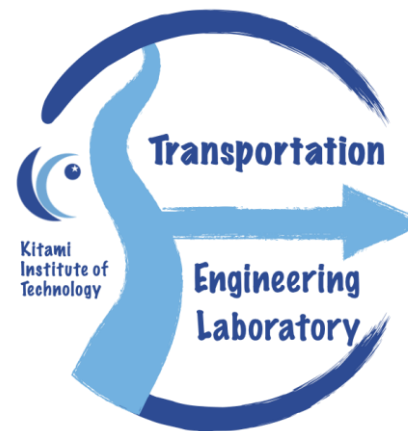
# Conclusions

- Relationship between biosignal and surface roughness
  - ✓ surface roughness inducing mental stress can be underestimated with IRI.
- Profile analysis focusing of waveband characteristics of surface profile
  - ✓ Mental stress increases with increasing profile components including wavelengths ranging from 4 to 8 m even if the IRI indicates an acceptable level.
- Gap analysis of user response and maintenance criteria
  - ✓ The insensitivity of IRI to the wavelengths between 4 and 8 m causes the gap in the maintenance criteria in terms of IRI and the road user rating.



# Thank you for your kind attention Question?

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<https://linktr.ee/transp.kit>

