Factors influencing Comfort measured and modelled

webinar on main results of the ComfDemo project – 23 nov 2022
recordings of turboprop flights

This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 831992.
The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

Program

14:00 Opening (*Dr. Victor Norrefeldt, Fraunhofer IBP*)

14:05 Interactive start: attendees share issues in turboprop flying

14:10 Overview: aircraft interior priorities based on passengers' opinions (*Prof. Dr. Peter Vink, vhp Human Performance*)

14:20 Inflight questionnaire results (*Prof. Dr. Britta Herbig, Ludwig-Maximilians-Universität München*)

14:30 The jacket results recording CO2, temp, humidity, acceleration etc (*Dr. Y. (Wolf) Song, TU-Delft*)

14:40 Interaction between attendees and speakers on webinar so far + discussion

15:00 Break

15:10 Results of measurements in the turboprop (*Dr. Michael Bellmann, itap GmbH*)

15:20 Vibration and noise in the flight and the lab (*Prof. Dr. Neil Mansfield, Nottingham Trent University*)

15:30 Experiencing noise cancelling headphones, earplugs in turboprops (*Gerbera Vledder, TU-Delft*)

15:40 A comfort model based on flight data (*Prof. Neil Mansfield, Prof. Dr. Britta Herbig*)

16:00 Interaction between attendees and speakers on webinar, questions + discussion

16:30 closing

Topic leader:

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Fraunhofer IBP

COMFDEMO partners:

vhp HUMAN PERFORMANCE

NOTTINGHAM TRENT UNIVERSITY

itap INSTITUT FÜR TECHNISCHE UND ANGEWANDTE PHYSIK GMBH

Opening

Dr. Victor Norrefeldt, Fraunhofer IBP

Interactive start

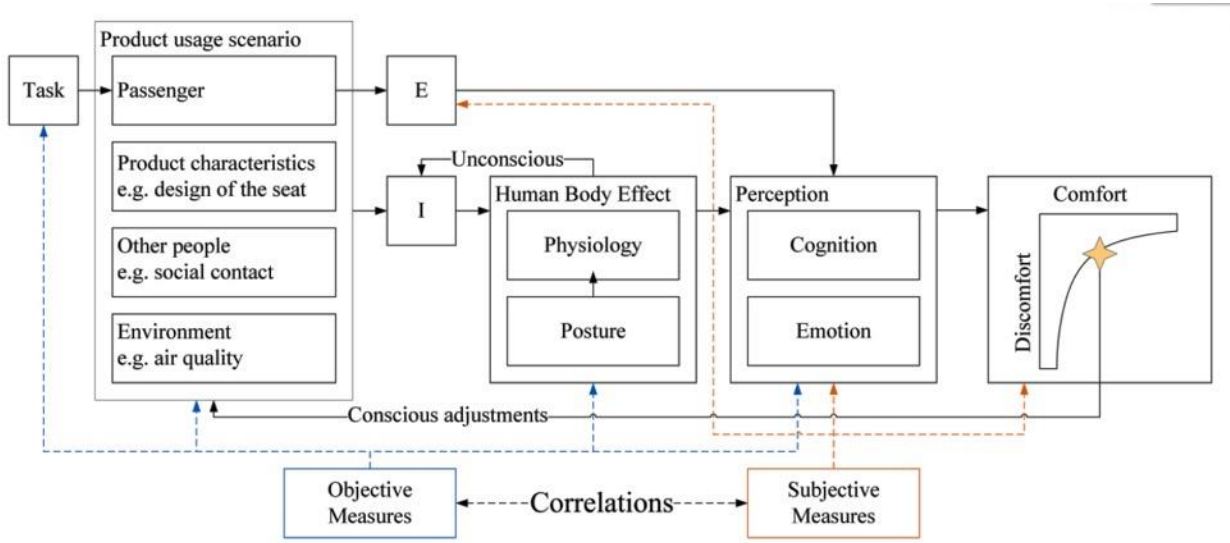
Attendees share issues in turboprop flying

Aircraft interior priorities based on passengers' opinions

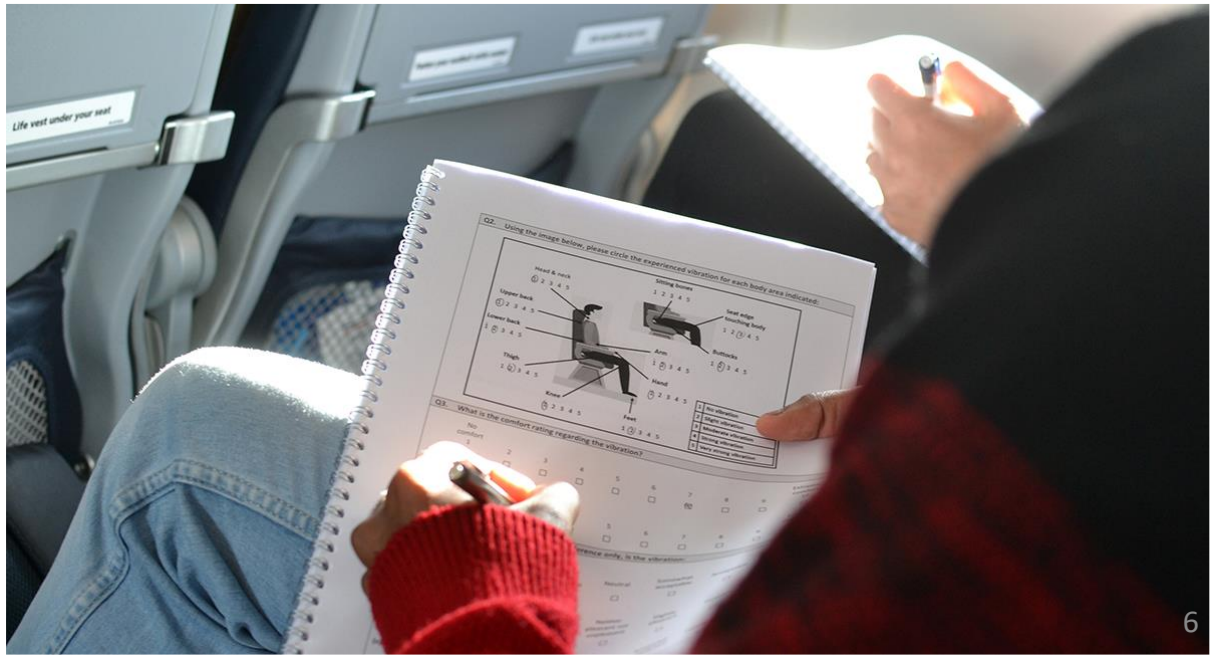
Prof. Dr. Peter Vink, vhp Human Performance

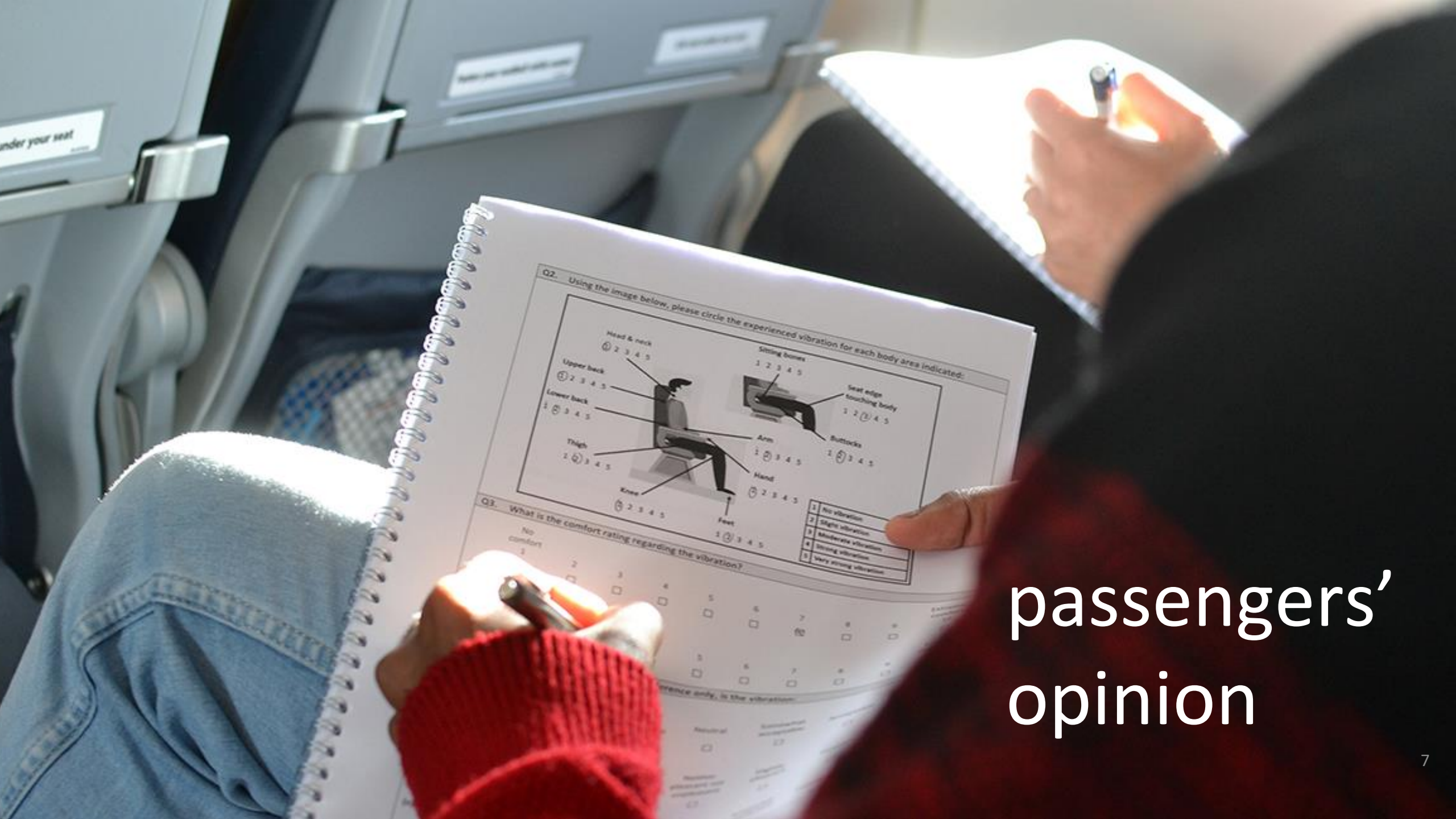
ComfDemo (cleansky2)

- Digital twin (comfort model):

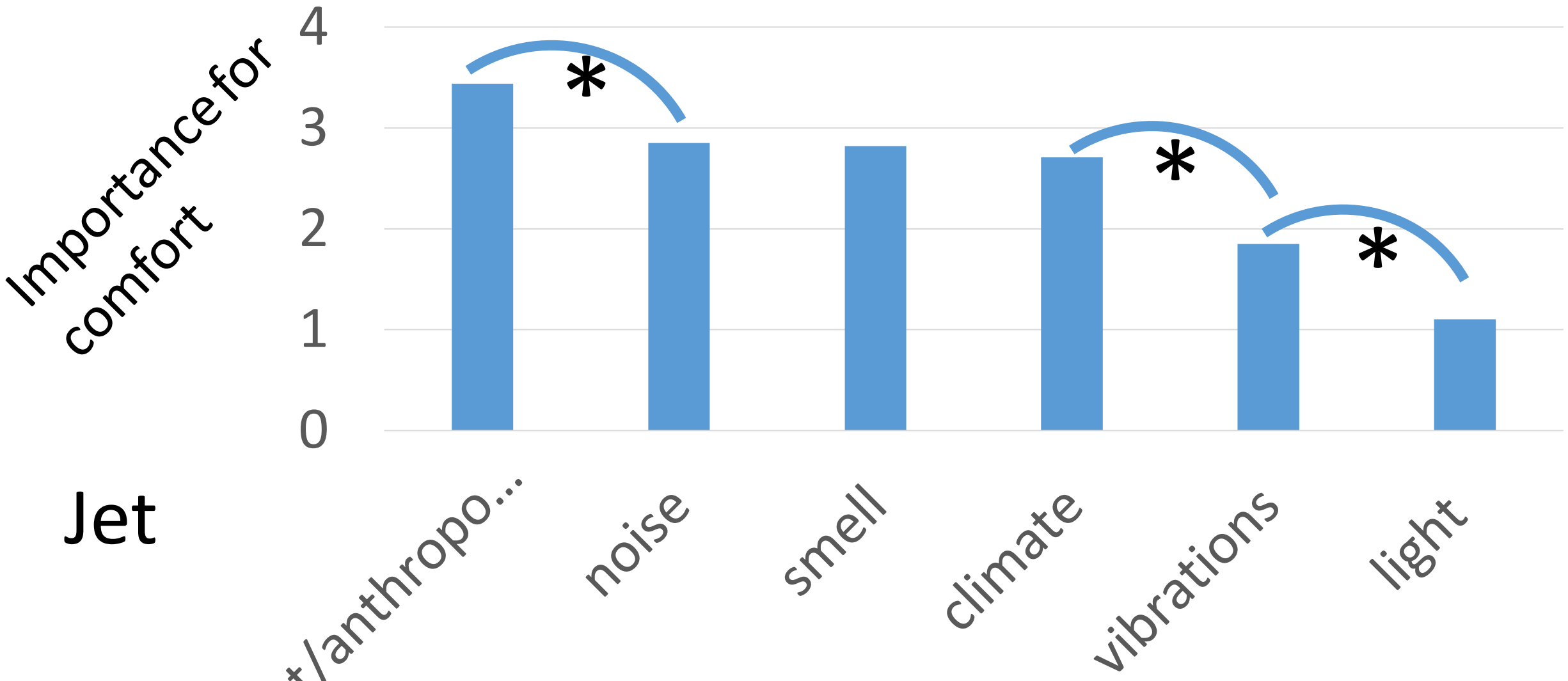


- Test protocol for Demonstrator:





passengers' opinion



Jet

n=183, *=sign,
Bouwens, 2018

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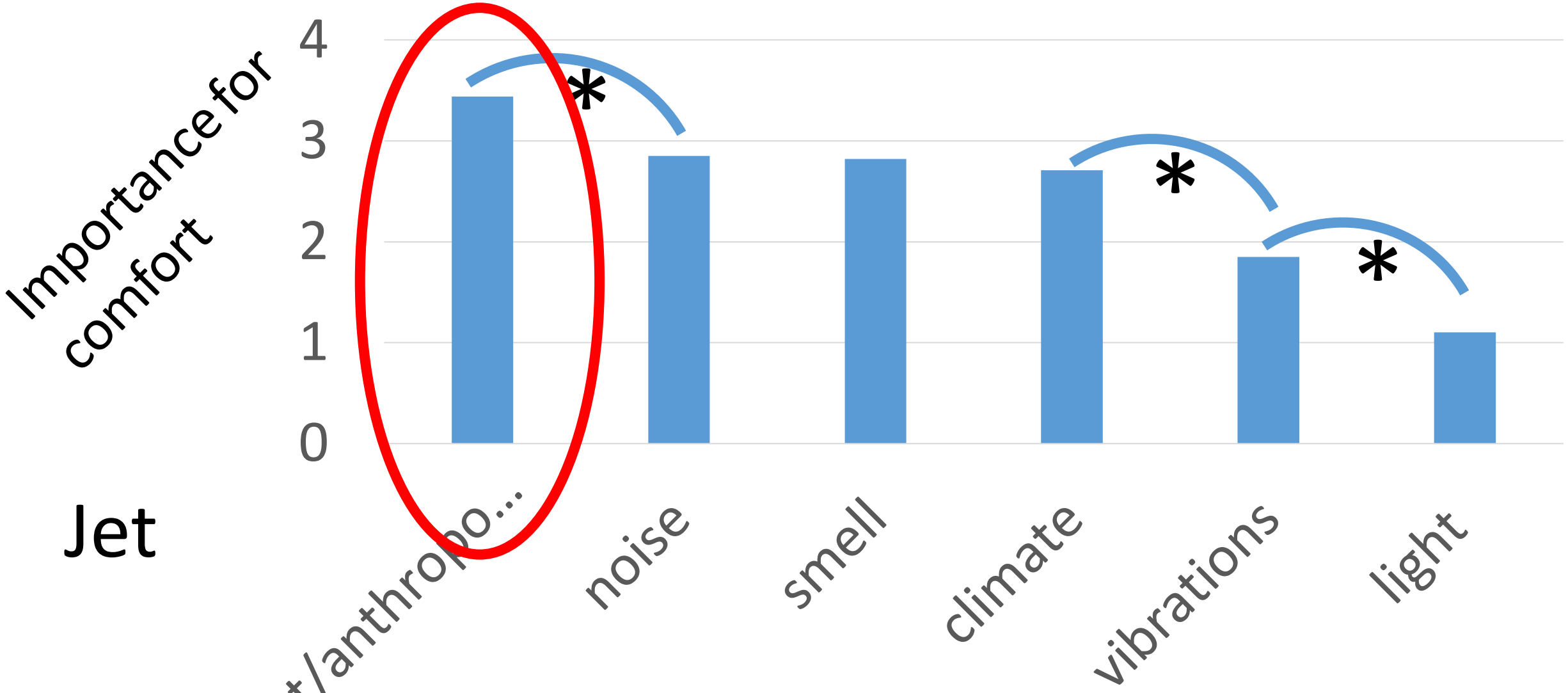

Jet

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Bouwens, 2018

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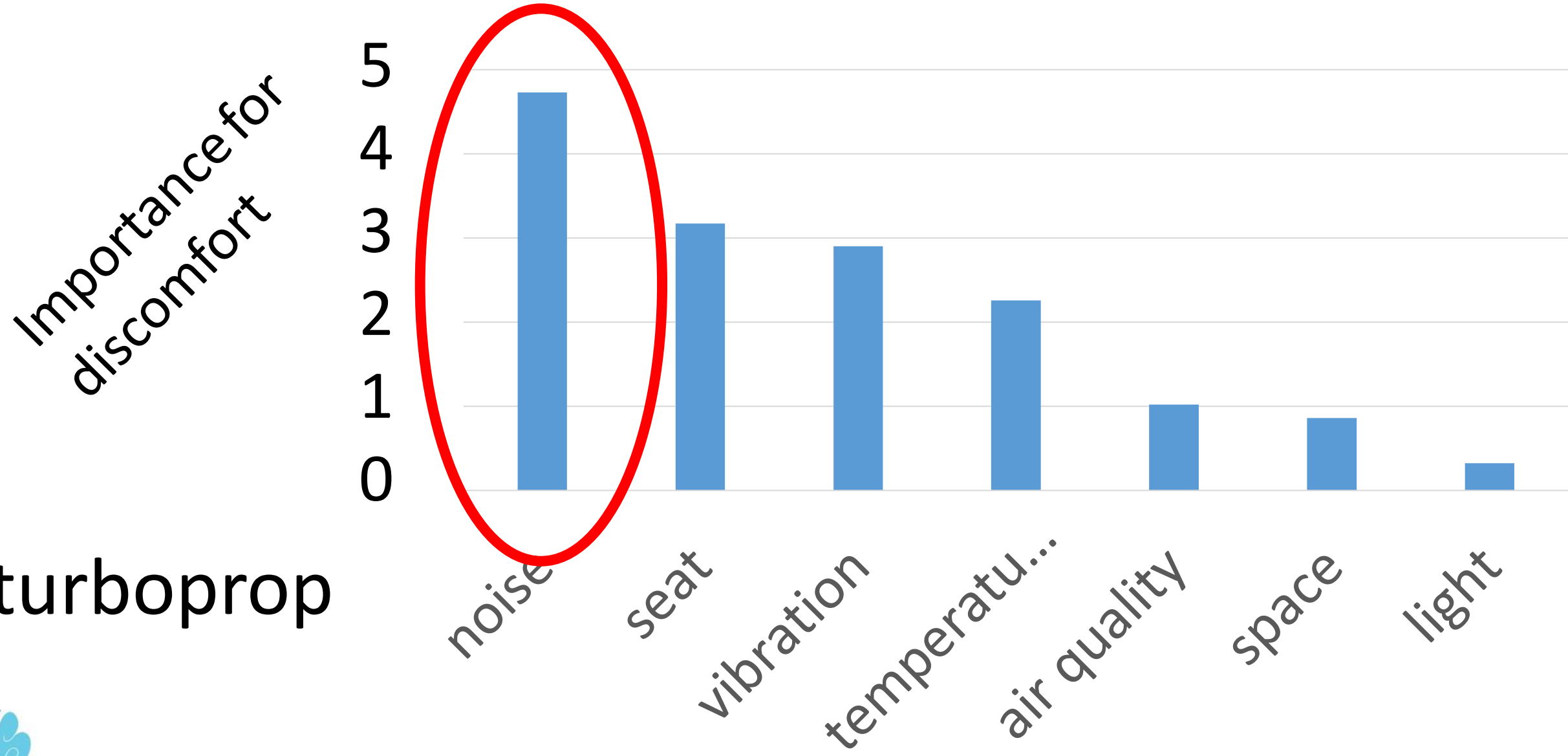
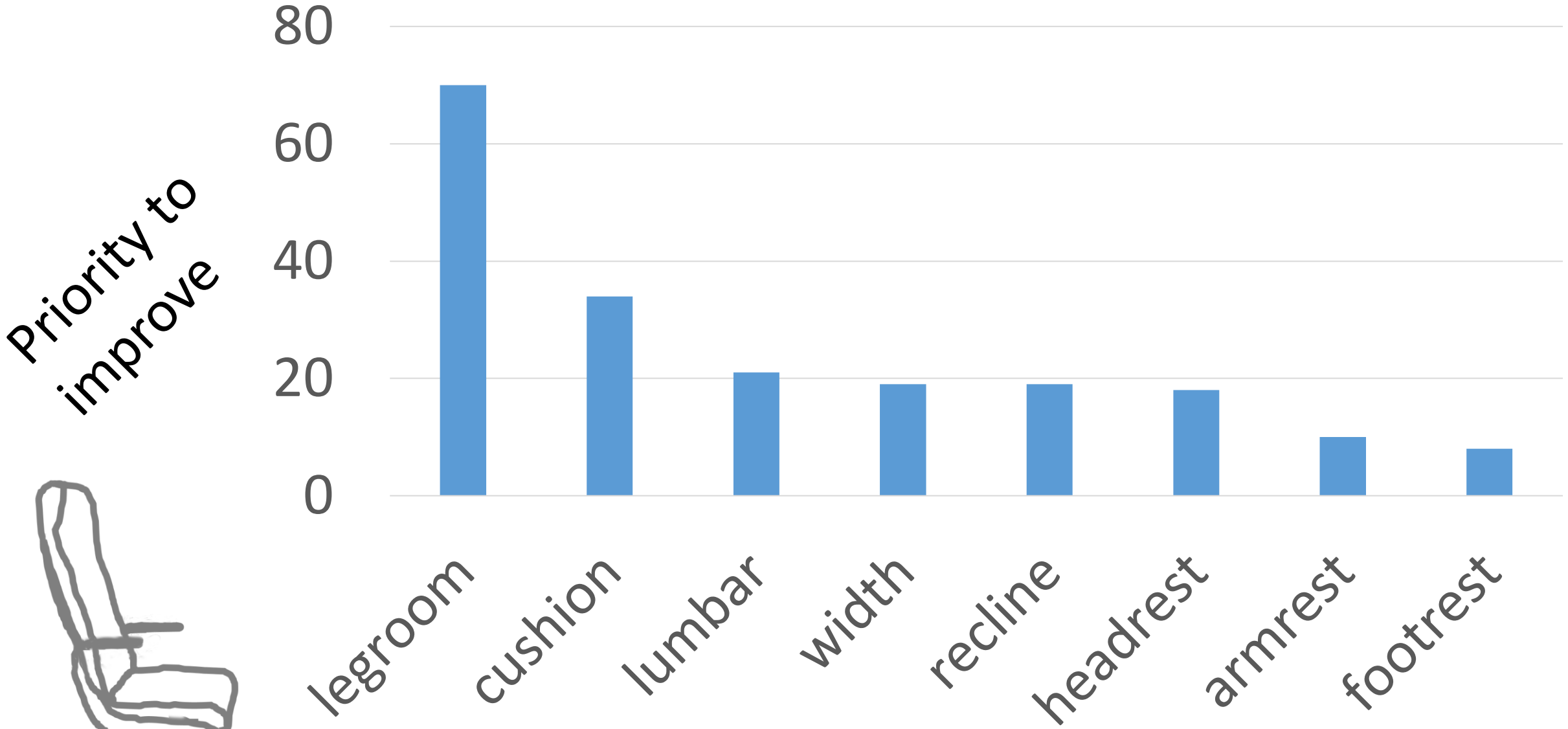
Nov 3, 2021 turboprop flights of 70 min. with passengers and researchers

turboprop



n=94, Vink et al., 2022



n=246, Nijholt, 2018

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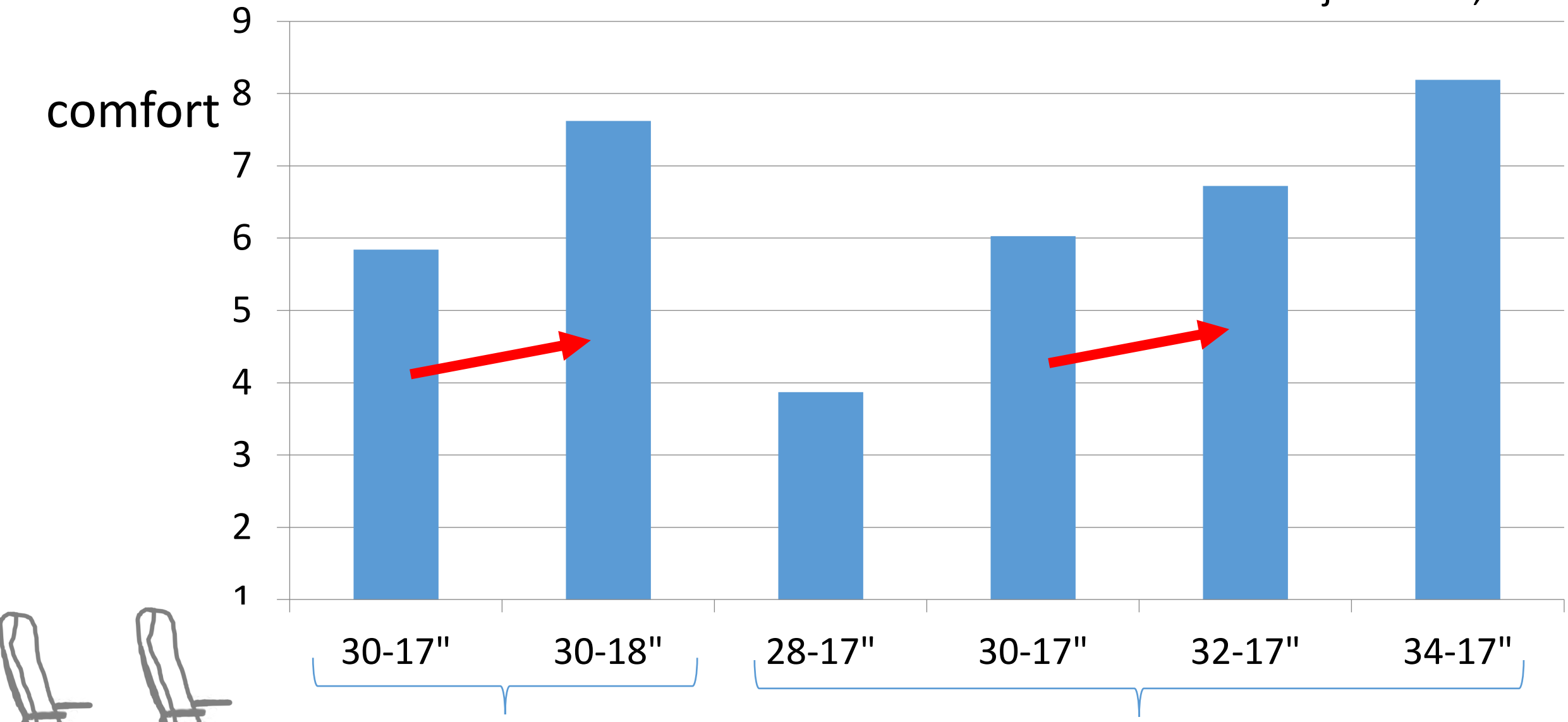
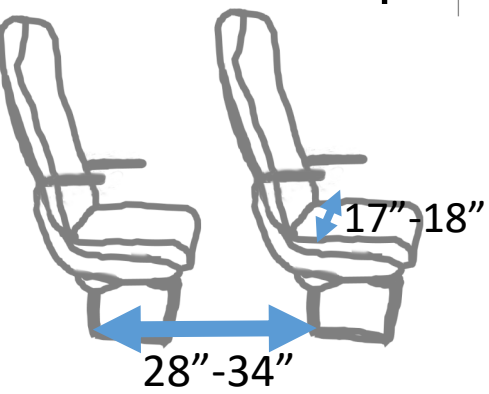
Pitch 28”-34”
Width 17”-18”

Anjani et al., 2021

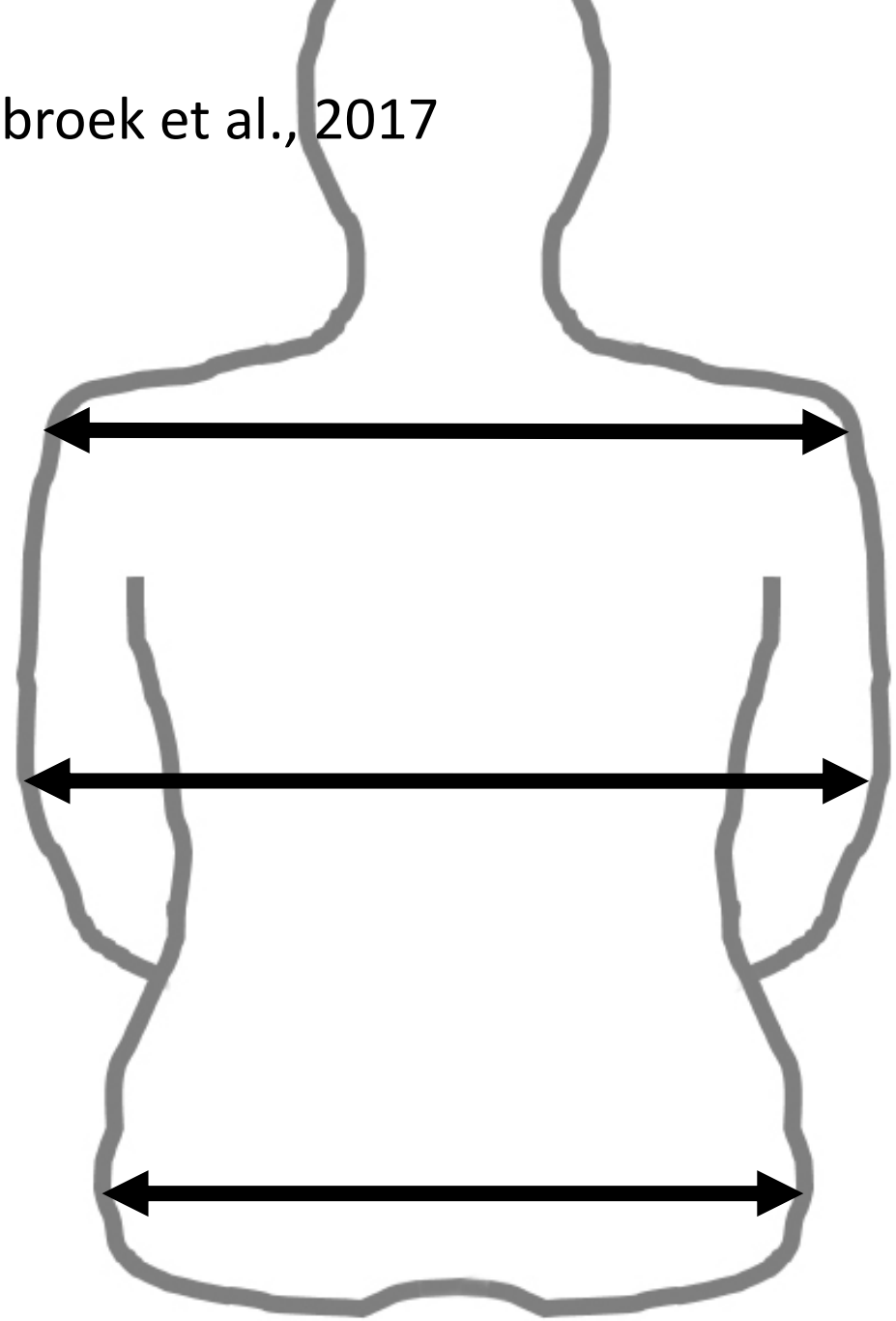




N=321,
seat width change

N=294,
seat pitch change

Molenbroek et al., 2017



Seat 18” wide (457 mm)

shoulder width: 453 mm for p95 female
494 mm for p95 male.

elbow width: 467 mm for p95 female
500 mm for p95 male.

hip breath: 434 mm for p95 female
404 mm for p95 male.

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Summary:

Propeller aircraft have potential (sustainable)

Comfdemo: digital model and protocol for tests in a Demonstrator

For protocol attention is needed for:

- Noise
- Seat dimensions (esp seat width)
- Vibration

This is all relevant for future propeller airplanes

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Inflight questionnaire results

Prof. Dr. Britta Herbig, Ludwig-Maximilians-Universität München

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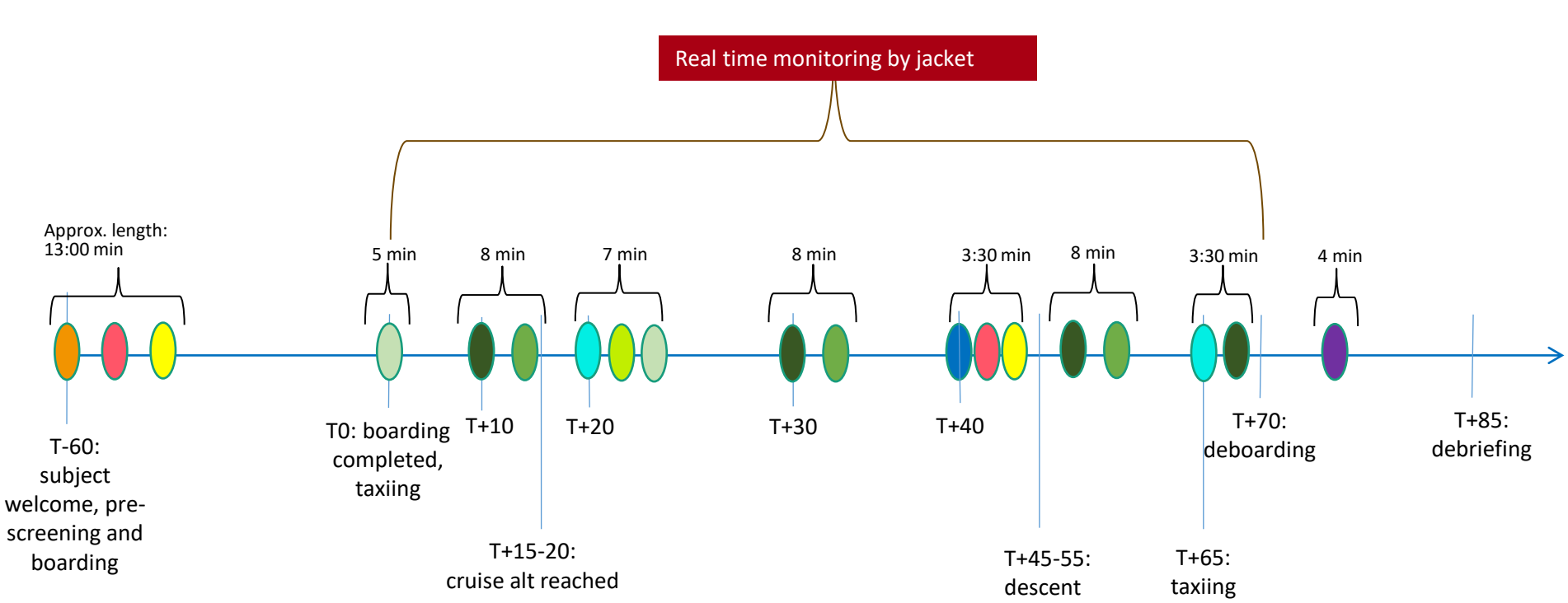
Sequence of questionnaire parts



- Pre-Screening (control variables)
- Mood
- Health symptoms
- Acoustic environment & vibration
- Thermal environment & quality of the air
- Lighting environment
- Local body part discomfort& overall comfort
- Postural sensation
- Spatial & visual perception
- Manipulation check

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Sample Characteristics

- Overall, 94 participants (3 participants were excluded)
- 58 men and 36 women
- Mean age 33.86 ± 14.31 years
- Mean BMI 23.60 ± 3.24
- Experience travelling in a turboprop aircraft:
  - 53.3% yes
  - 32.2% no
  - 14.4% did not know
- Majority of participants indicated a positive attitude towards flying (M = 5.89, SD = 1.26)

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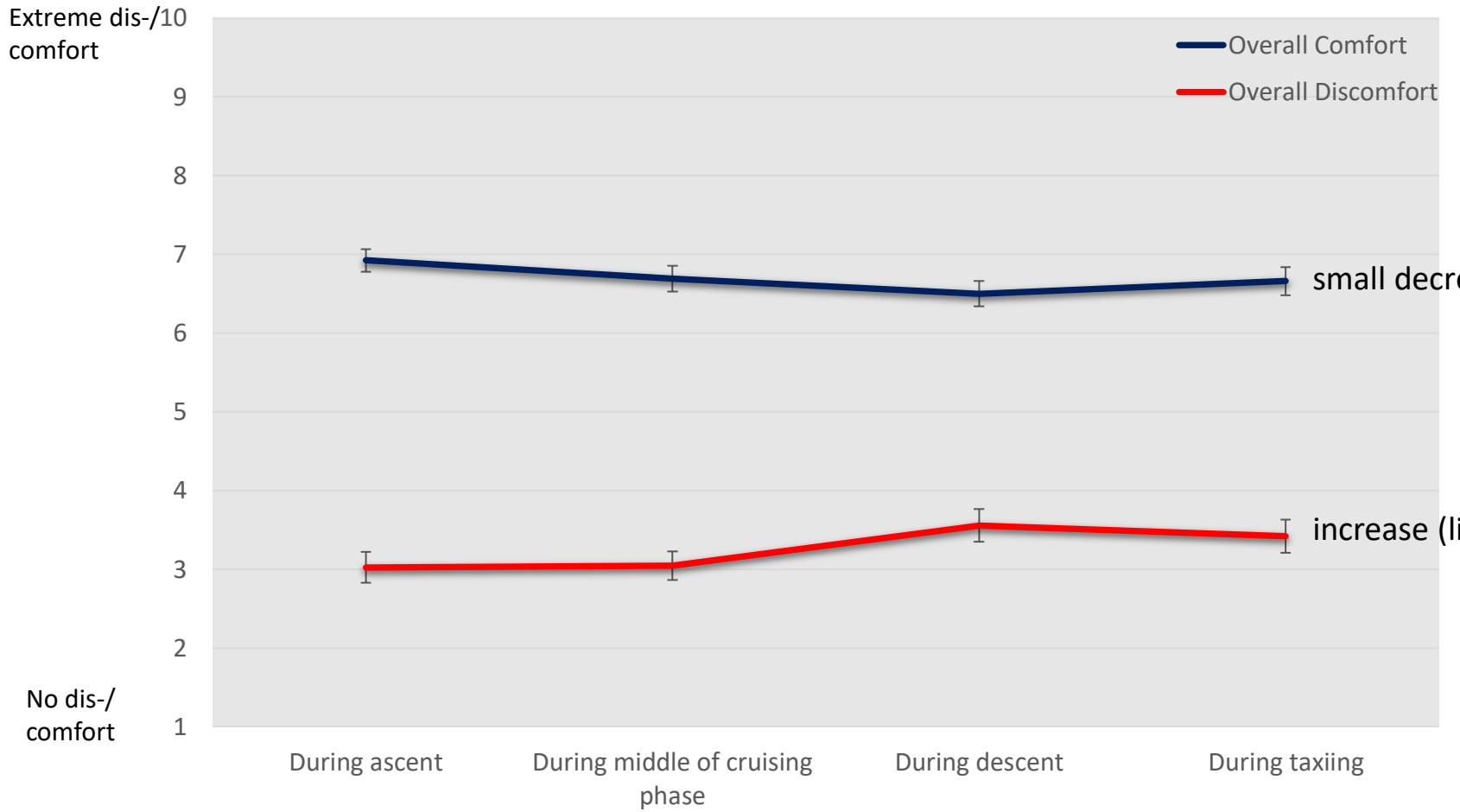
Overall Dis-/Comfort Rating over time



small decrease (quadratic p=.071)

increase (linear p=.018)

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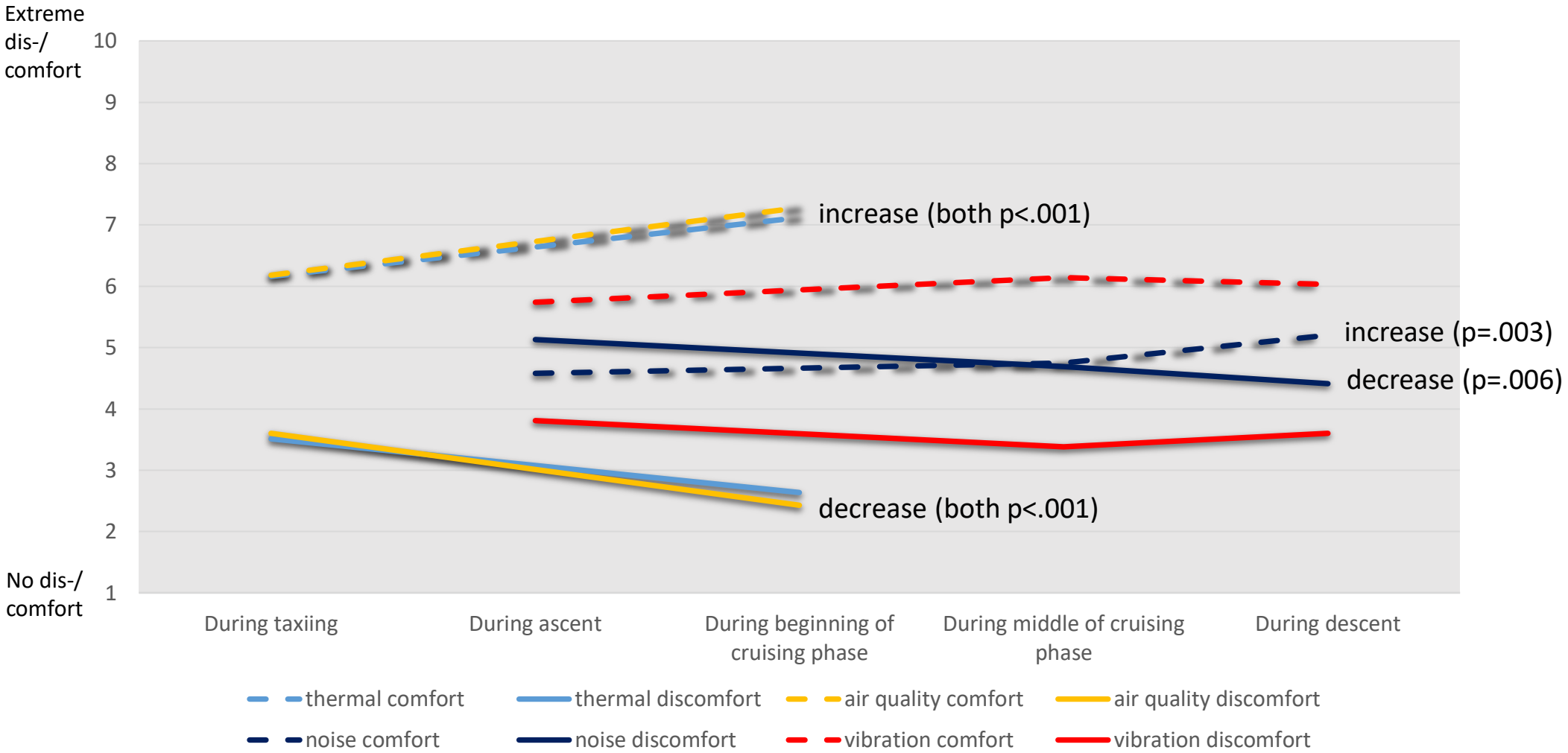
Dis-/comfort: Environmental parameters over time



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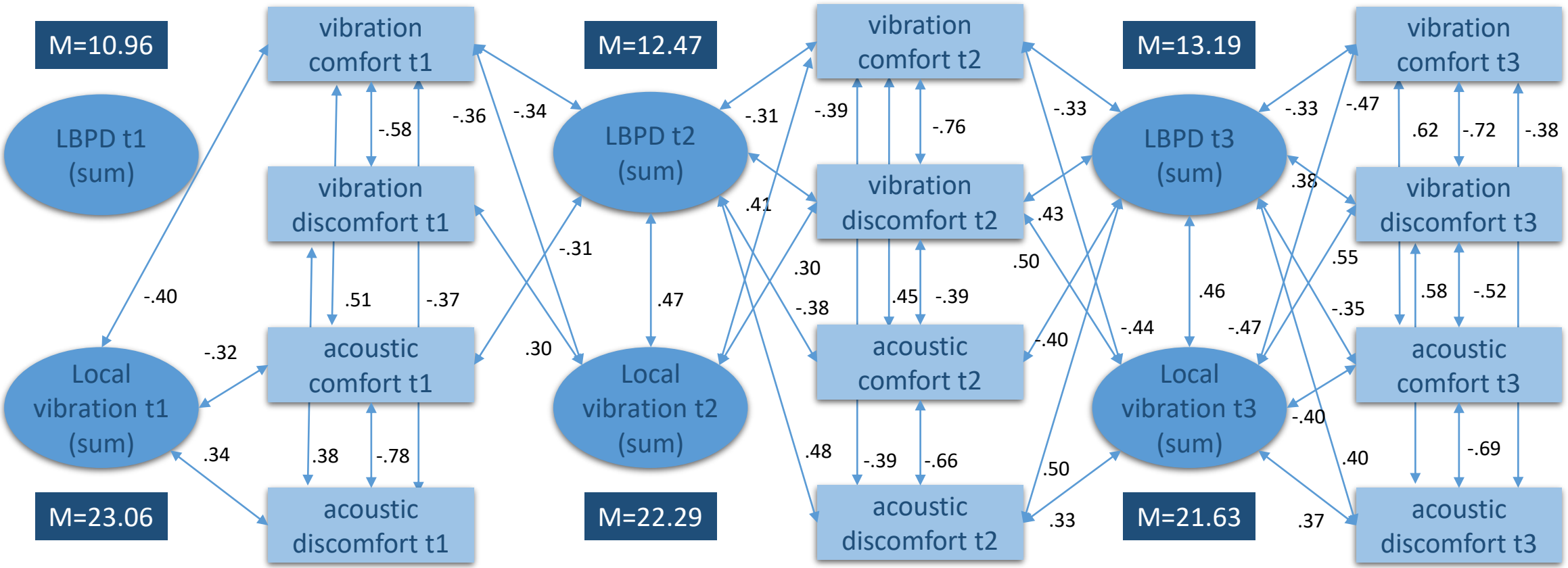
Acoustics and Vibration: Associations to local body part discomfort (LBPD) and vibration experience



*Range LBPD 9 - 45, Local vibration 11 – 55, higher values: stronger bodily sensations
only medium-sized correlations r>.30 (9%+ shared variance) according to Cohen (1992), autocorrelation across time omitted

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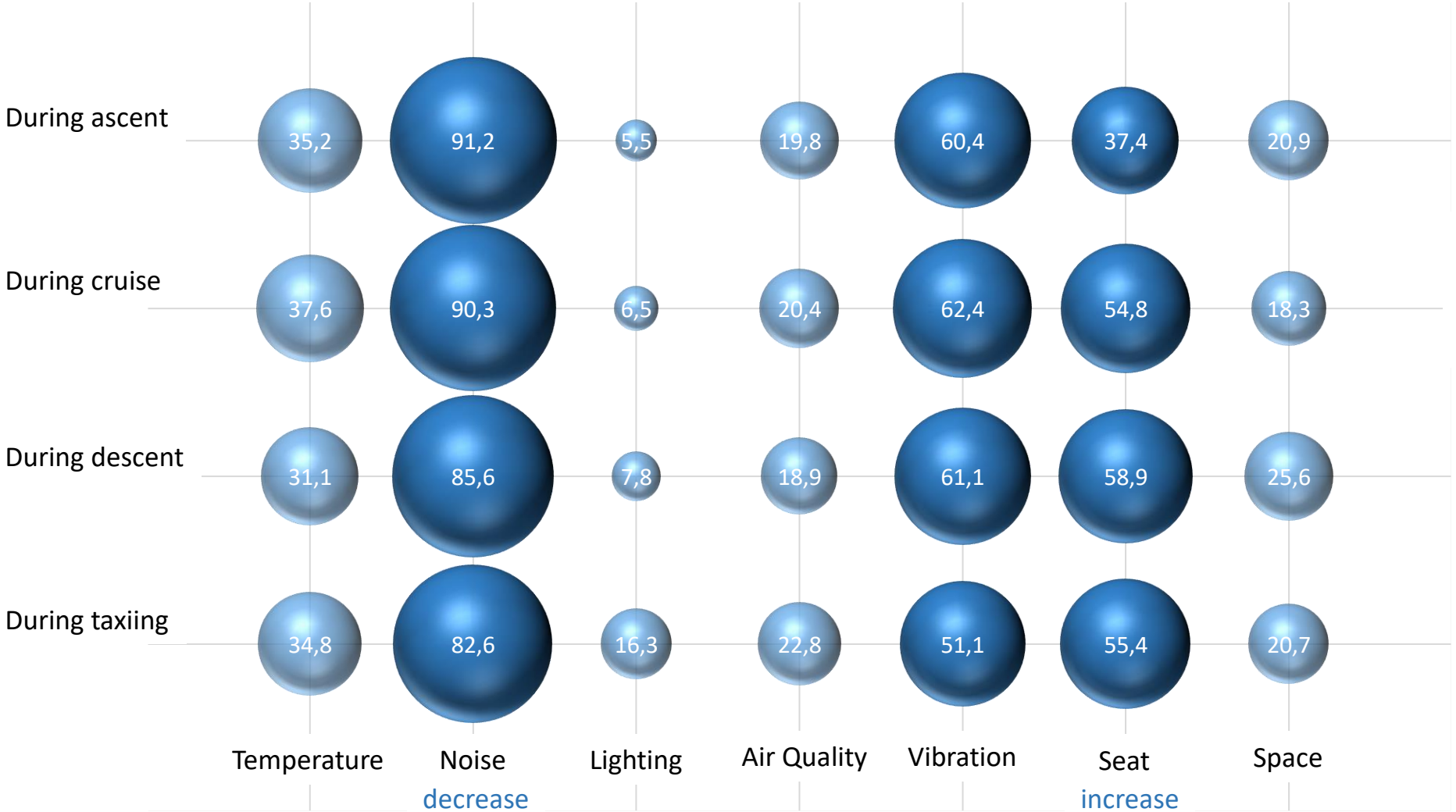
Discomfort Factors

- Please mark the *three* factors most contributing to your experienced level of *discomfort* (percentage of ticked answers):



All factor combinations per measurement time differ systematically from uniform distribution

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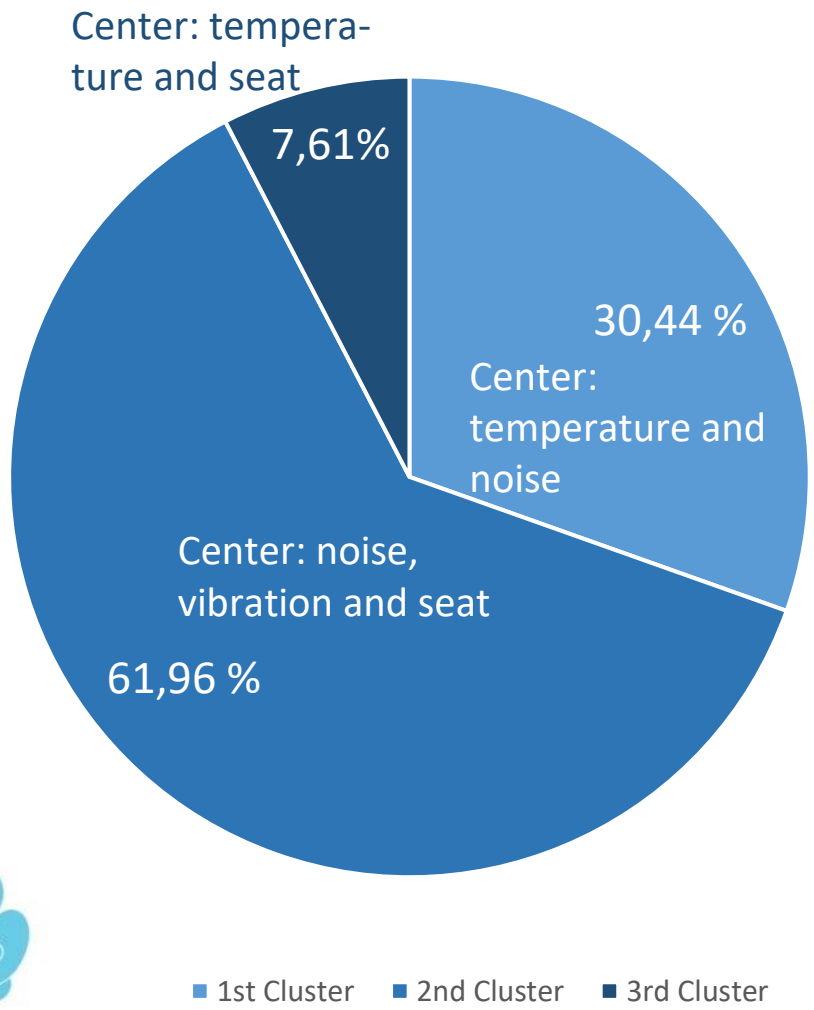
Cluster of Overall Discomfort Factors



Person-related control variables in clusters

No differences regarding:

- Age, sex, anthropometrics, BMI
- Flight attitude, turboprop experience, negative affectivity
- Flight, row

Differences regarding:

- Flight experience (number of flights): Cluster 1 (3,11) less experienced than cluster 2 (8,43)
- Noise sensitivity (mean1-5): Cluster 1 (2,43) less sensitive than cluster 2 (2,83)

Discomfort factor	Overall after deboarding
Temperature	34 (37.0%)
Noise	**84 (91.3%)**
Lighting	8 (8.7%)
Air quality	18 (19.6%)
Vibration	**58 (63.0%)**
Seat	**49 (53.3%)**
Space	17 (18.5%)

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Decision to Fly again with Turboprop Aircraft

Would you consider flying with this type of aircraft again?	YES N=80	NO N=11	p
Flight experience (# flights in 2019)	6,68	7,45	.050*
General environmental sensitivity	8,59	11,55	.021*
Discomfort regarding acoustic environment ascent	4,94	7,09	.003**
Discomfort regarding acoustic environment cruise	4,47	6,27	.017*
Discomfort regarding acoustic environment descent	4,28	6,09	.016*
Discomfort regarding vibration cruise	3,10	5,64	.000***
Discomfort regarding vibration descent	3,32	5,91	.000***
Local vibration during ascent (bodily sensations)	23,0	27,13	.029*
Local vibration during descent (bodily sensations)	14,67	26,64	.033*

No differences regarding light-, spatial-, postural-, air quality- or thermal discomfort, noise sensitivity and other attitudes, health symptoms, local body part discomfort, flight or row

Mann-Whitney-U-Test, *p ≤ .05, **p ≤ .01, ***p ≤ .001

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Summary

- In general, people felt rather comfortable (although decreasing over time) and would fly again with turboprop aircrafts (85.1%)
- Noise, vibration and seat are the dominant discomfort factors for most participants across all flight phases
- Levels of noise and vibration related discomfort are also the ones discriminating between participants who would fly again with turboprop and who would not
- Development of comfort and discomfort experience over bodily sensations in turboprop aircrafts seem to have a rather complex conditional structure → Challenge for modelling

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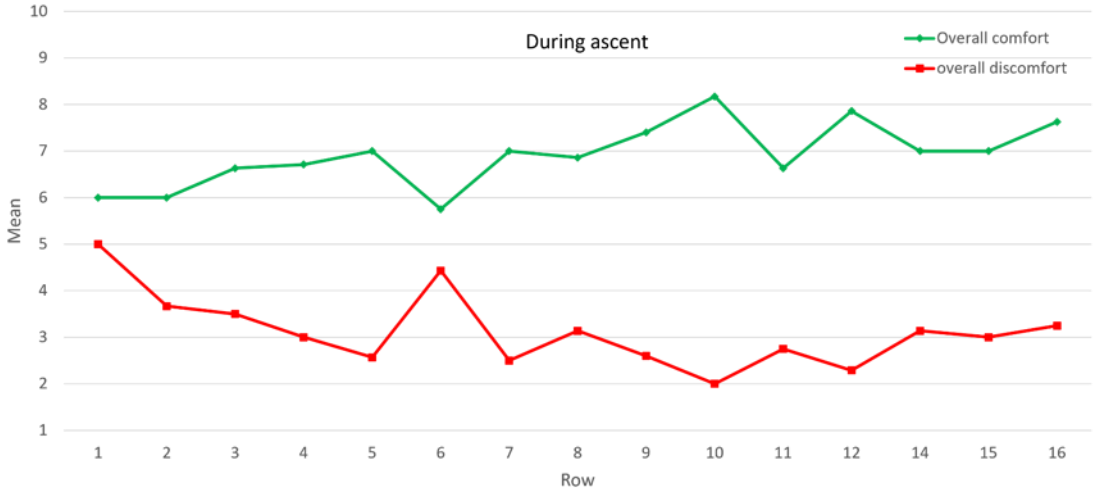
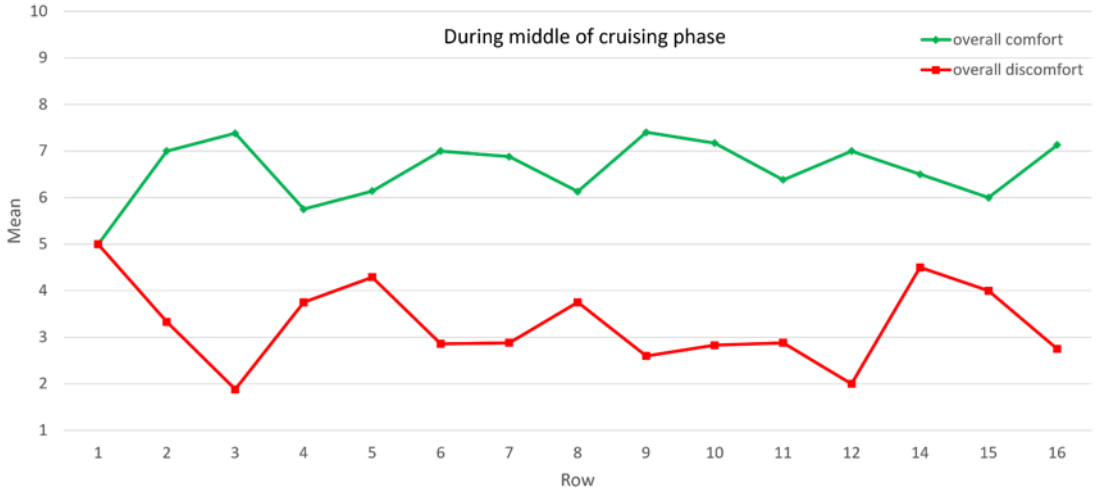
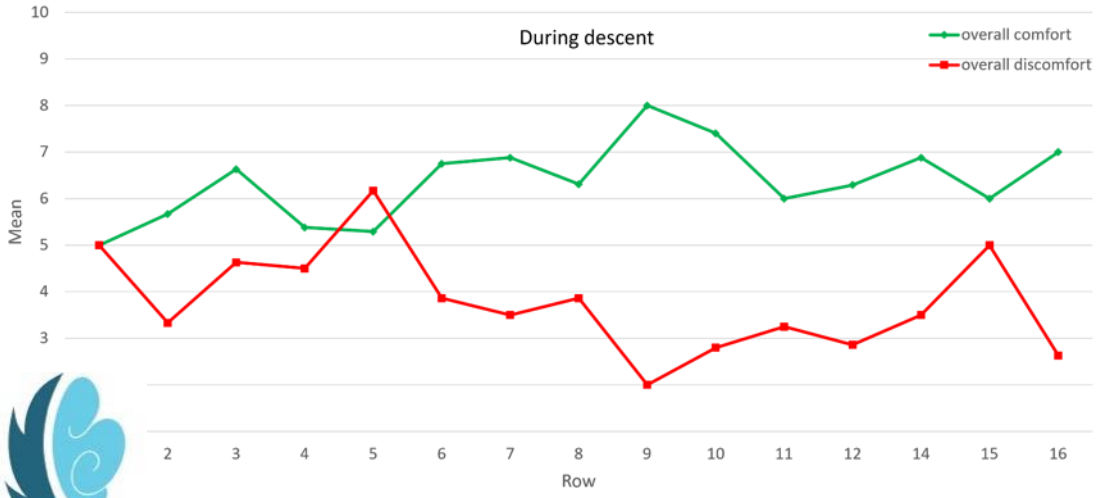
Overall Dis-/Comfort Rating stratification







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Prediction of flight pleasantness at end of flight

Dependent Variable: How pleasant was this flight?	N predictors	R^2	ΔR^2	β
Sociodemographics and anthropometry	**8**			
… sex		.035^{+}	.035^{+}	-.187^{+}
Psychological „Make-Up“ (Attitudes, Fears, Affect)	**10**			
…positive flight attitude		.051*	.051*	.226*
Experienced discomfort during Flight	**24**			
…vibration during descent		.116**	.116**	-.341**
…thermal factor during whole flight		.184***	.068*	-.265*
…general discomfort during ascent		.220***	.036^{+}	-.201^{+}
…vibration during ascent		.267***	.047*	.259*
Physical “complaints”	**44**			
…local discomfort in middle back during descent		.164***	.164***	-.405***
…local discomfort in head & neck during cruising phase		.216***	.052`*	-.227*

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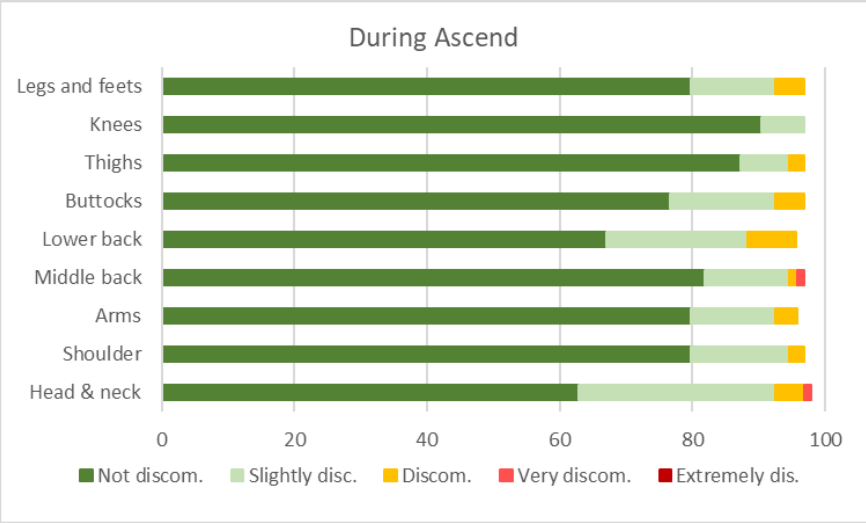
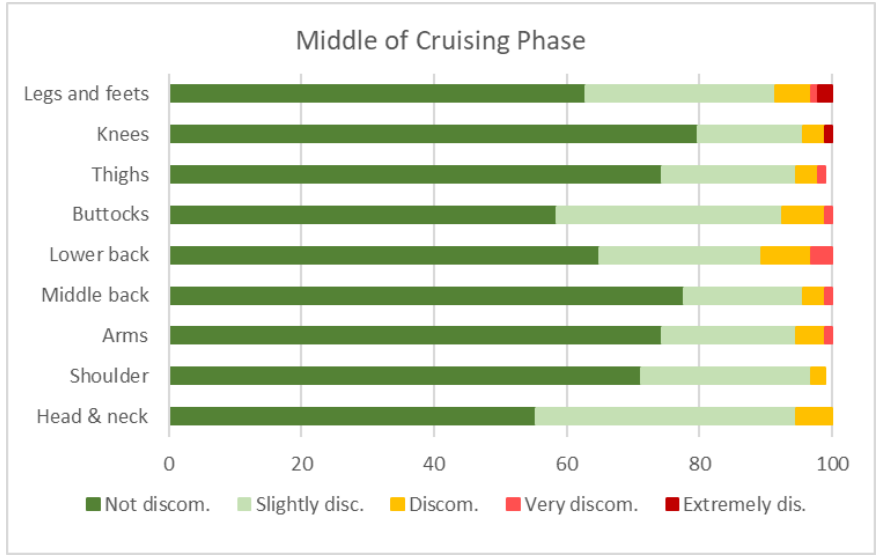
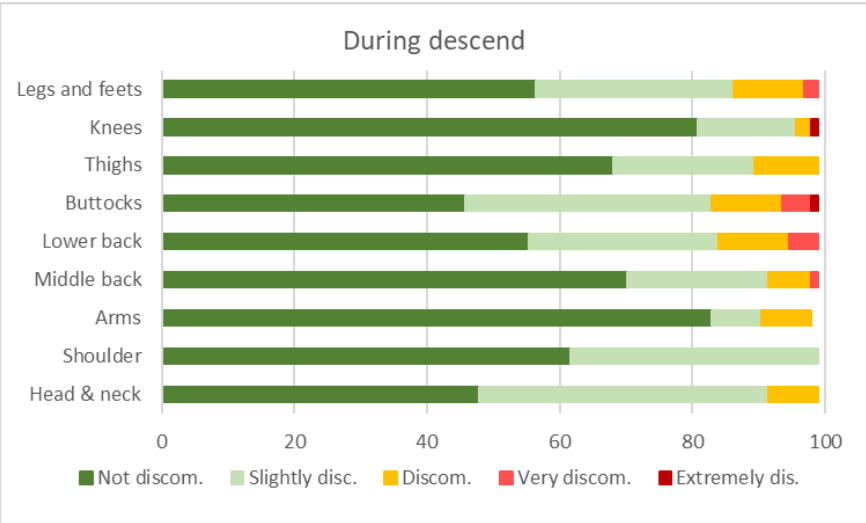
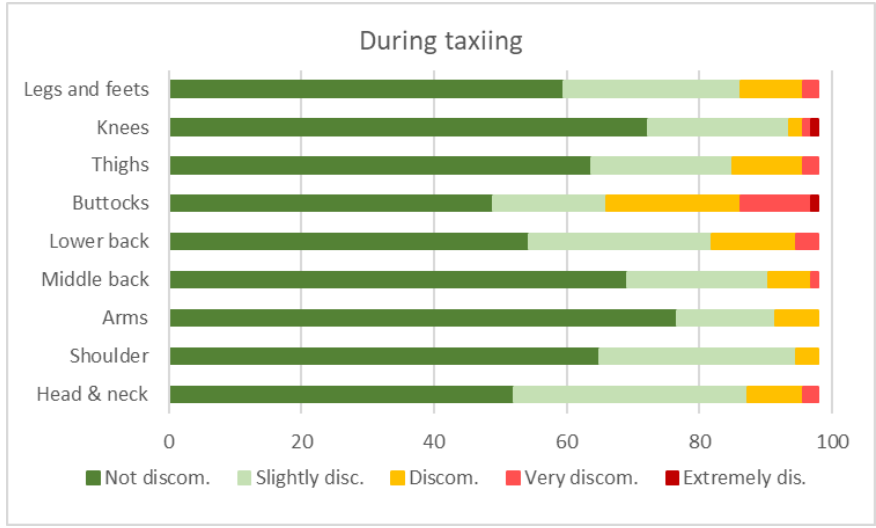
Note. Multiple linear regressions with forward selection, $^{+}$p<.10*p ≤ .05, **p ≤ .01, ***p ≤ .001

Local Body Part Discomfort – Frequency of answers %









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Digital twin of comfort: Modelling passengers' comfort experience

Dr. *Y. Song, TU-Delft*

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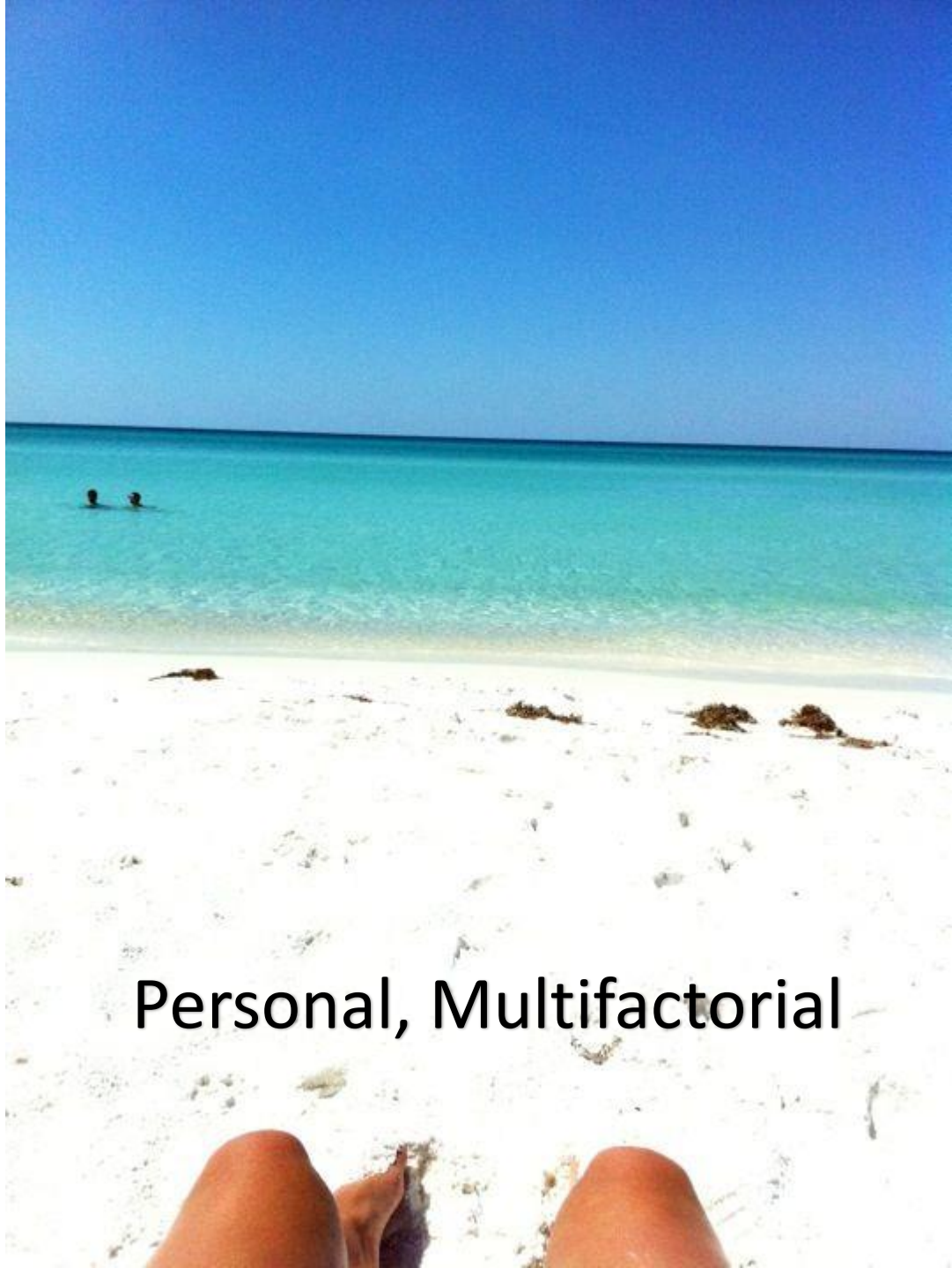
Experiencing comfort

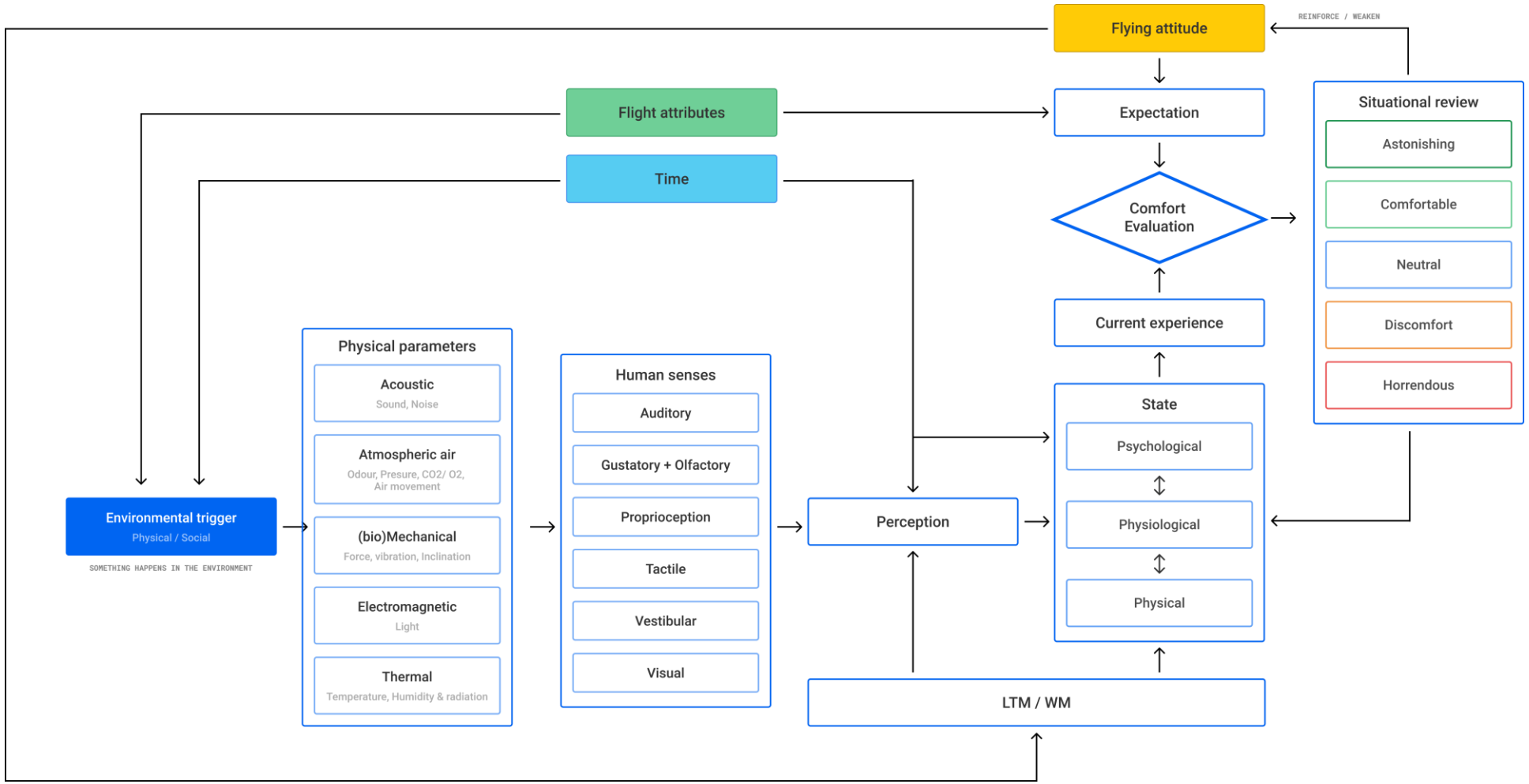
A product in itself can never be comfortable.

The **user** decides whether or not a product is **comfortable**, or leads to **discomfort**, by using the product.

Mansfield, N., Naddeo, A., Frohriep, S., & Vink, P. (2020).
Integrating and applying models of comfort. Applied Ergonomics, 82(May 2019), 102917.



An example of qualitative comfort models



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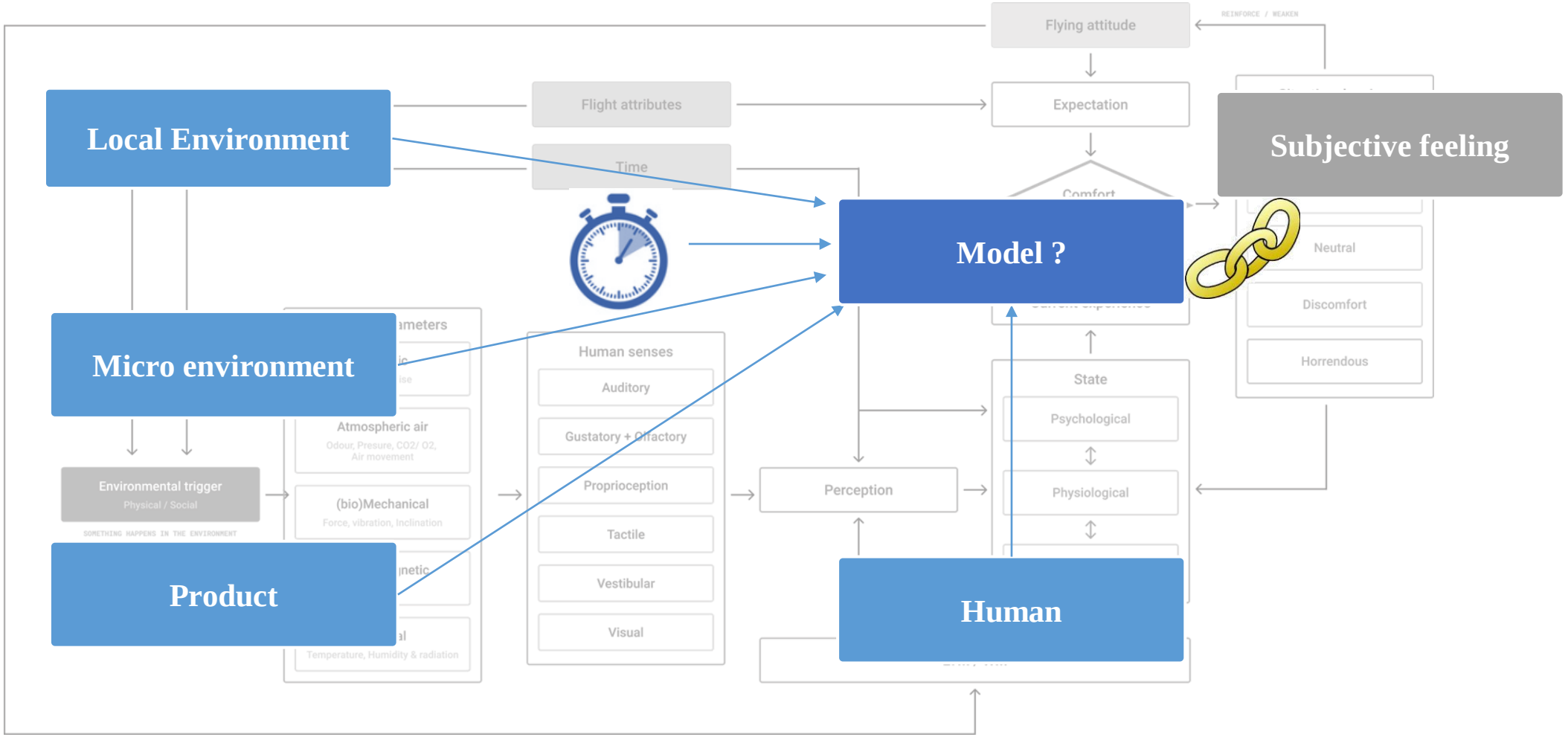
Factors in the qualitative comfort model



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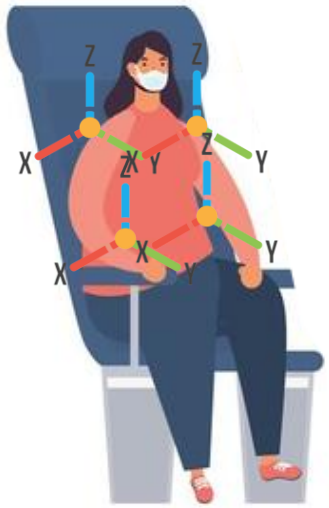
Highlighted measurable factors – 32 parameters

Local Environment
- Noise

Micro environment
- Co2
- Humidity
- Temperature
- Red light intensity
- Orange light intensity
- Yellow light intensity
- Green light intensity
- Blue light intensity
- Violet intensity

Human



+

- Gender
- Age
- Stature
- Body Mass
- Popliteal height
- Buttock popliteal depth
- Hip width

Product
- Flying time
- Row
- Seat
- Flight scheduled time

COMFDEMO

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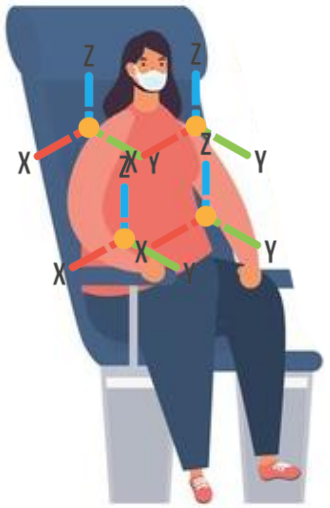

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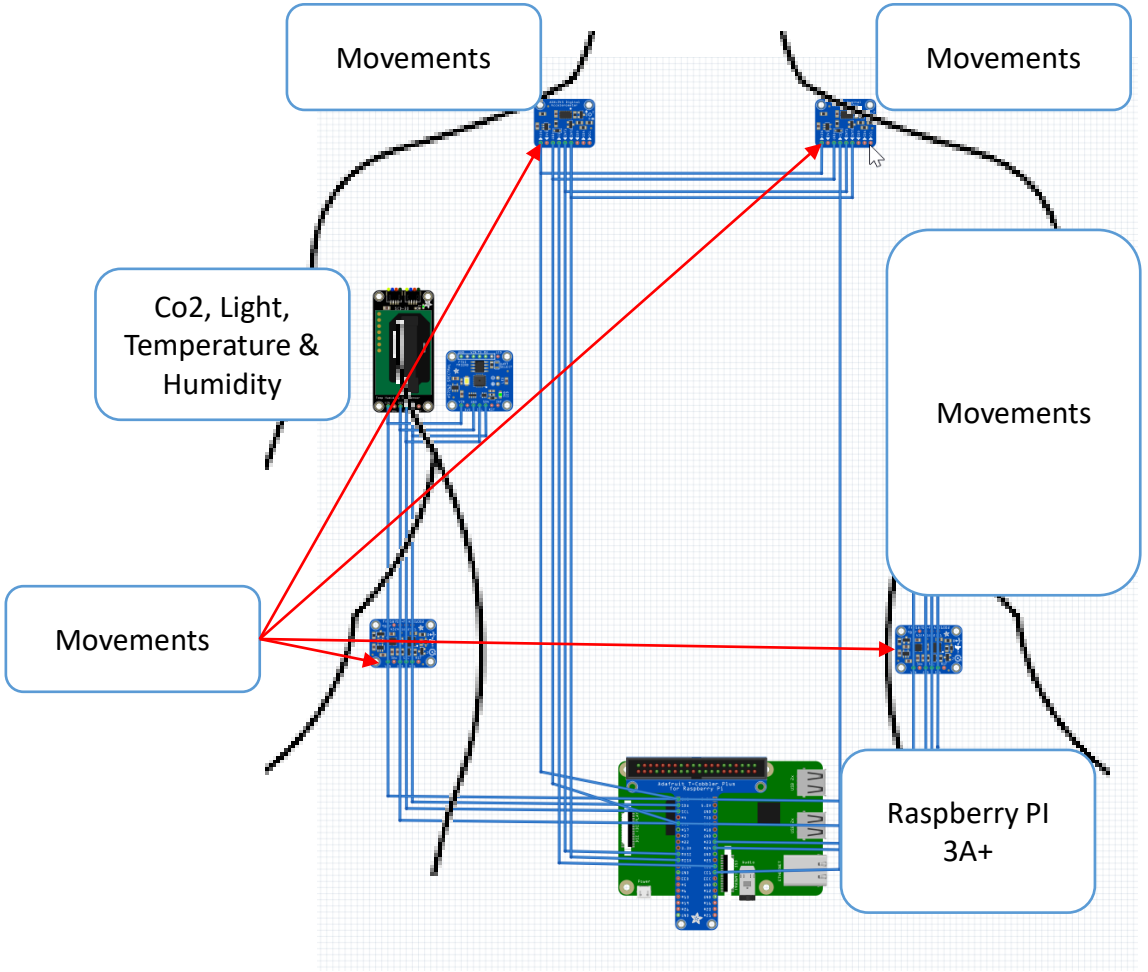
Wearable Jacket:
An integrated comfort measurement tool



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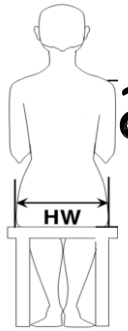
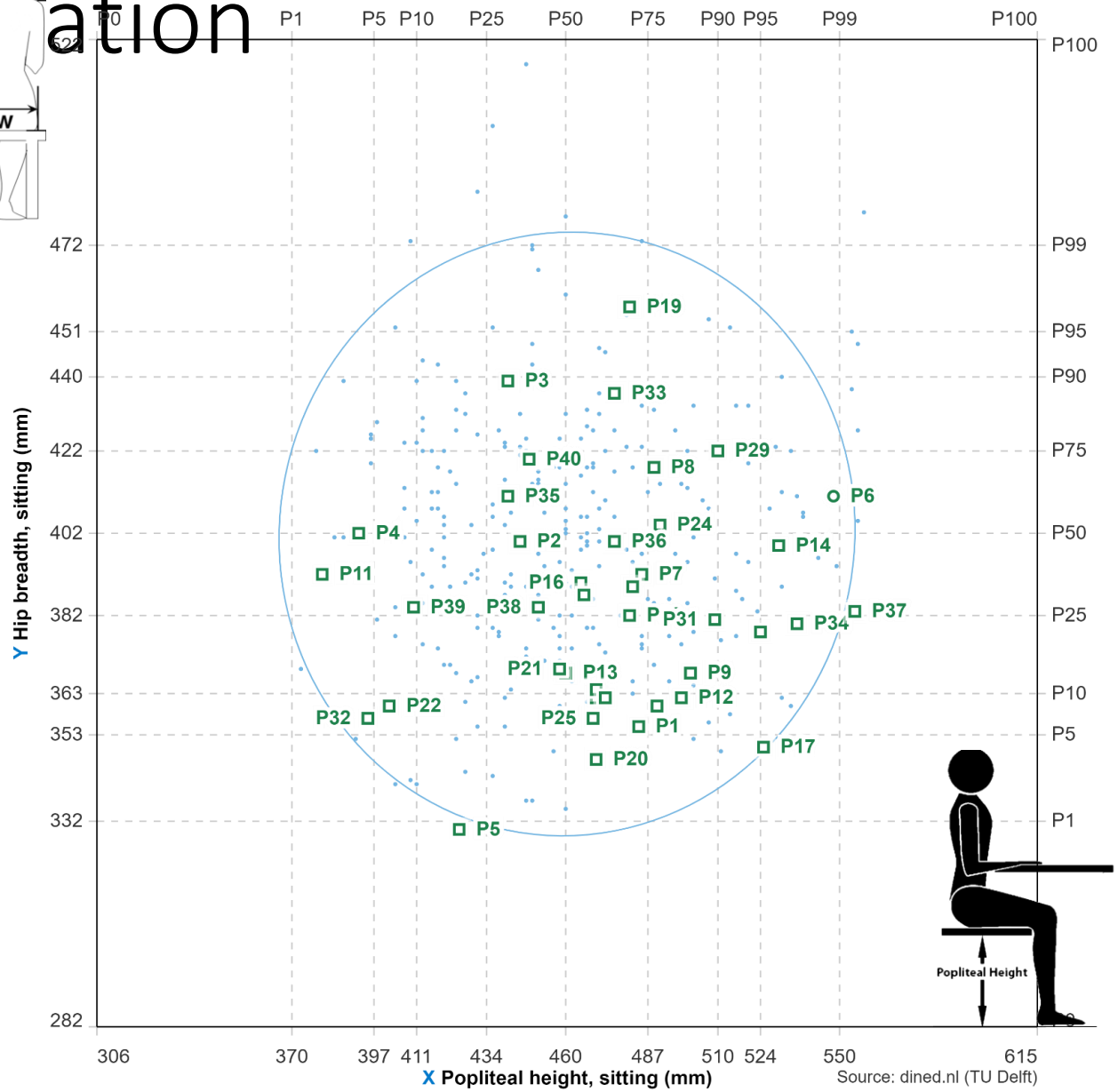
A representative population

- **Age:**
  - 35.15± 15.08 years old
- **Stature**
  - 174.2± 8.6 CM
- **Body mass**
  - 74.0±13.9 KG
- **Gender**
  - 26 males & 14 females

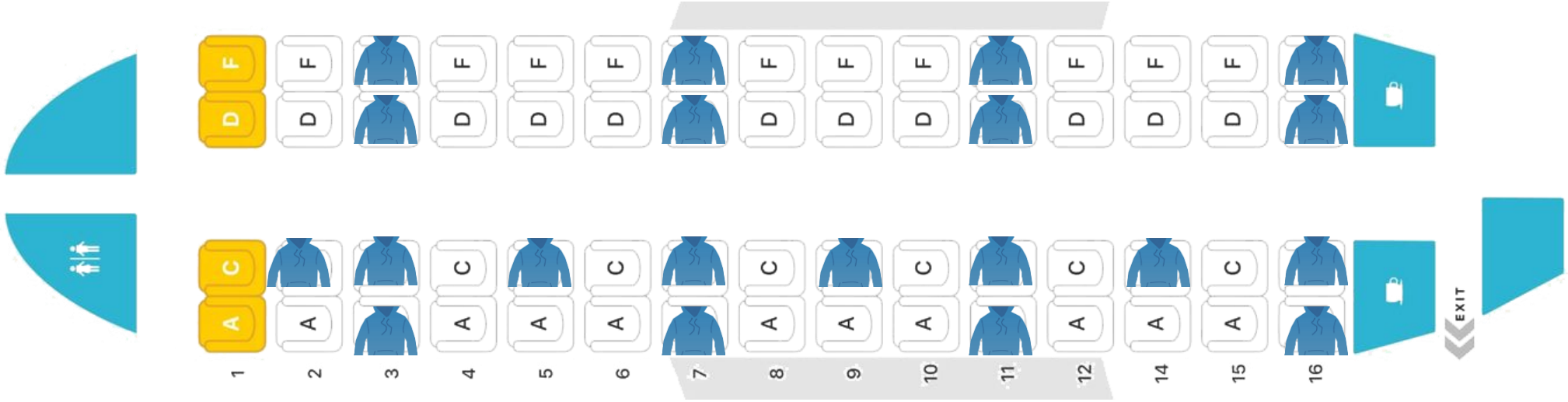




Cabin layout & location of Jackets

Morning

Afternoon



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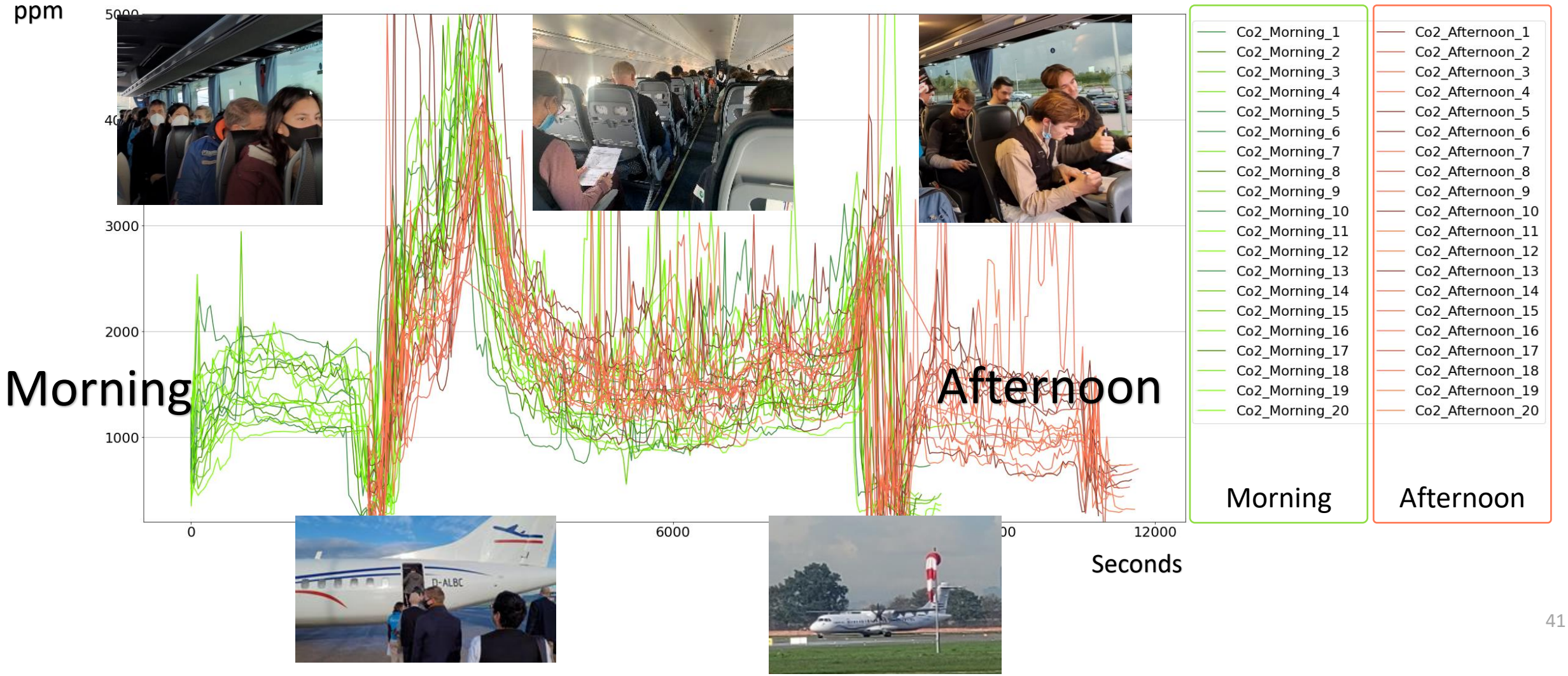
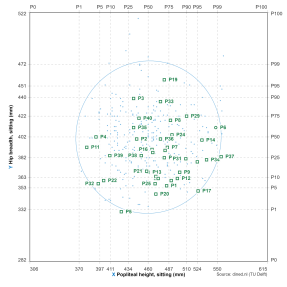
Data example -- CO2 levels



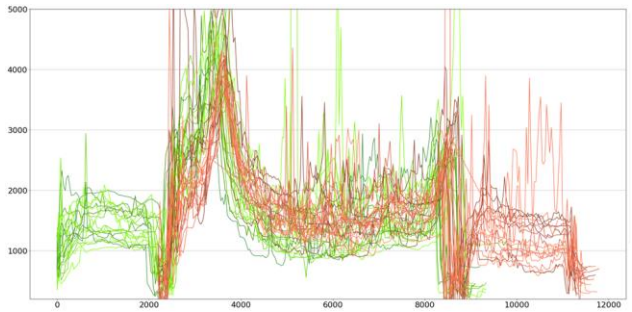
First attempt of a quantitative comfort model

Human, e.g. movements, anthropometry measures

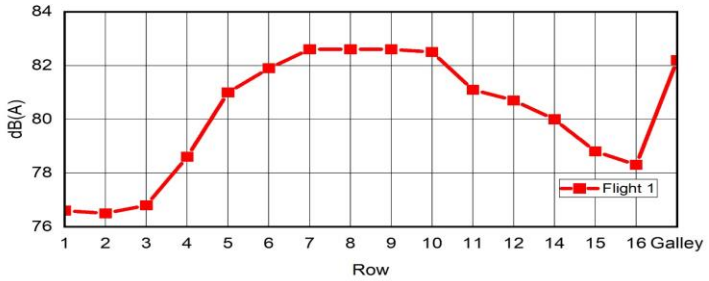


Product, e.g. rows of the seat

Micro environment, e.g. co2 level



Local environment, e.g. noise level



Modelling tool

Questionnaire

Hypothesis & Data pre-processing

In the first attempt, we use the changes of comfort /discomfort, as the baseline differs per person

60s were set as the time unit

Data augmentation: we linearly interpolate the comfort/discomfort scores

All data is normalized to the range of 0 ~ 1 where the minimum is 0 and the maximum is 1

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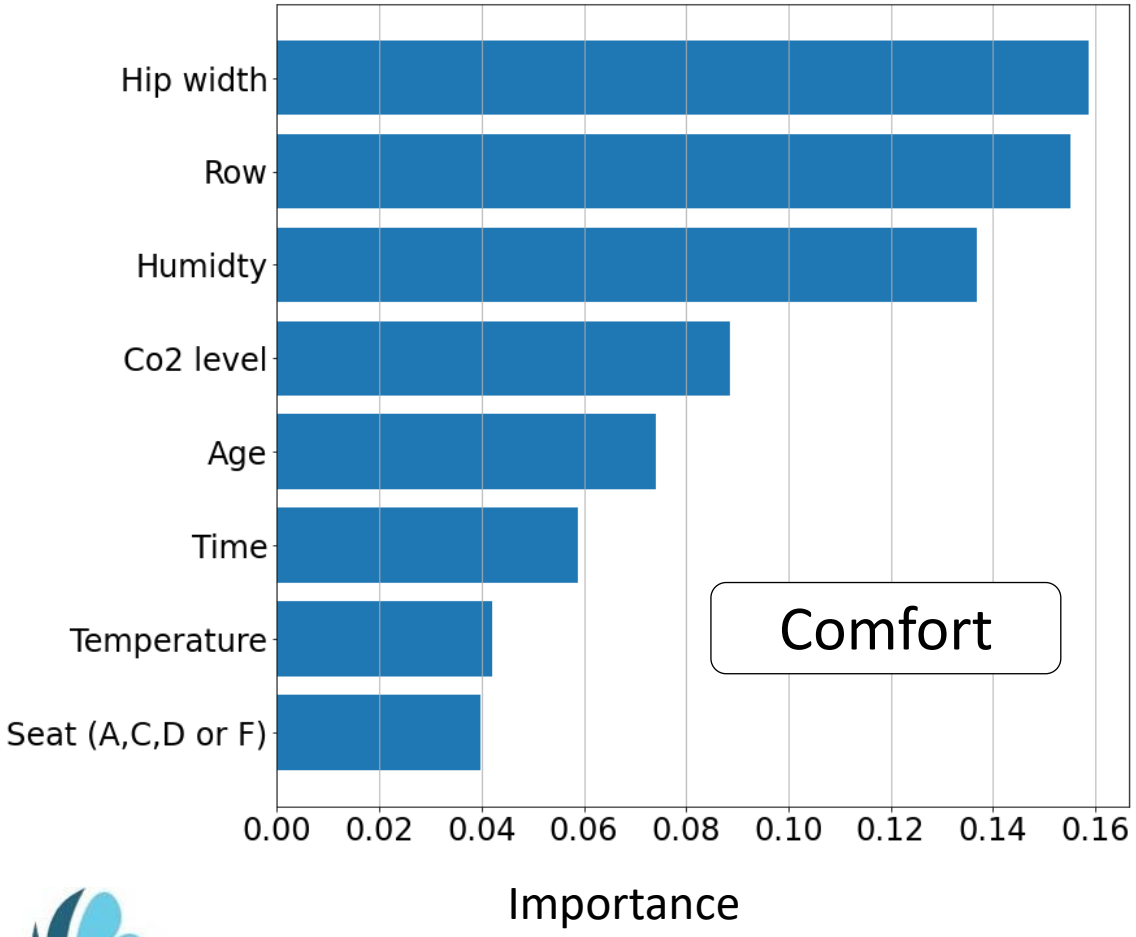
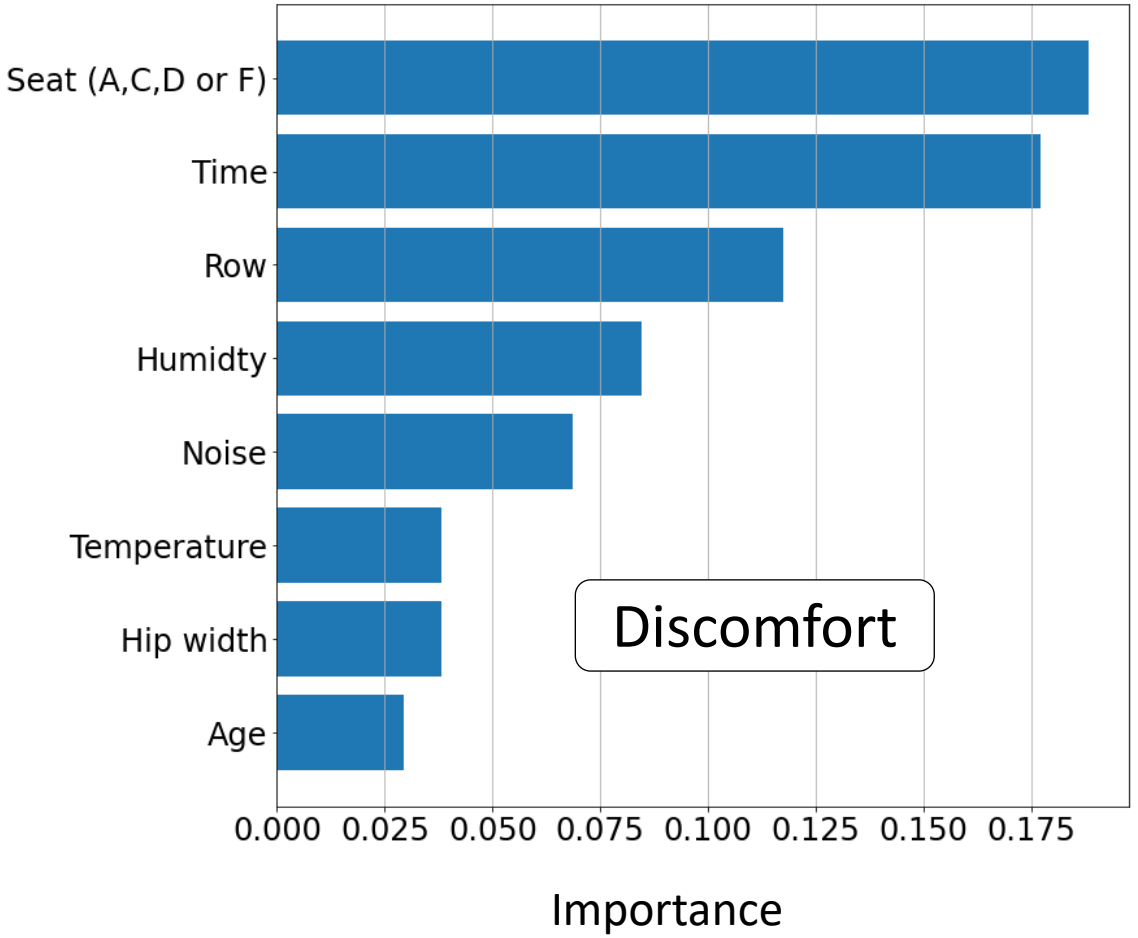
First attempt:
The importance of factors regarding comfort & discomfort





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Summary:	The preliminary results show that we are able to make a step towards modelling human comfort experience using Jacket data
	Anthropometry, seat positions, time, humidity, CO_2, temperature and noise are leading factors that influence the feeling of comfort/discomfort
Limitations	Noise and vibration in micro environment were not included in the model
	In Lubeck air, the seat pitch was 34 inch, which might influence the importance of other anthropometric measures, e.g. stature
Future works	More data on different types of seat layouts and airplanes
	Advanced modelling tools with in-depth explanation of different factors

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Interaction and Questions

Interaction between attendees and speakers on webinar so far + discussion

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Coffee Break

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In-flight measurement of sound and vibration inside the cabin

Aenne Euhus, Adrian May, Dr. Michael Bellmann
itap GmbH

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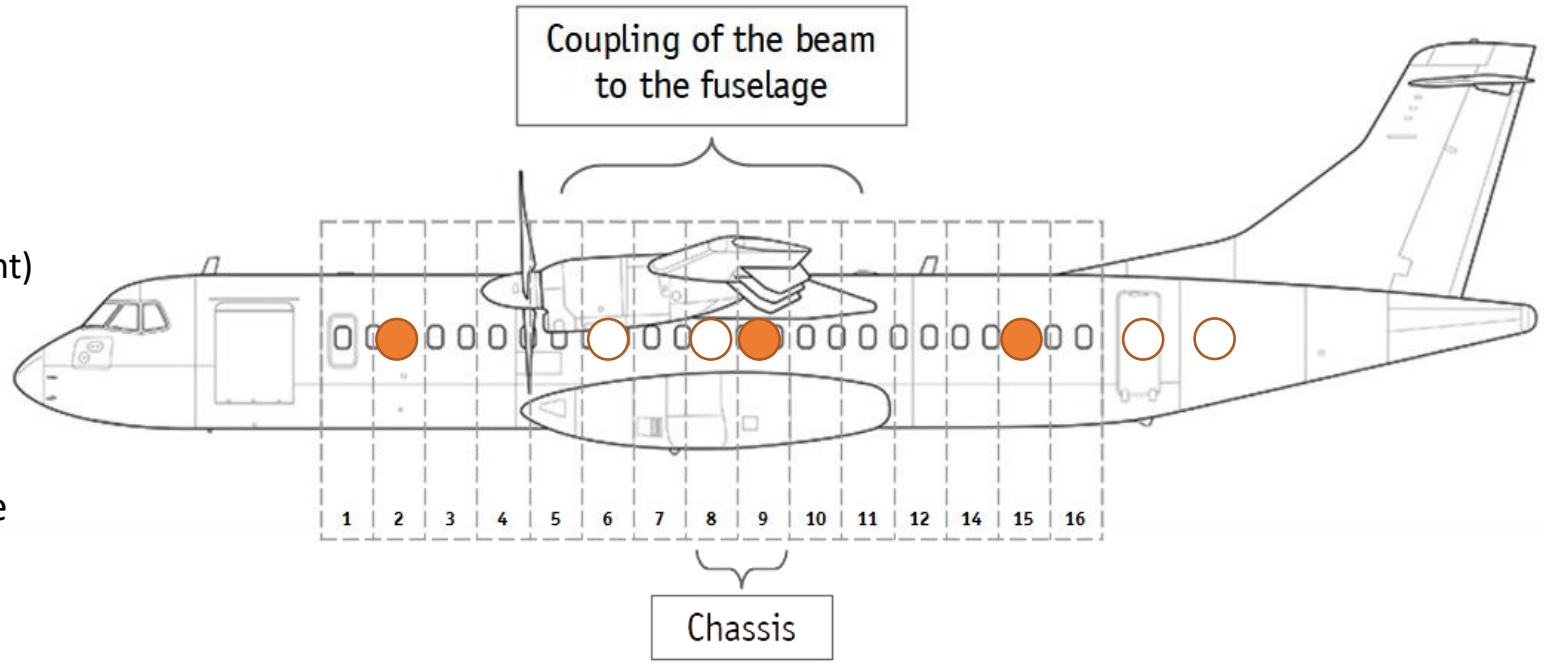
Flight situation and measurement positions

Nov. 3rd 2022: 3 flights (1st and 2nd flight with PAX; 3rd flight without PAX) in ATR72-500:

- Measurement positions of noise and vibrations
  - Continuous measurements in row 2 & 15:
  - Continous measurements row 9 (only 3rd flight)

- Additional spot measurements:
  - around the coupling area of the beam to the fuselage (row 6-8)
  - around the galley
  - in the toilet (incl. flushing)



Due to technical defect there is no data avaiable for:

- vibration x-axis
- vibration z-axis

@ row 15 | 3rd flight

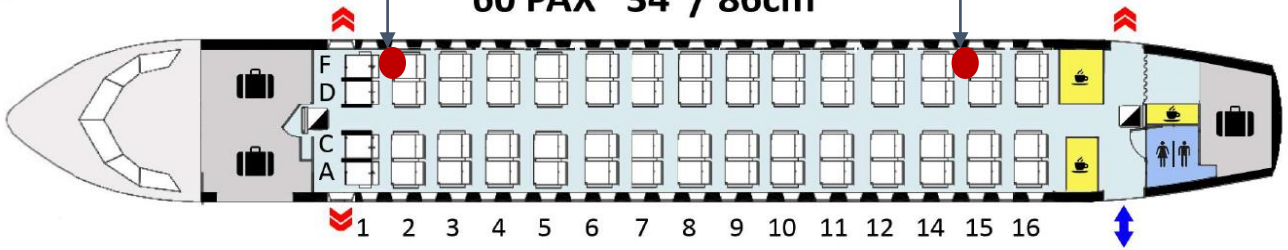
Flight situation and measurement positions 1st & 2nd Flight

Lübeck Air

ATR72-500

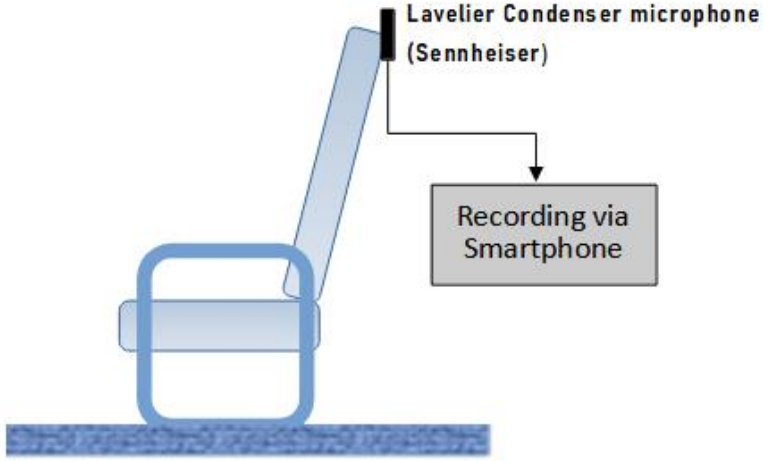
- MAIN ENTRY DOOR
- EMERGENCY EXITS
- ATTENDANT SEAT
- BAGGAGE COMPARTMENT
- GALLEY
- TOILET

Continuous noise measurements from taxiing to taxiing
at row 2 and row 15 with lavalier microphones



1st & 2nd Flight **with** Participants

- 1st Flight (60 PAX)
- 2nd Flight (60 PAX)



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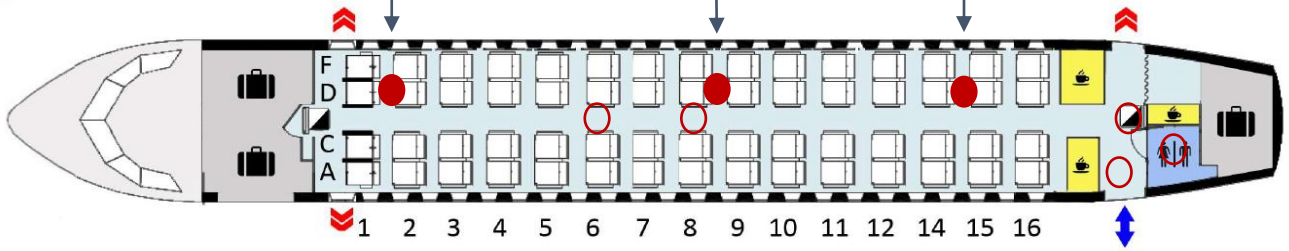
Flight situation and measurement positions 3rd Flight

Lübeck Air

ATR72-500

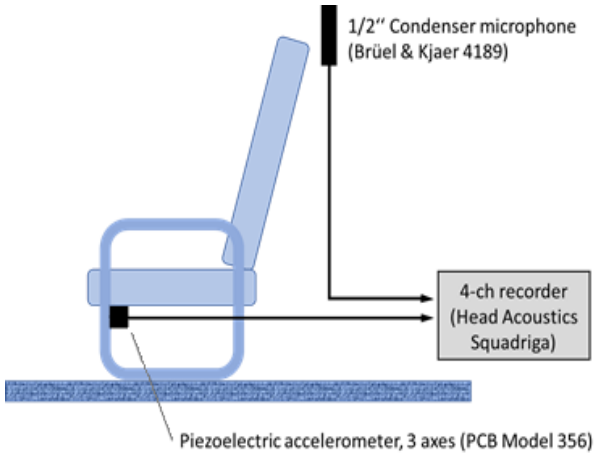
Continous noise & vibration measurements from taxiing to taxiing

- MAIN ENTRY DOOR
- EMERGENCY EXITS
- ATTENDANT SEAT
- BAGGAGE COMPARTMENT
- GALLEY
- TOILET



3rd flight **without** PAX:

- ● noise and vibration measurements at row 2, 9 & 15
- ○ additional spot-measurements in aisle, galley and toilet



➢ *Due to safety restrictions extensive NVH measurements only during 3rd flight (without PAX)*

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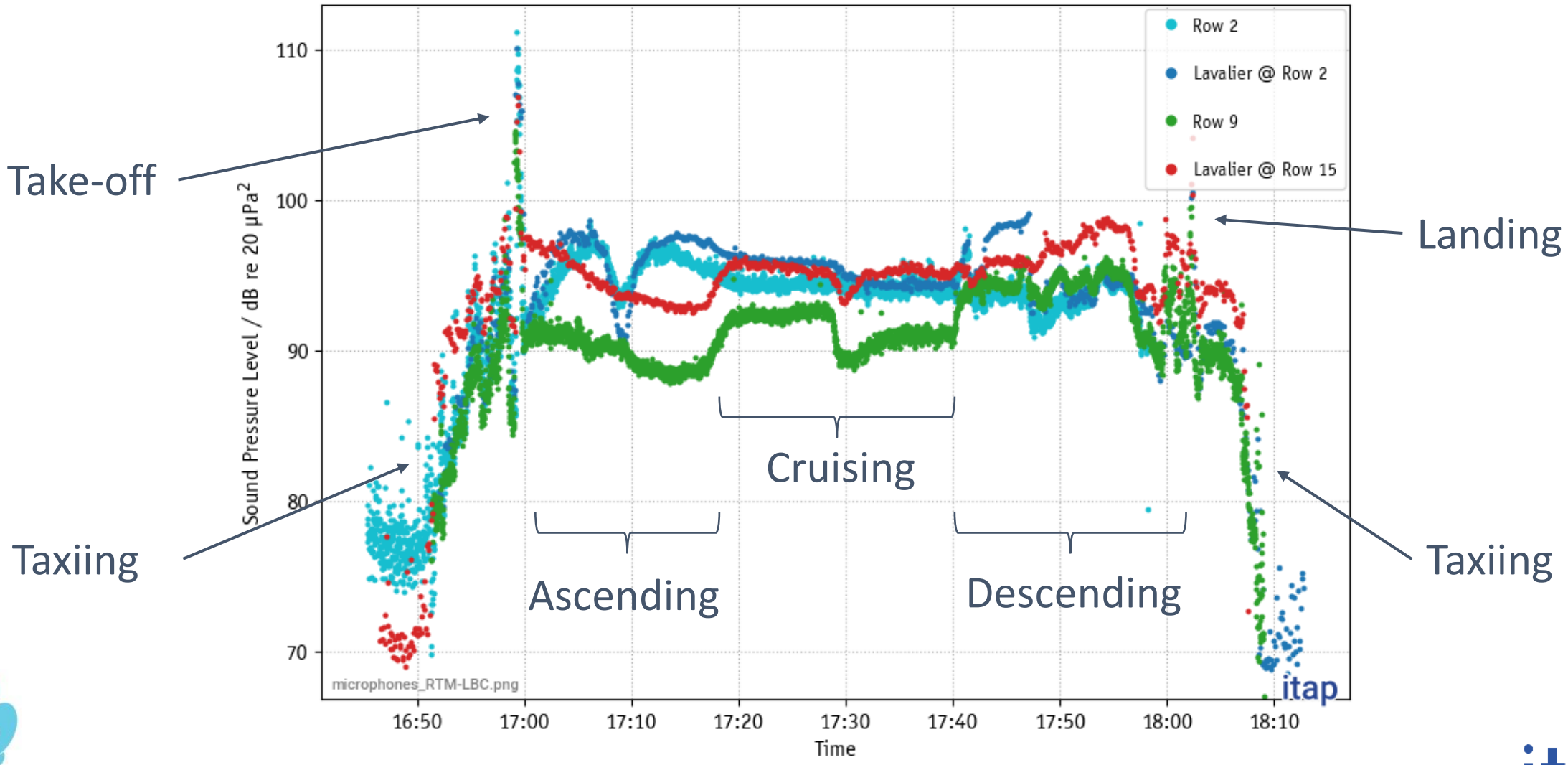
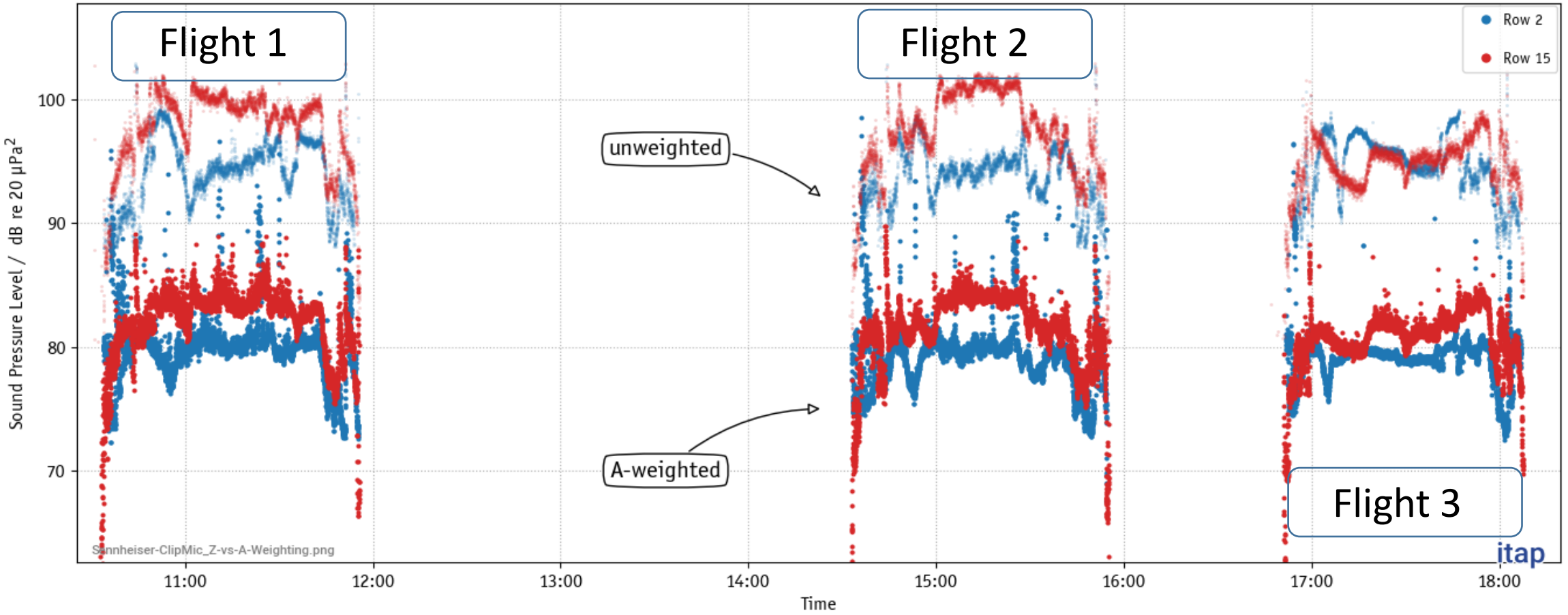
Measured Sound Pressure Level over time 3rd flight

no PAX



Measured Sound Pressure Level over Time

Comparison of flights



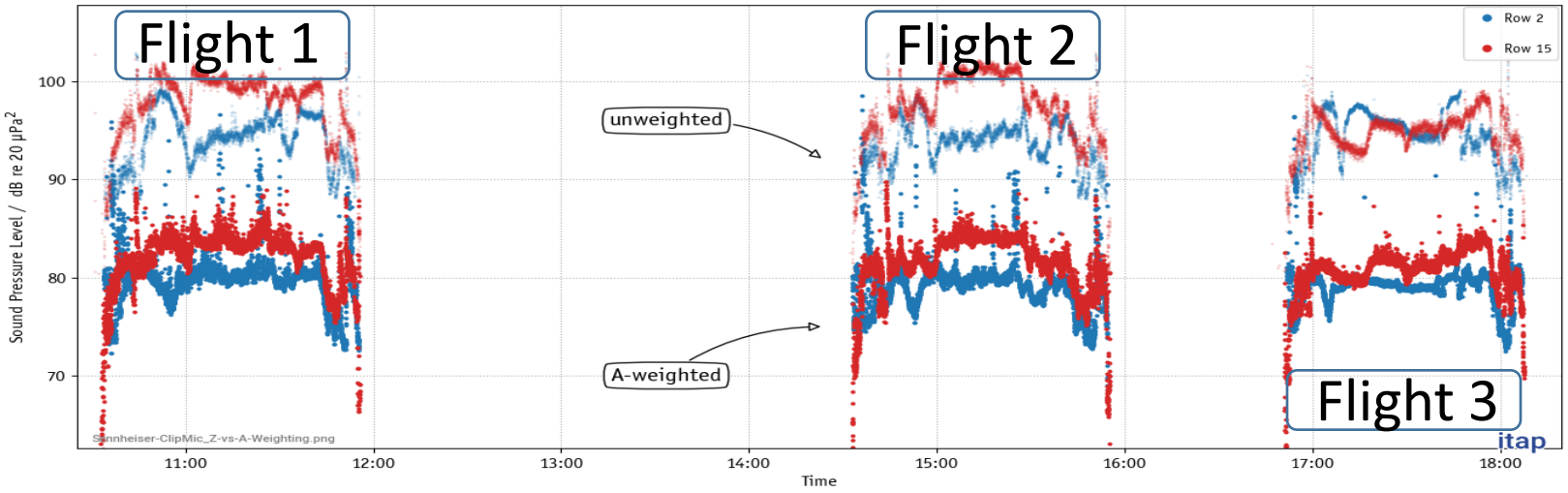
Measured Sound Pressure Level over Time

Unweighted SPL

- similar levels in both rows flight 1 and 2
  - both flights with PAX
- during cruising: higher levels @ row 15 of up to 10 dB compared to row 2
- flight 3: similar SPL @ row 2 and row 15

A-weighting SPL

- slightly reduced level-differences between row 2 and row 15 for all flights
- row 15 lower levels during flight 3
- Influencing factors: PAX, altitude, speed, other ?



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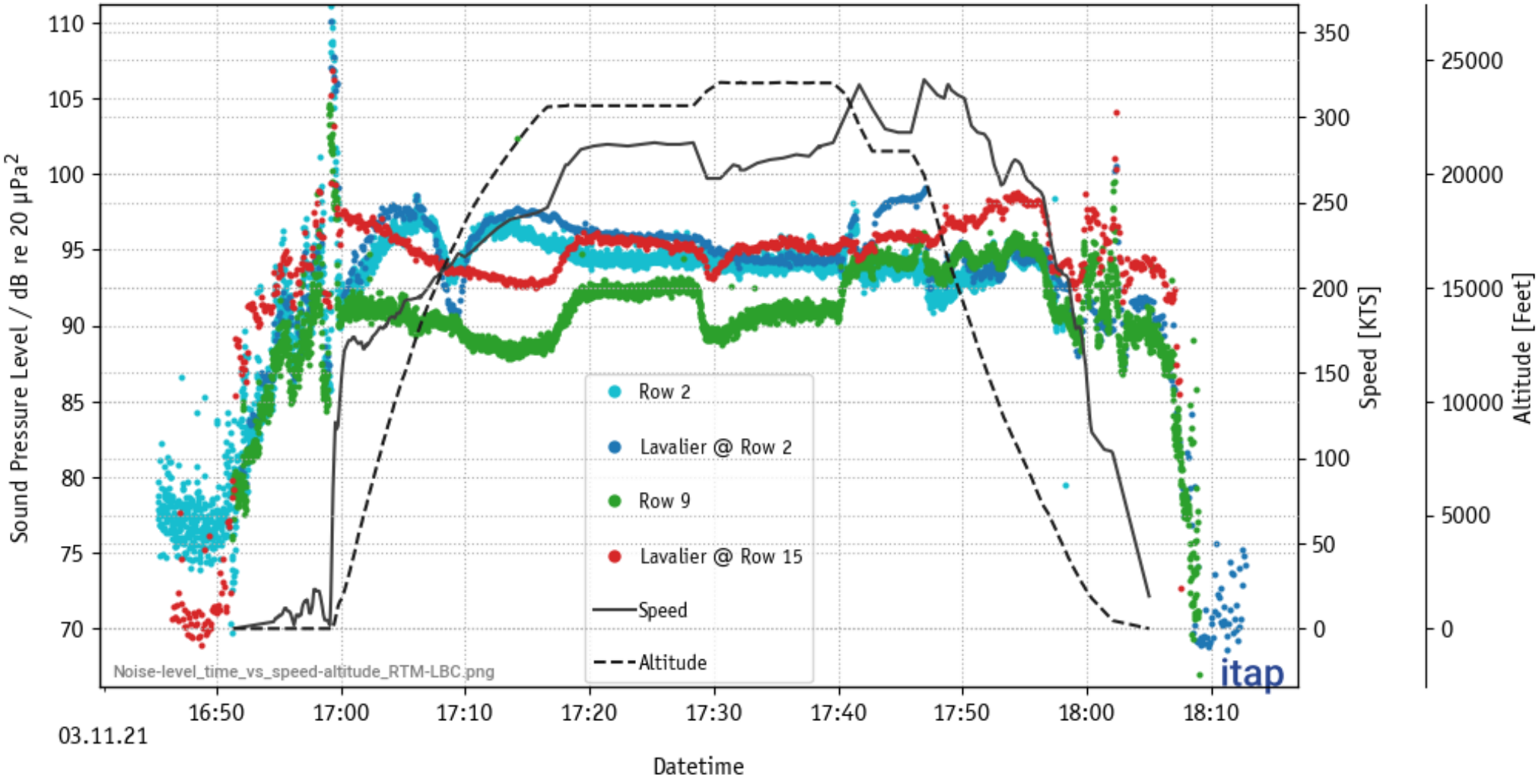
Influencing factors on measured SPL 3rd flight



- significant speed-dependency @ row 9 and row 15
- Take- off starting with high velocity and SPL

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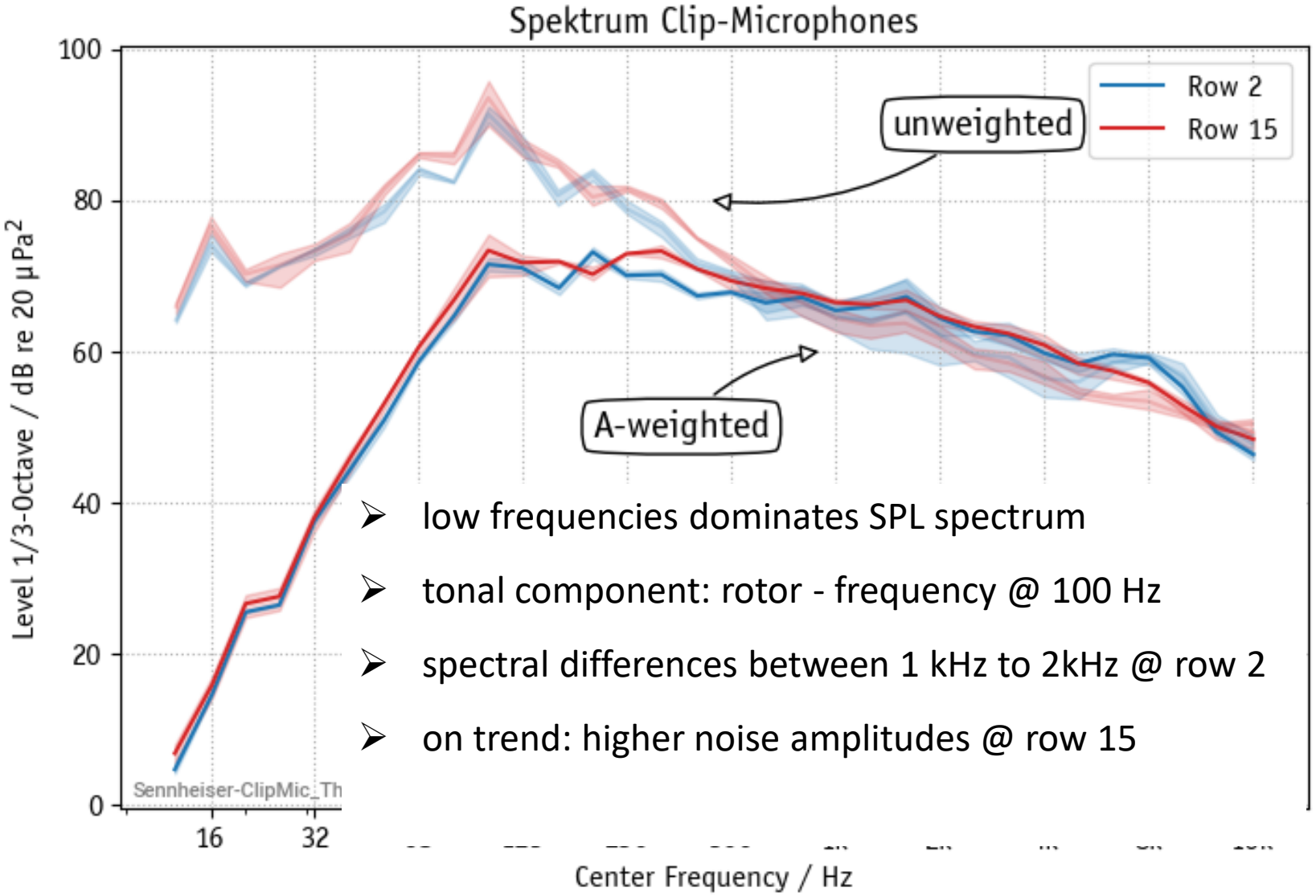
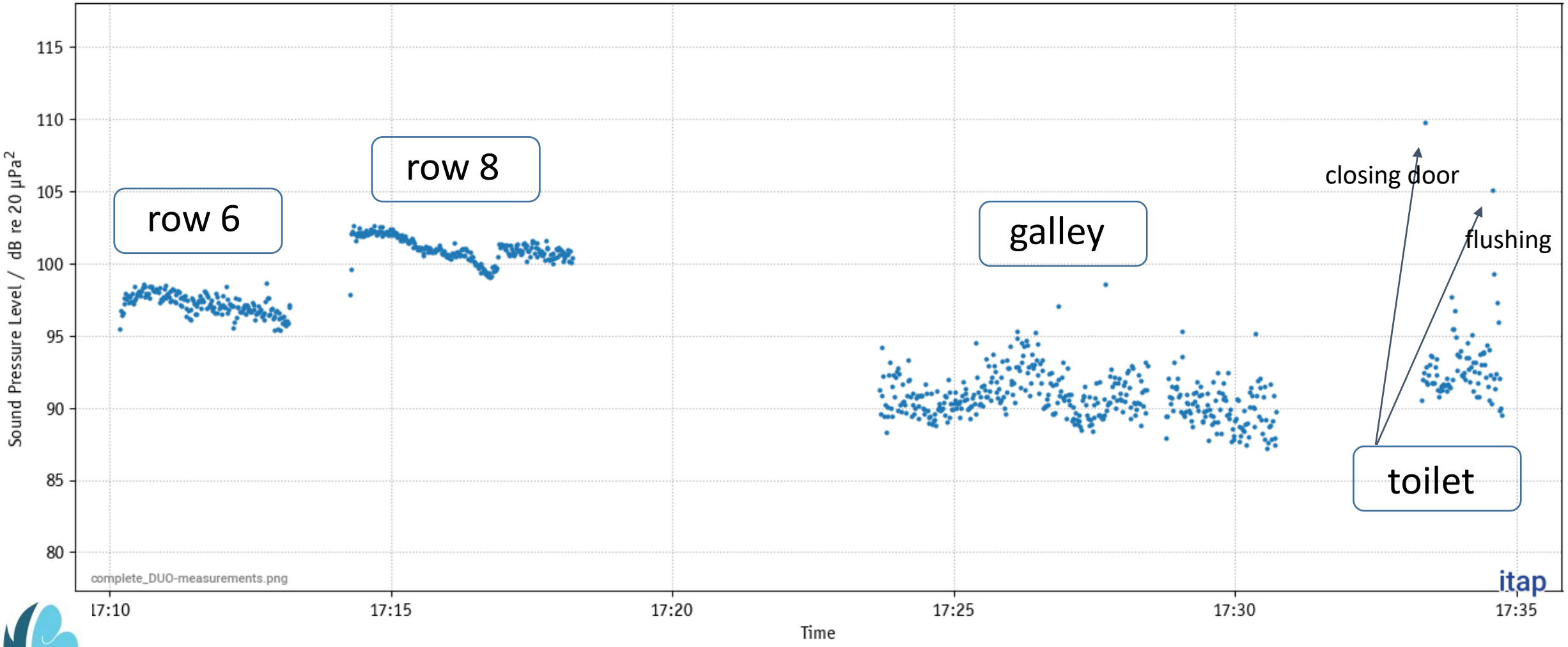
Noise spectra during cruising



- low frequencies dominates SPL spectrum
- tonal component: rotor - frequency @ 100 Hz
- spectral differences between 1 kHz to 2kHz @ row 2
- on trend: higher noise amplitudes @ row 15

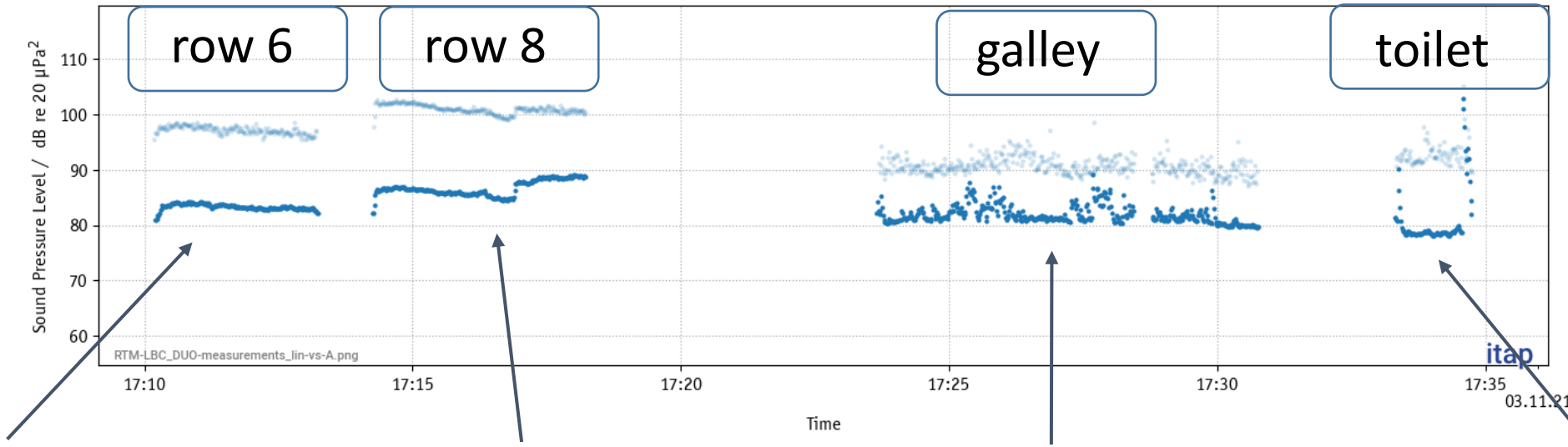
Measured Sound Pressure Level during cruising

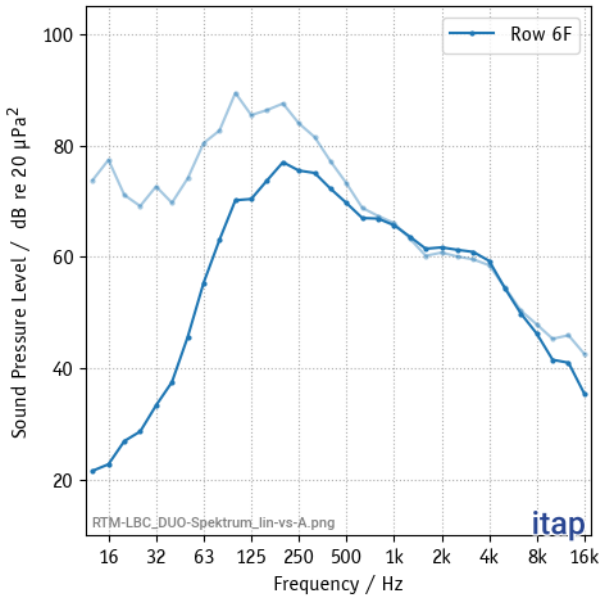
spot measurements as SPL vs time during 3rd flight

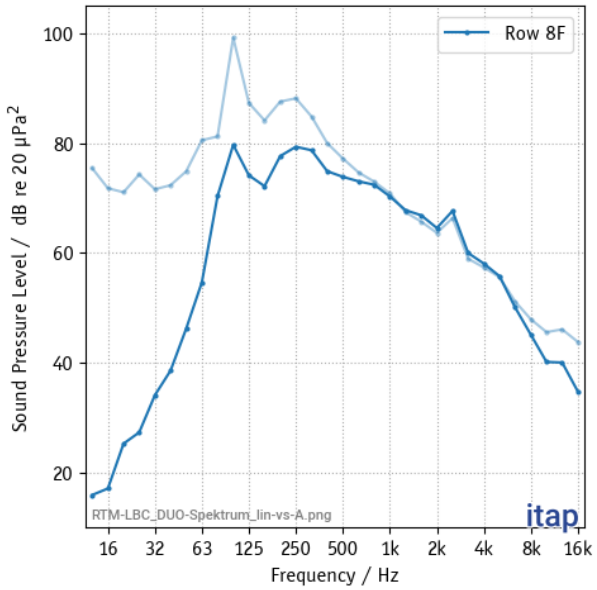


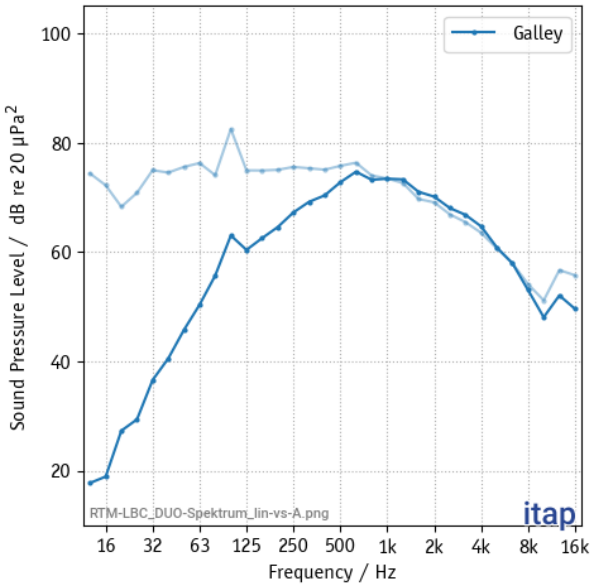
Measured Sound Pressure Level during cruising

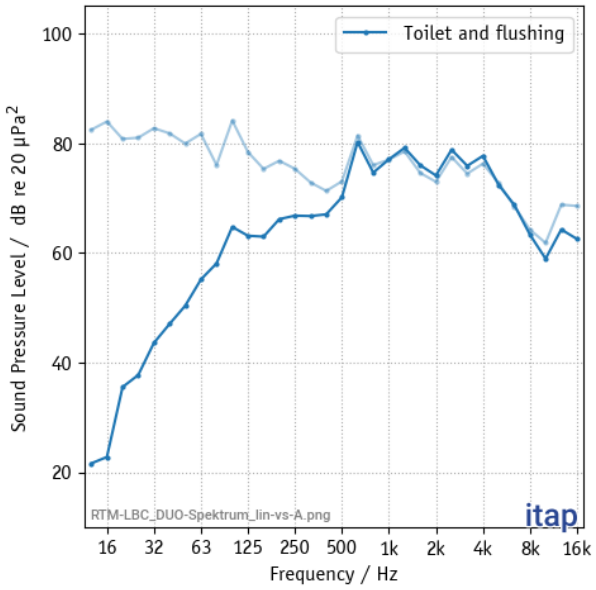
sprectra of spot measurements during 3rd flight



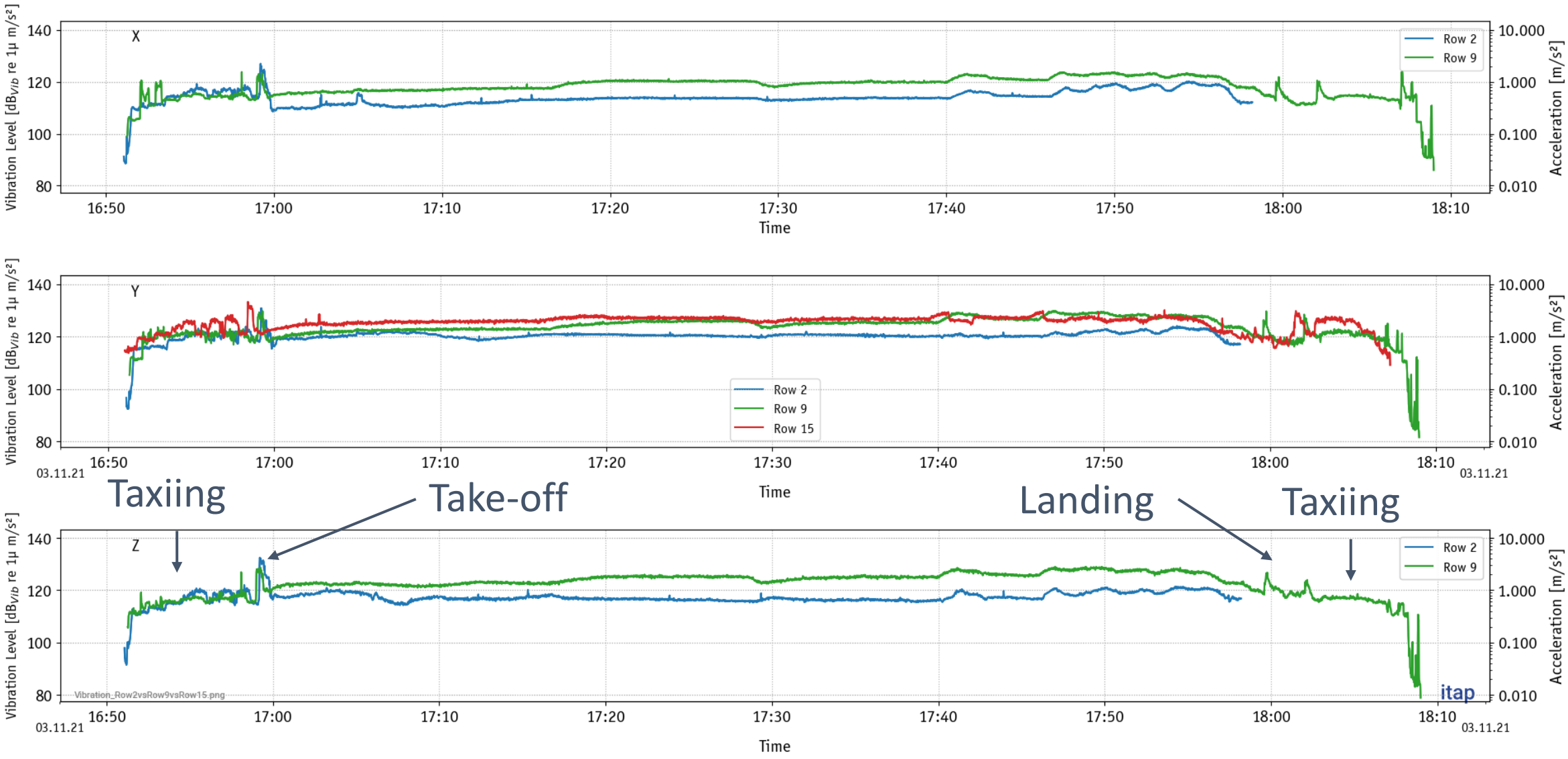








Measured Vibration level over Time 3rd flight
no PAX



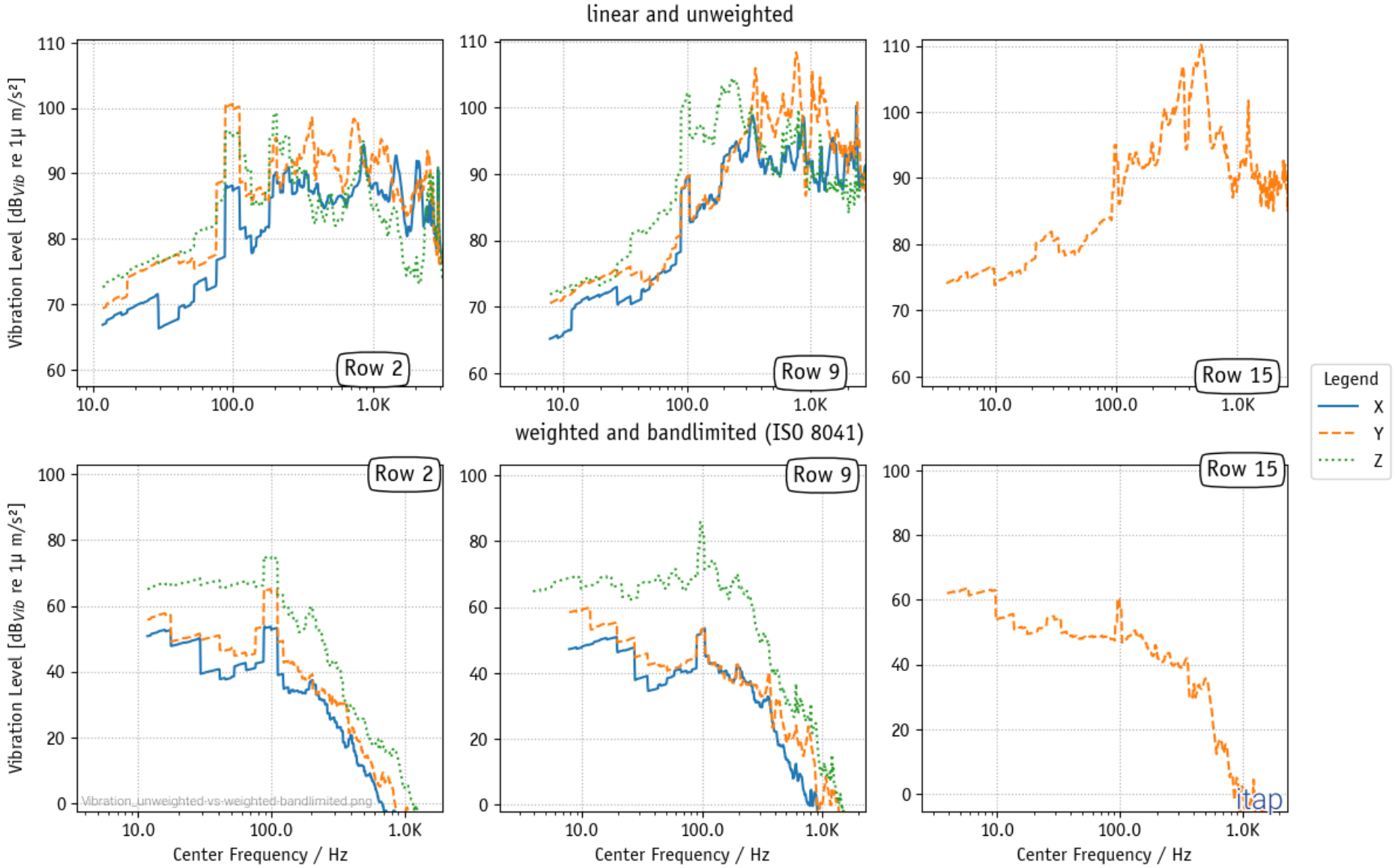
Take Home Message

- Continuous Noise & Vibration measurements during 3 fligths with/without PAX in an ATR72-500
- Noise and Vibration significantly depending on flight phase (taxiing, take-off etc.) in level and spectrum which is highly correlated with altitude & flight speed
- Noise and Vibration significantly depending on location within the cabin (during cruising)
- SPL is dominated by rotor frequency and by very low frequencies
  SPL(A) differ in 1 and 2 kHz frequency band
  → for objective description of perceived noise psycho-acoustic metries are required
- Noise (& Vibration) might also depending on amount of PAX

Outlook:

- Recordings can be used for cabin demonstrator tests
- Further (psycho-acoustic) analysis are ongoing

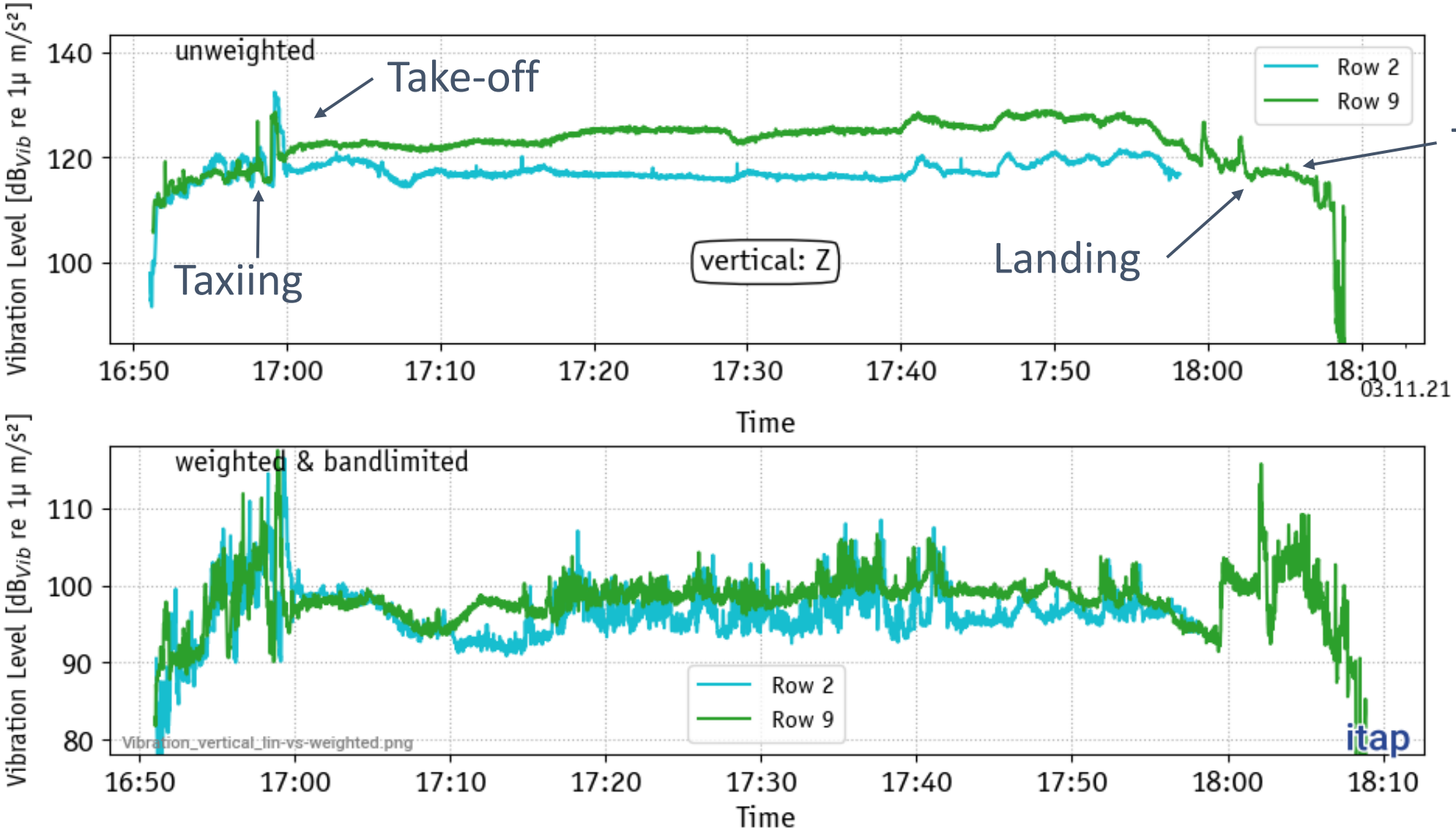
Measured Vibration level over Time 3rd flight - **cruising**



- blade frequency (~100 Hz) is dominating
- @ row 9 and 15 higher frequencies dominating at Y axis

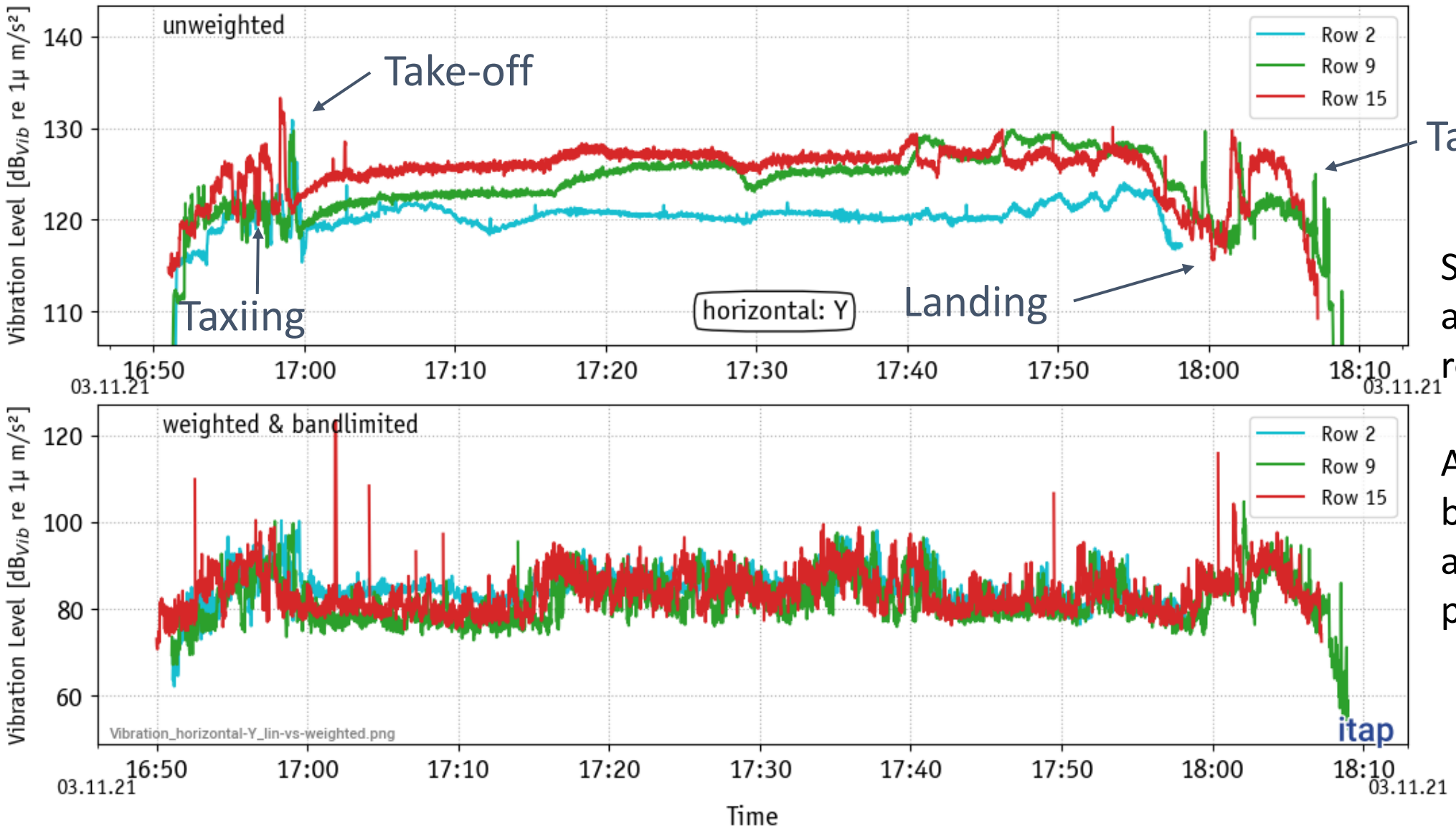
- ***only*** blade frequency (~100 Hz) is dominating
- assuming horizontal axes (X,Y) are not perceived

Measured Vibration level over Time 3rd flight



Similar course between row 2 and row 9.
Higher amplitudes at row 9, independent of weighting.

Measured Vibration level over Time 3rd flight



Similar course and amplitudes between row 9 and row 15.

After weighting and bandlimiting similar amplitudes at all positions.

Laboratory evaluation of human response to aircraft environments

Prof. Dr. Neil Mansfield, Nottingham Trent University
Dr. Geetika Aggarwal, Dr. Fred Vanheusden, Dr. Steve Faulkner

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Aim – to understand how passengers integrate comfort / discomfort factors

1. Voice of the customer survey
2. Dual-modality trials
3. Tri-modal trials

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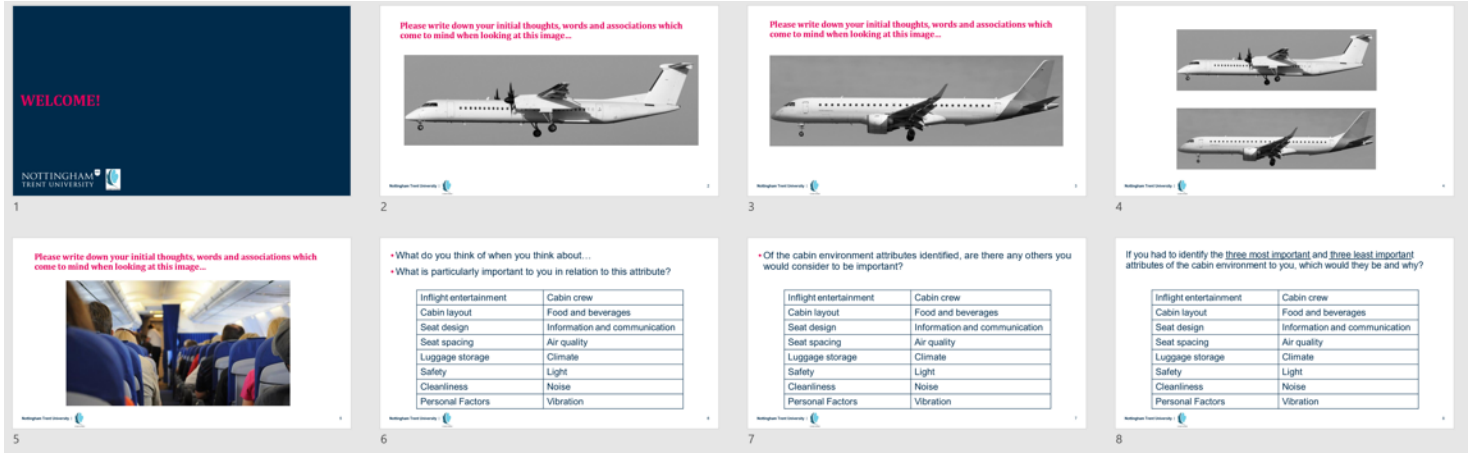
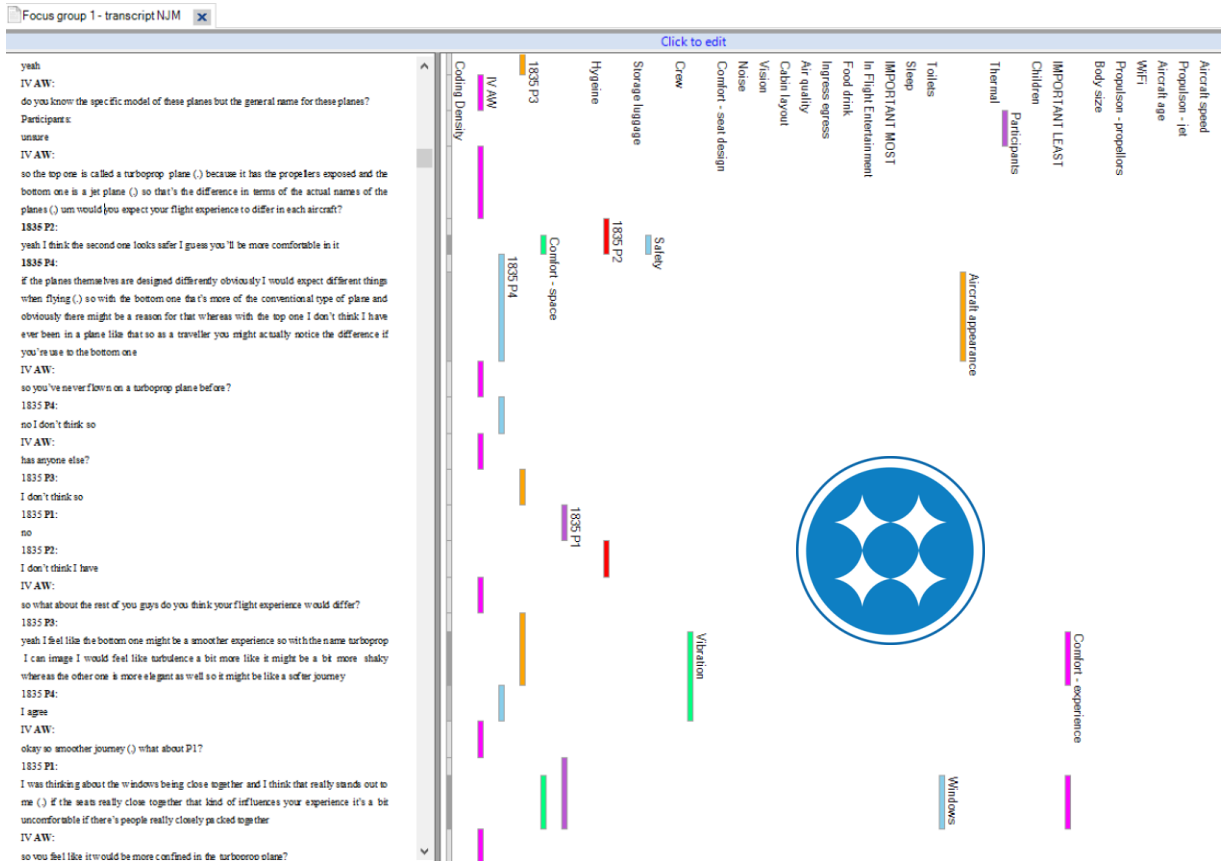
Voice of the customer study

Voice of the customer study

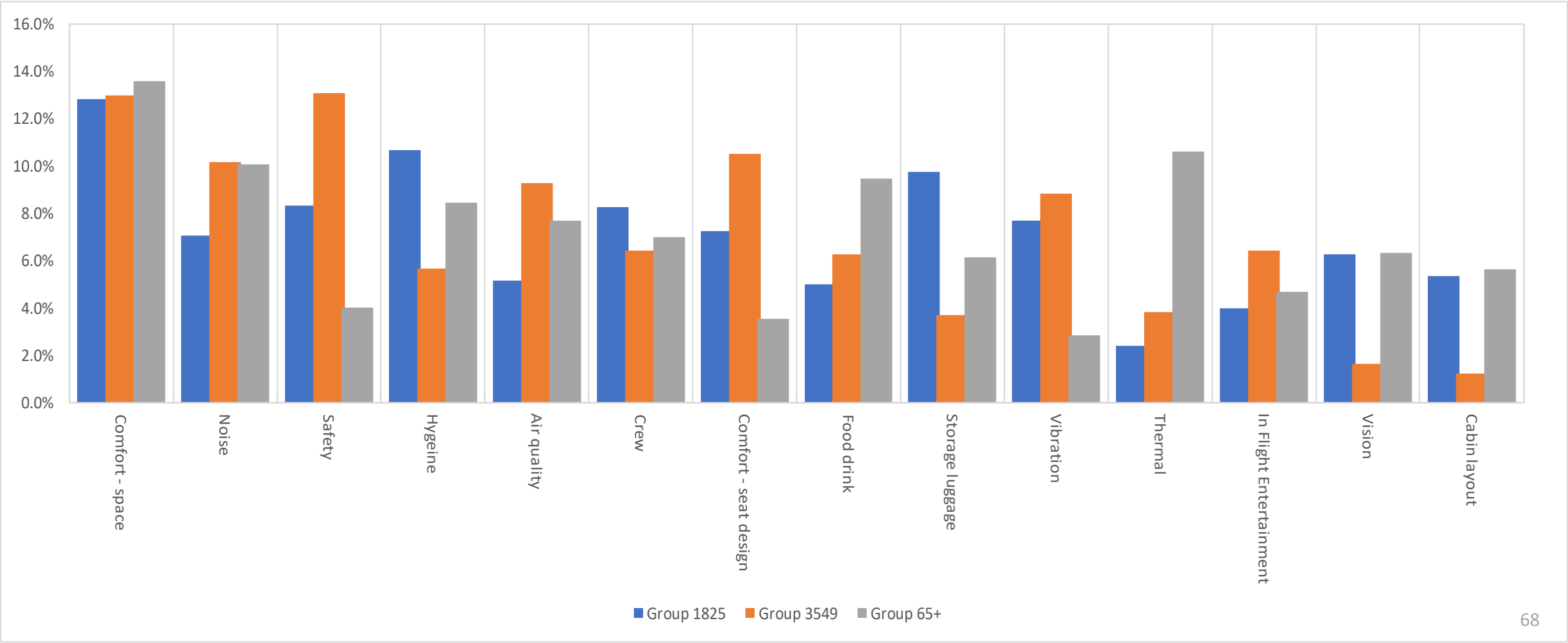
- Focus group study to elicit opinions on aircraft and flight experiences
- Three focus groups:
  - Group 1, 18-25, n=4
  - Group 2, 35-49, n=5
  - Group 3, 50-70, n=5
- Transcribed and analysed in nVivo



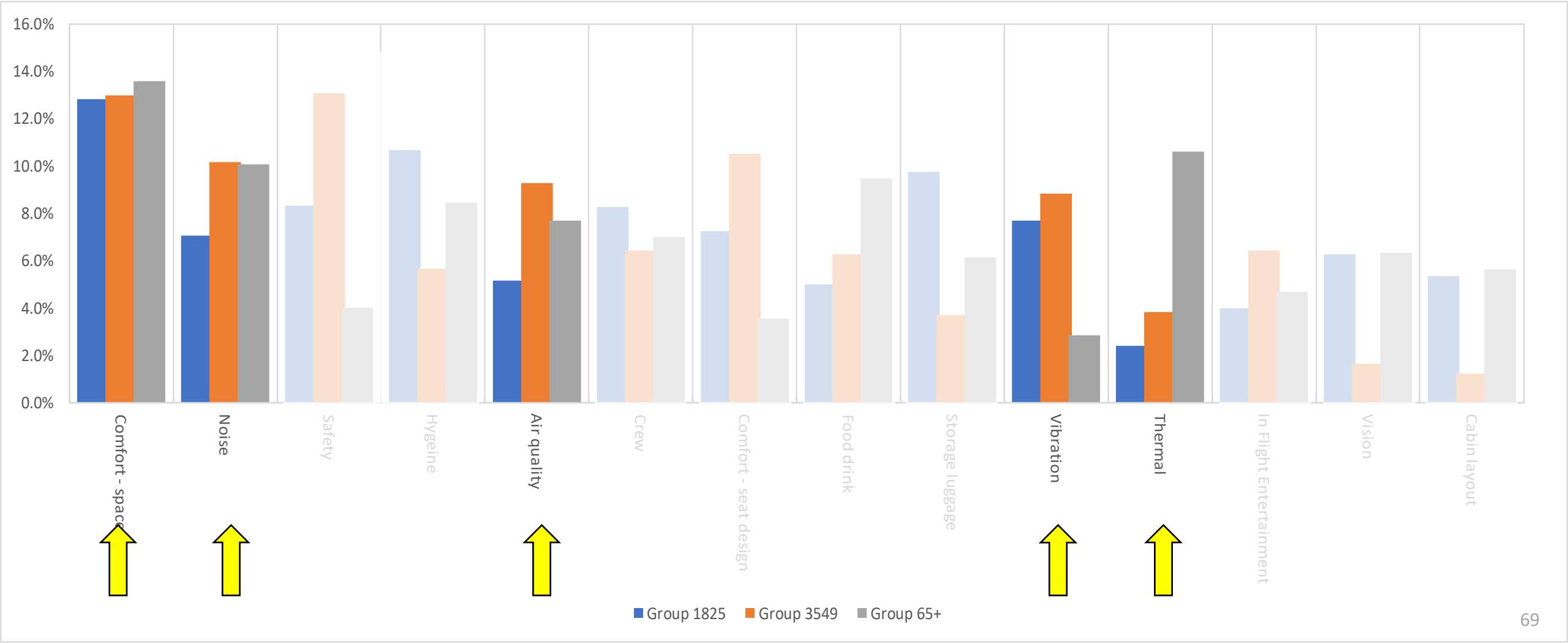


Ethical approval from NTU ethical advisory committee

Voice of the customer:
Normalised coding count (top 10 for each)



Voice of the customer:
Normalised coding count (top 10 for each)



Combined stressors

Additive:

Impact of ‘A’ and ‘B’ combined (%) = Impact of ‘A’ (%) + Impact of ‘B’ (%)

Synergistic (cross-modal):

Impact of ‘A’ and ‘B’ combined (%) > Impact of ‘A’ (%) + Impact of ‘B’ (%)

Antagonistic (masking):

Impact of ‘A’ and ‘B’ combined (%) < Impact of ‘A’ (%) + Impact of ‘B’ (%)

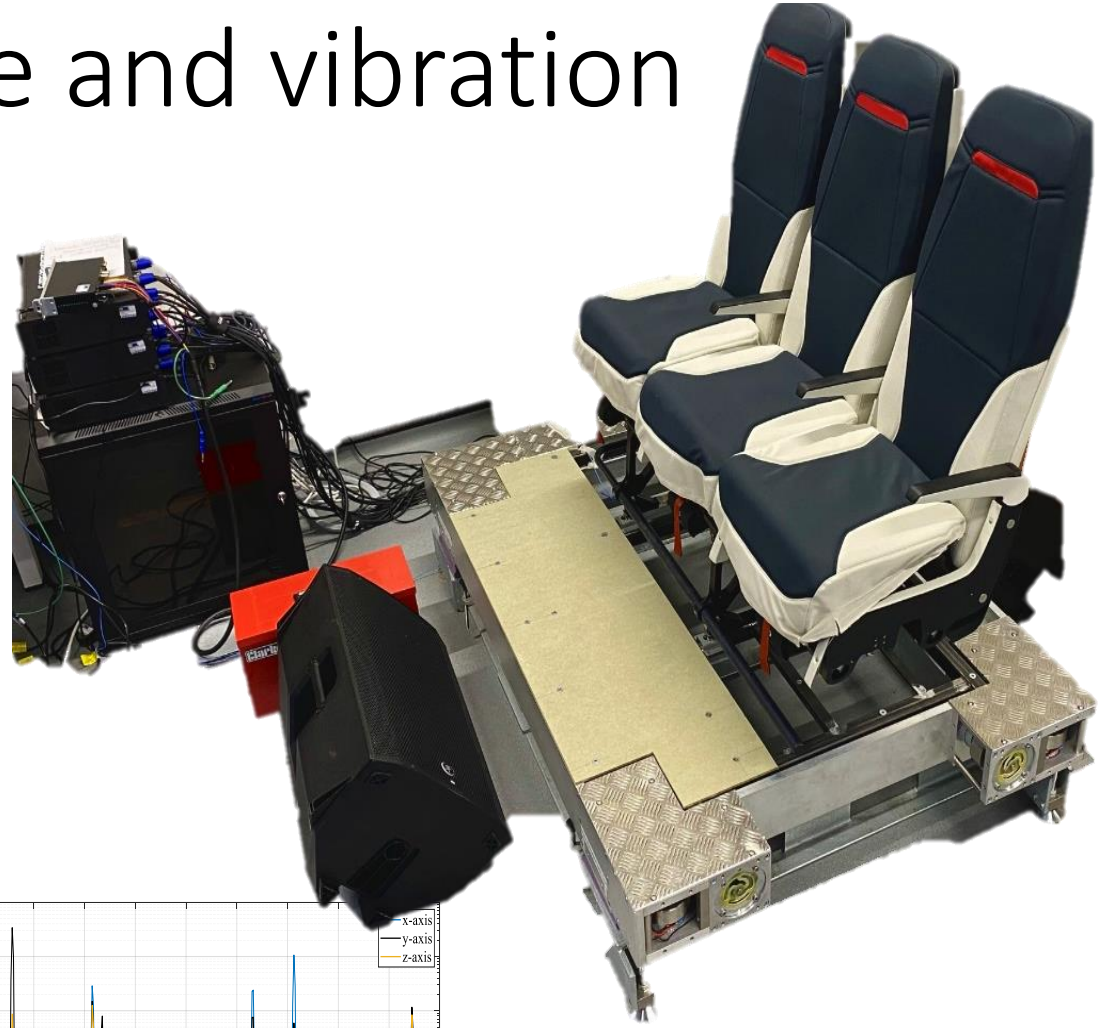
Dual modality trials

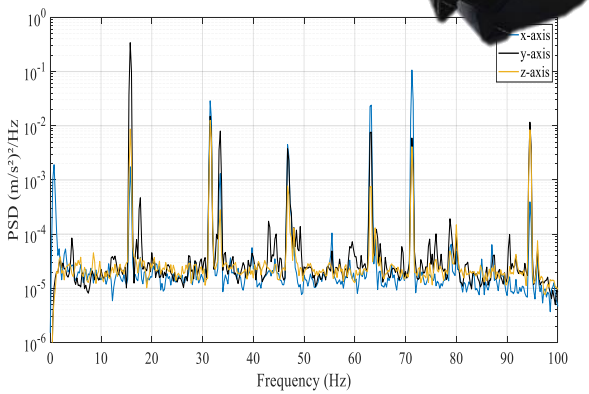
Dual modality trials – noise and vibration

- 18 volunteers, 1 person at a time
- 4 x turboprop vibration
- 4 x turboprop noise
- Each sample, 15 seconds

Turboprop cabin vibration (m/s² r.m.s.)	Turboprop cabin noise (dB(A))
0.50	72
0.67	78
0.83	84
1.00	90

Bandlimited, 0.8-100 Hz
unweighted





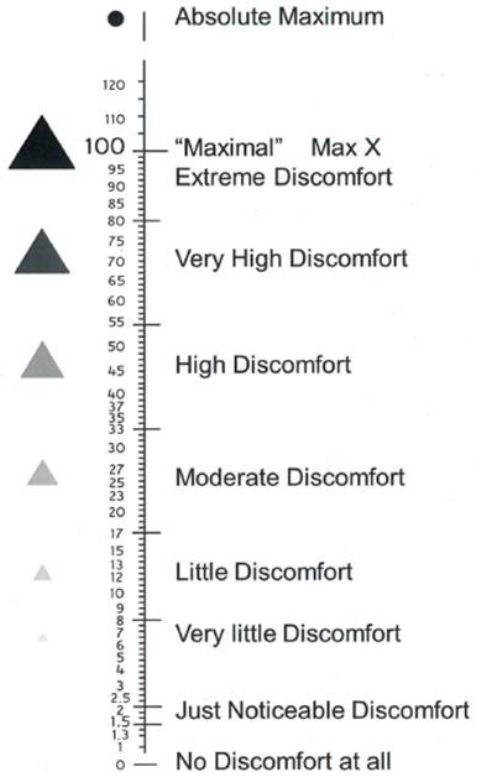
Subjective data collection – ISO2631-1 / CR100

2(a)

1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

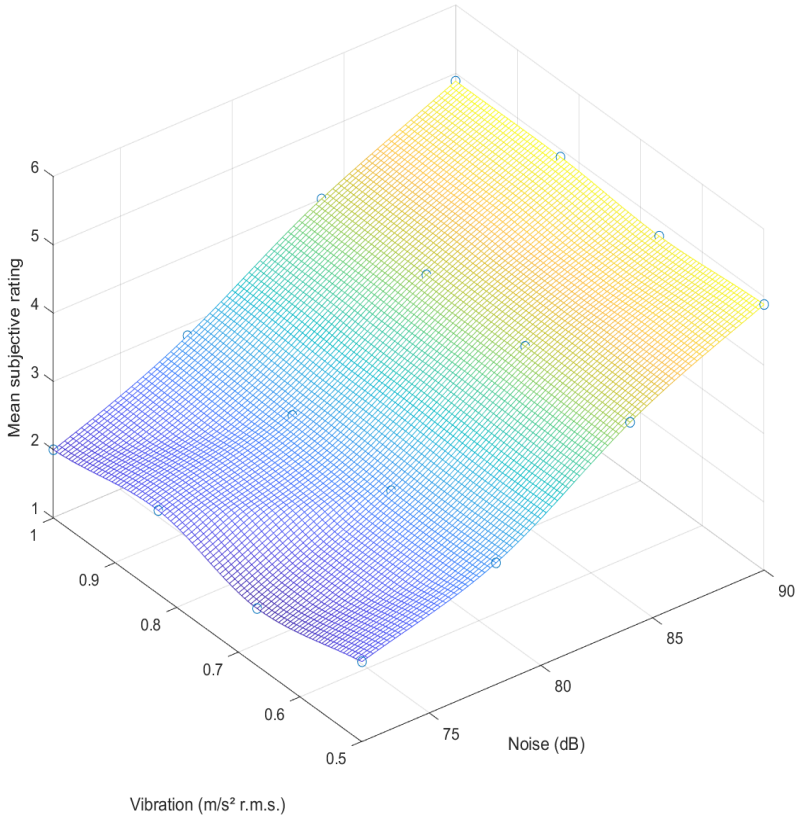
1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

2(b)



Subjective response scales. (a) Noise ratings and Vibration ratings based on scale from ISO 2631-1. (Sammonds et al., 2017 and Mansfield, N.J. 2004) (b) Borg CR100 scale for overall discomfort ratings. Adapted from (Borg. E, 2002).

Noise Discomfort



1	Not uncomfortable
2	A little uncomfortable
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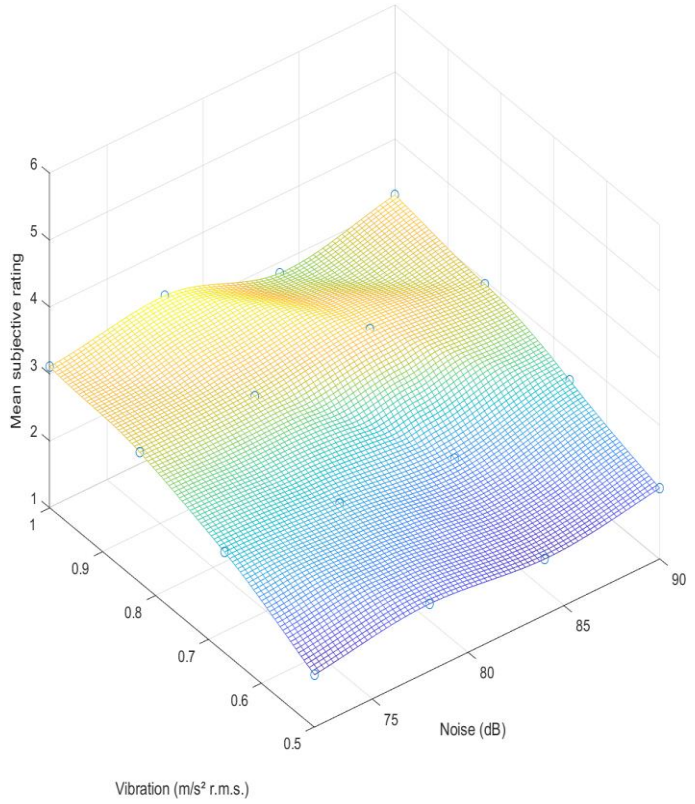
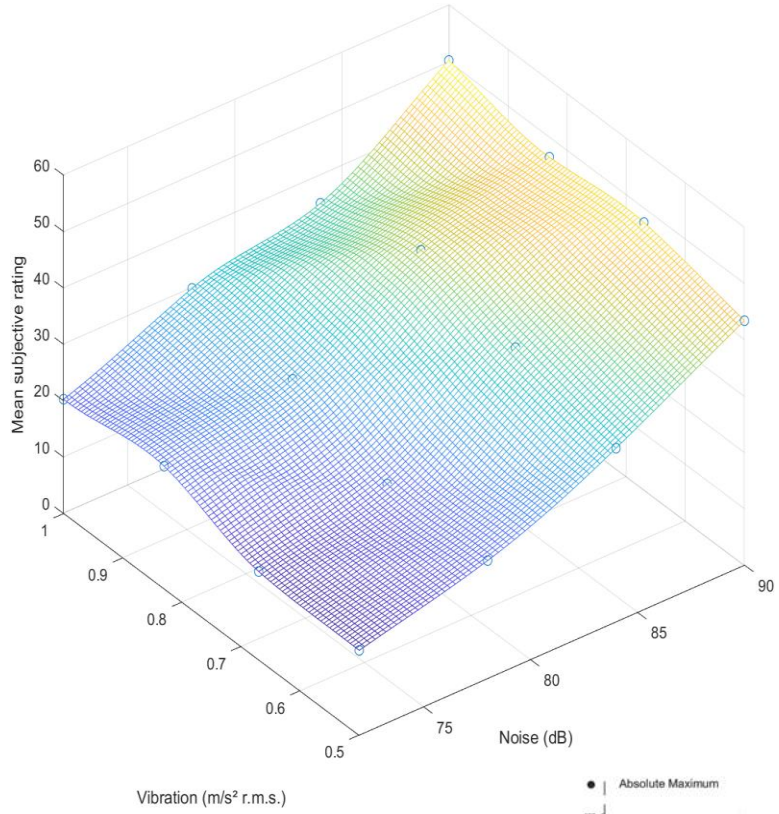
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

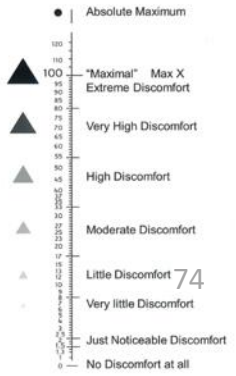
Vibration Discomfort



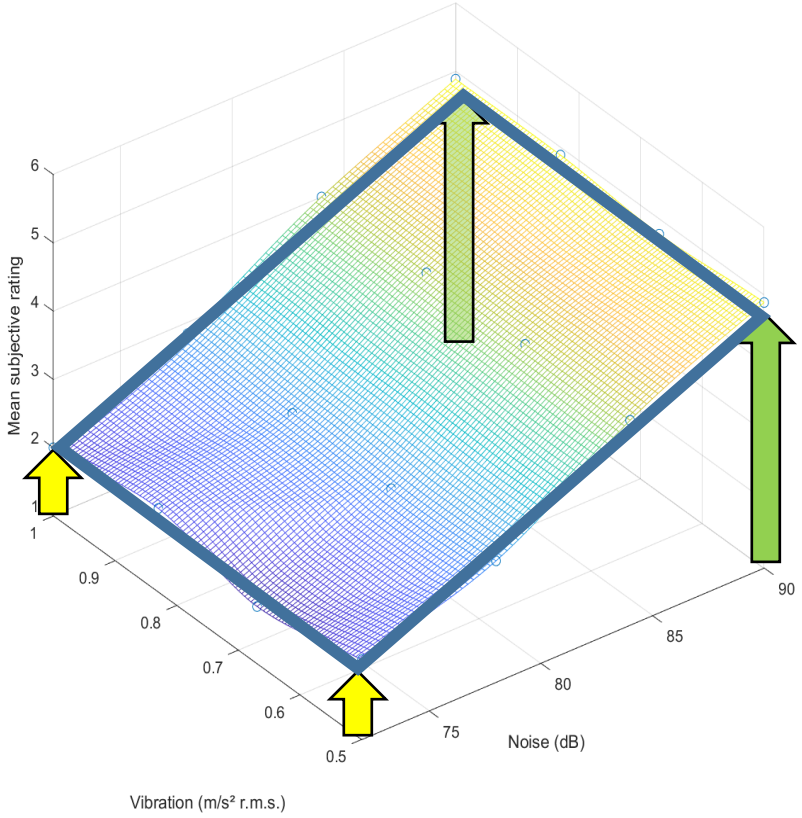
1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

Overall Discomfort



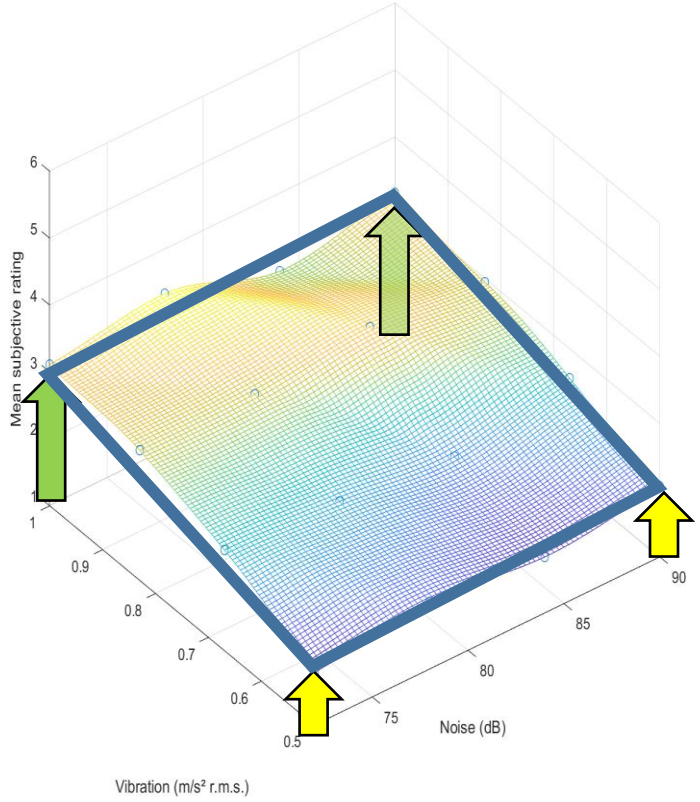


Noise Discomfort



1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

Vibration Discomfort



1	Not uncomfortable
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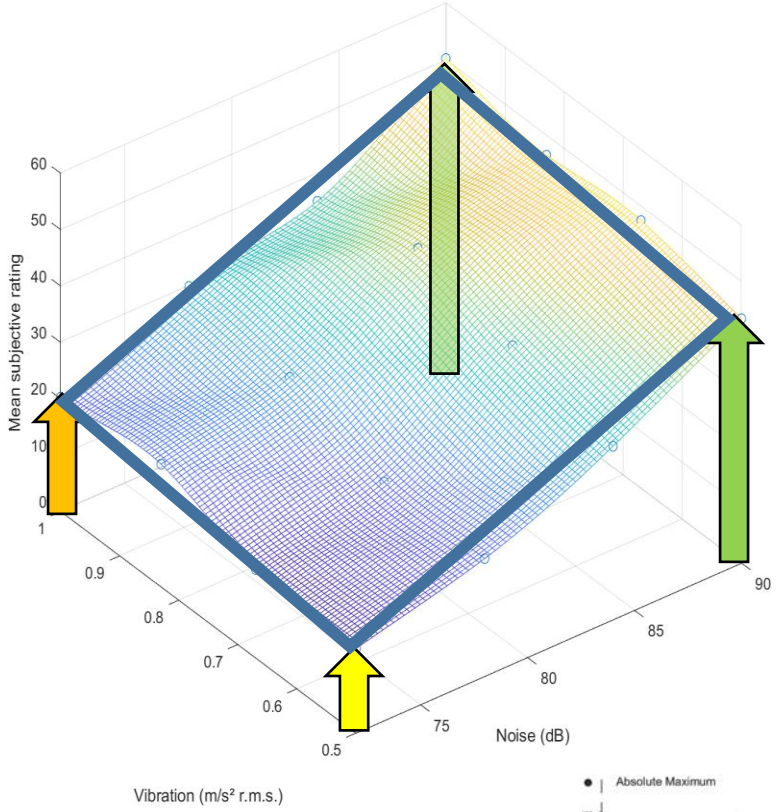
Overall Discomfort



Tri-modal trials

Tri-modal trials

- Environmental chamber
- Airline seat (BAe 146)
- 20 volunteers, 1 person at a time
- Vibration:
  - 0.75, 1.5, 2.25, 3.0 m/s² bandlimited
- Noise:
  - 78, 82, 86, 90 dB(A)
- Ramped temperature:
  - 20, 24, 28, 32 deg C

Tri-modal trials

(a) Please rate your discomfort from the NOISE:

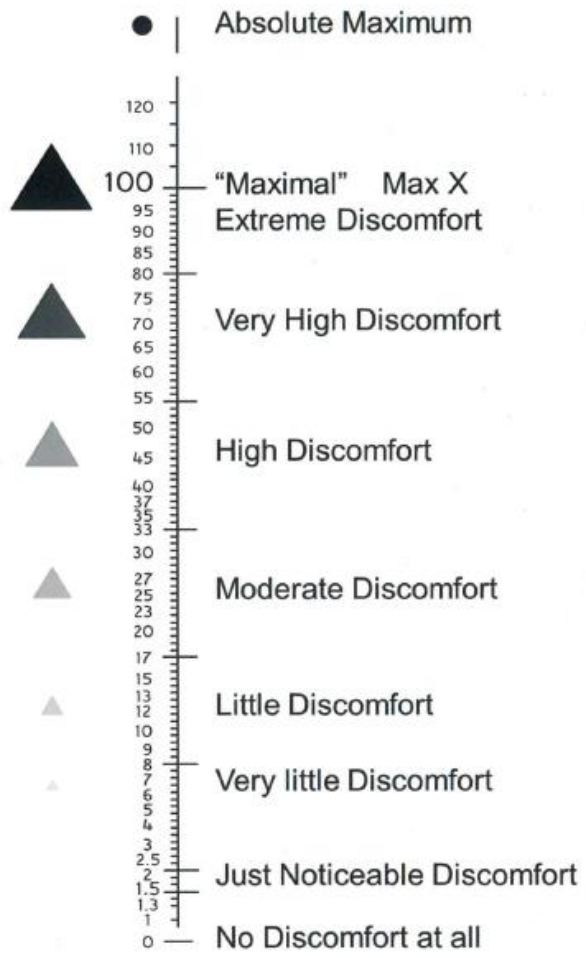
no discomfort										extreme discomfort
0	1	2	3	4	5	6	7	8	9	10

(b) Please rate your discomfort from the VIBRATION:

no discomfort										extreme discomfort
0	1	2	3	4	5	6	7	8	9	10

(c) Using the following scale please rate how you feel now:

Hot	3
Warm	2
Slightly Warm	1
Neutral	0
Slightly Cool	-1
Cool	-2
Cold	-3



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“In order to improve your comfort would you prefer to reduce the noise, vibration, increase temperature or decrease temperature?”

Forced choice question

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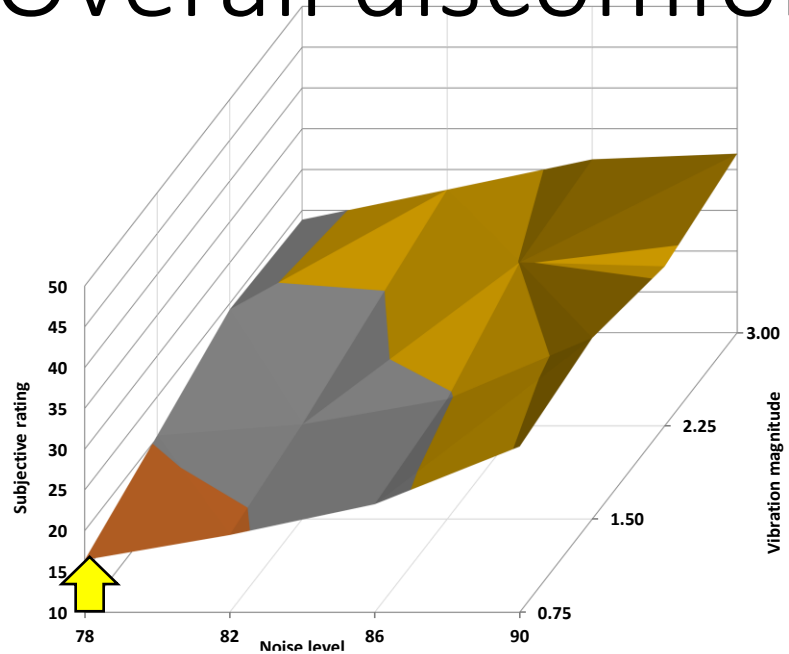
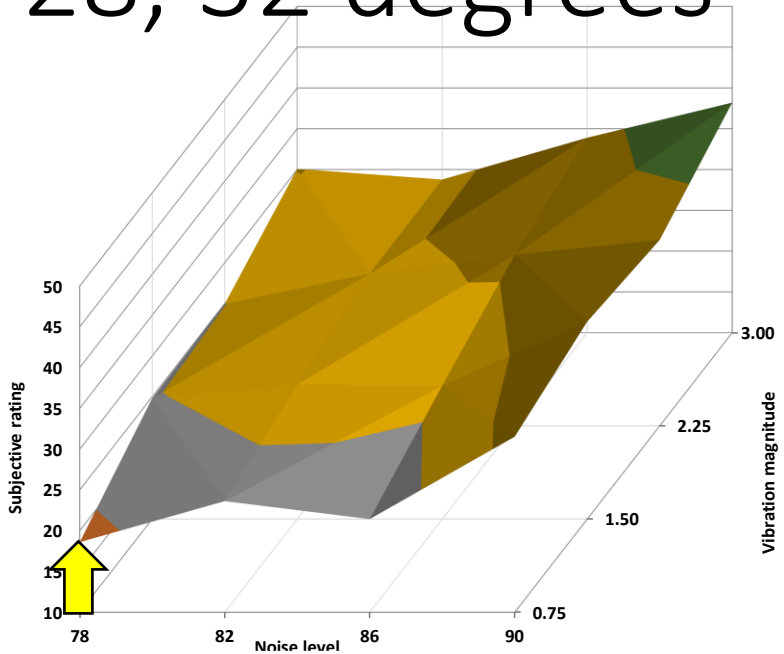
Overall discomfort – 20, 24, 28, 32 degrees

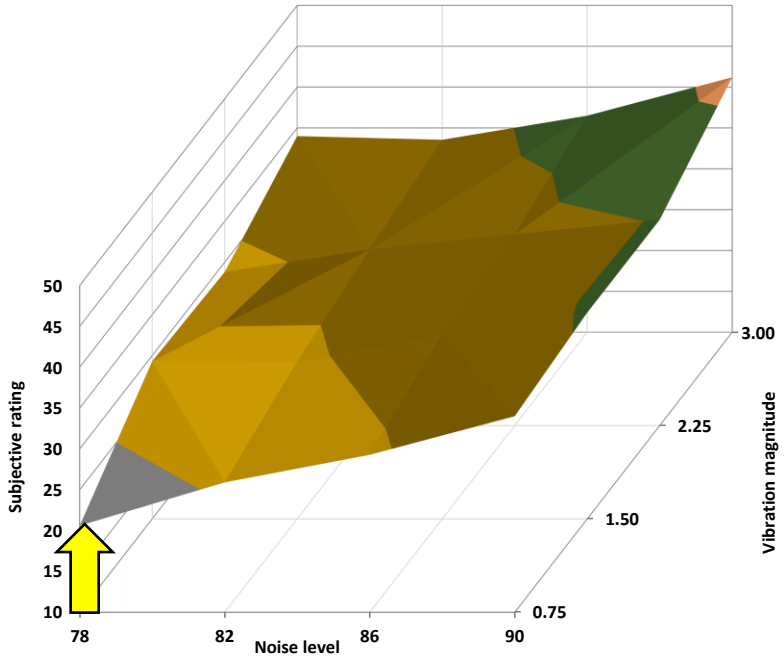
20°



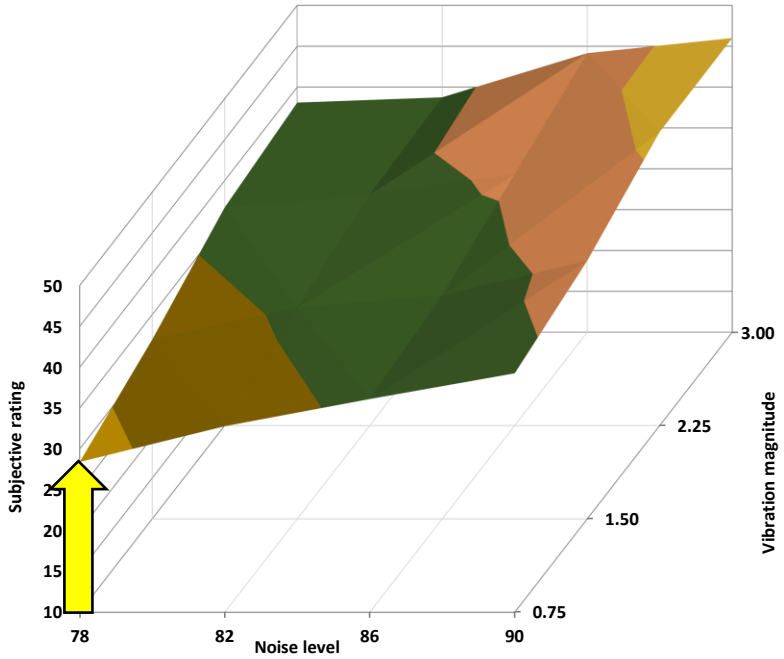
24°



28°

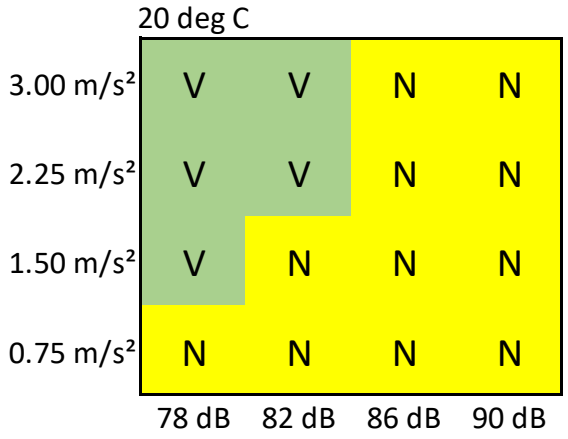


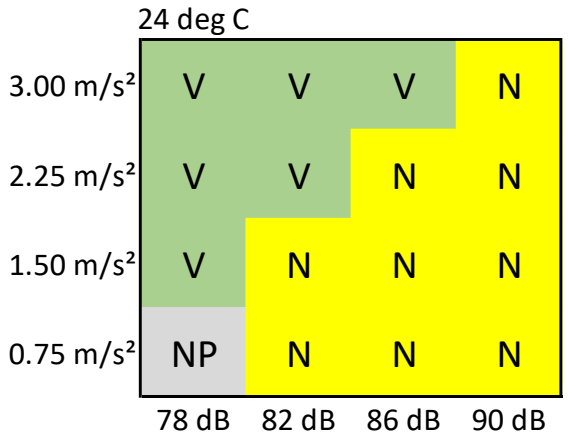
32°

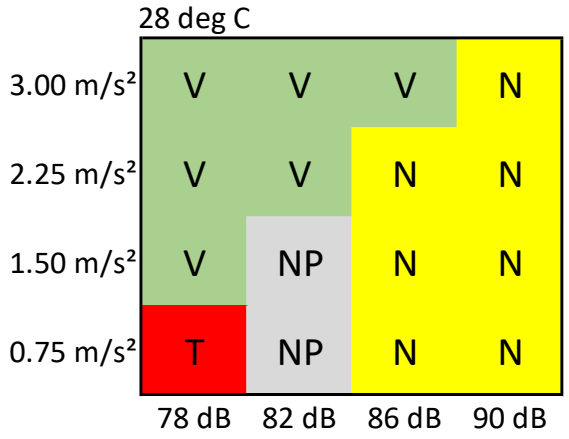


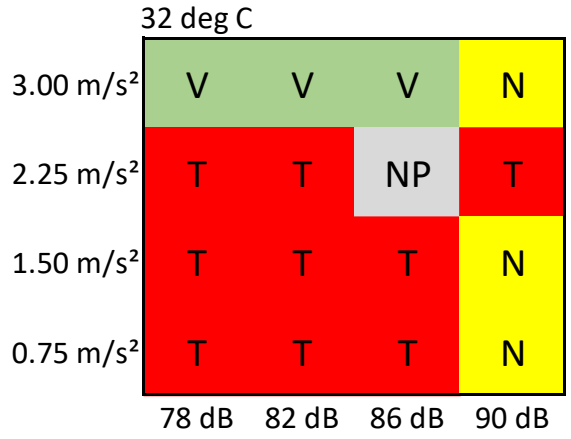
Preference

V	> 50% prefer to reduce vibration
N	> 50% prefer to reduce noise
T	> 50% prefer to reduce temperature
NP	no preference > 50%









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Conclusion/Key Takeaways

- This research study investigated the relative contribution of noise, vibration and thermal/temperature stimuli to human discomfort in an aircraft cabin.
- The vibration discomfort ratings of the participants increased with increase in vibration magnitudes, but not with noise or temperature.
- The noise discomfort ratings of the participants increased with increase in noise, but not with vibration or temperature.
- The overall discomfort score of the participants increased with increase in noise levels, vibration magnitudes and temperature.
- Preference for modality to improve environment varies with noise, vibration and temperature.

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Impact of noise cancelling headphones on passenger comfort in Turboprop airplanes

Gerbera Vledder, TU Delft

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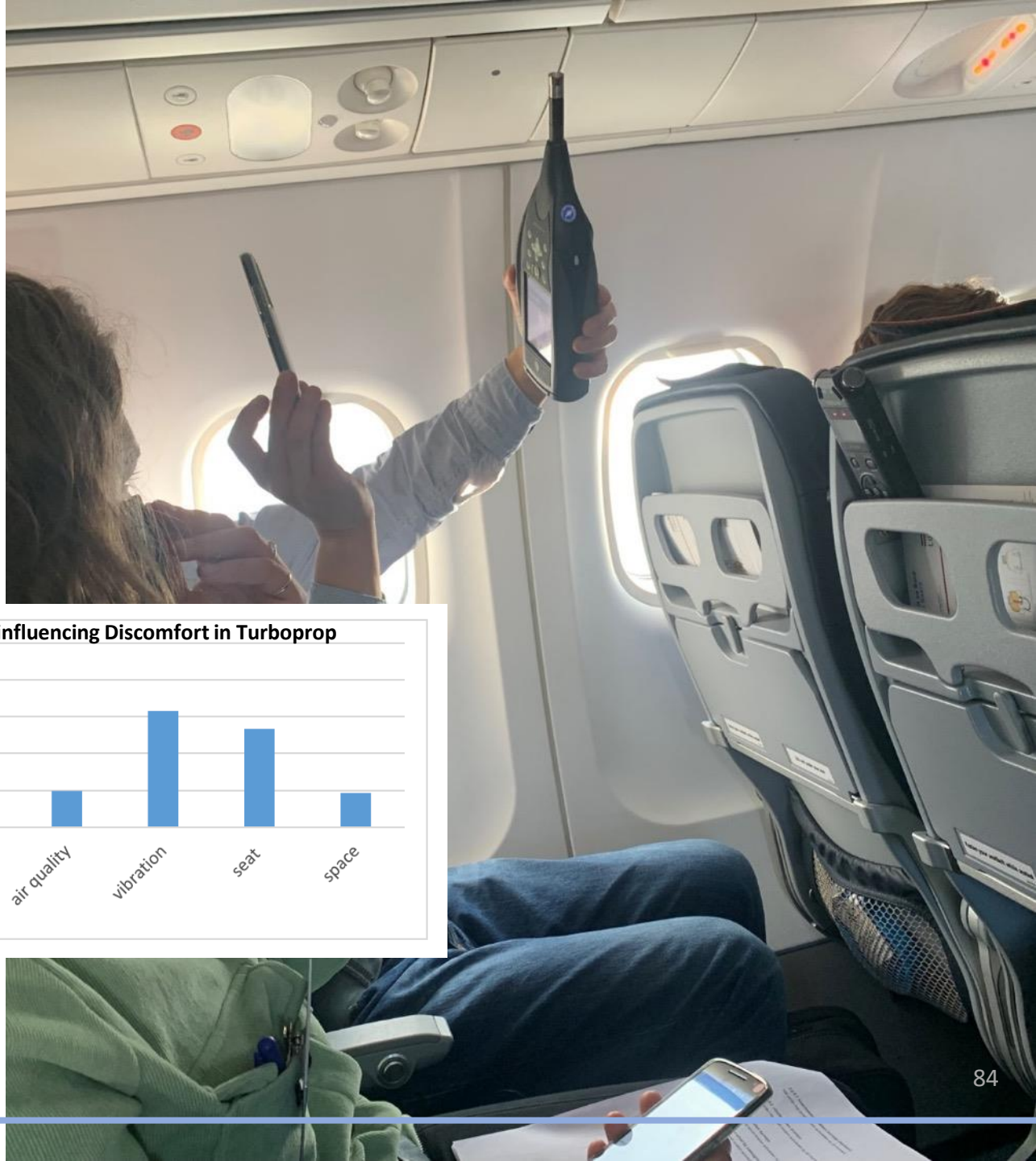
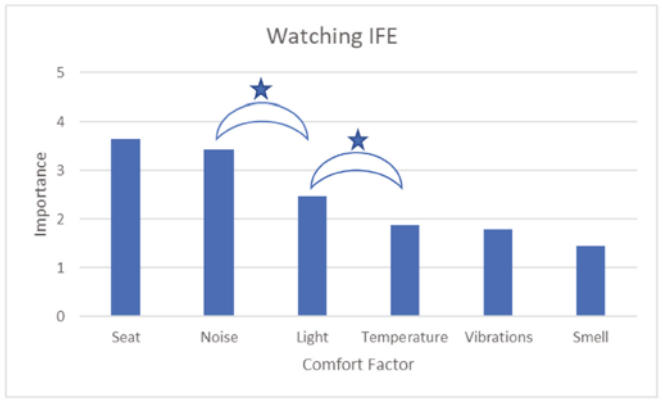
TU Delft

Background

- In turboprop aircraft the sound volume is much louder compared to a jet.
- Influence of noise on passenger comfort and discomfort (Bouwens, 2018)(Vink et al., 2022)
- Being in control of noise levels improves the aircraft seat comfort (Bouwens et al., 2021).





**Bouwens, 2018*

**Vink et al., 2022*

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Research objectives

- Influence of active noise cancelling headphones (ANC) on comfort of passengers in turboprop airplanes during in flight entertainment.
- Comparison of ANC headphones with earplugs.
- Comfort difference between turboprop airplane and jet engine airplane sound.

Vs.

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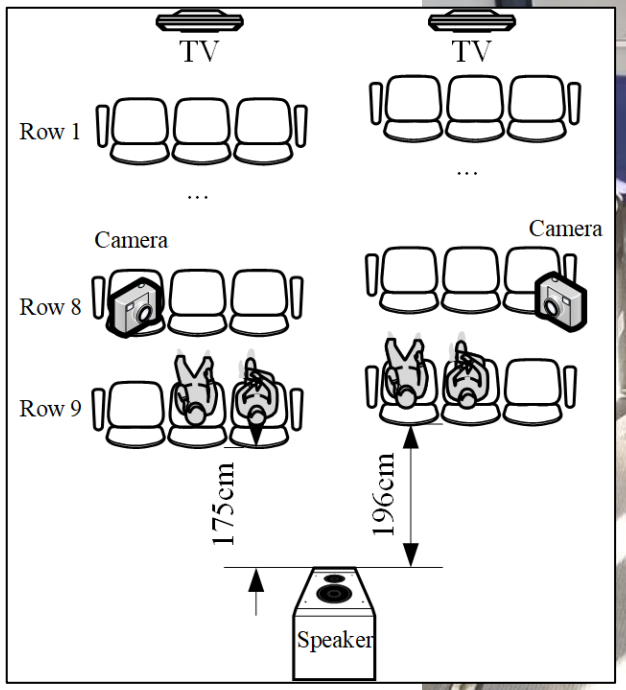
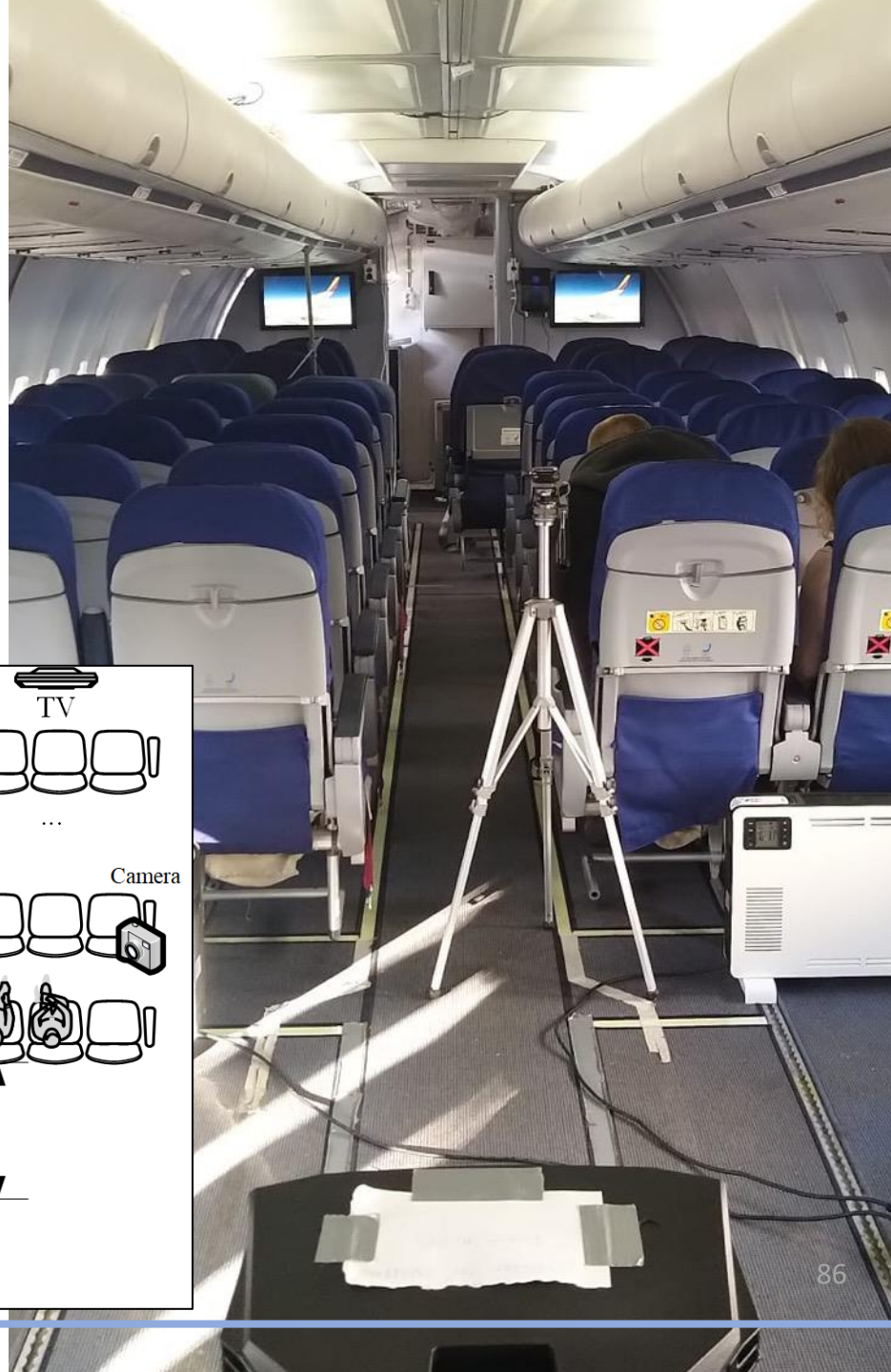
Research setup

- 24 participants (age 18-39)(50/50% Male/Female)
- Passenger activity: Smartphone, book or e-reader device (without sound)
- 4 conditions x 45 min.
    1. Jet engine sound
    2. Turboprop sound
    3. Turboprop sound + ANC headphones
    4. Turboprop sound + earplugs

** The recorded sound and volume of Comfdemo is used as basis for this test.*





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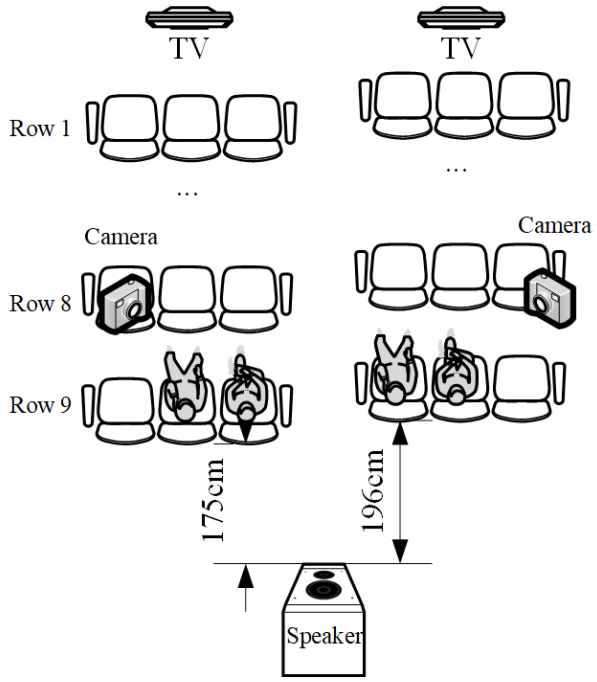
Noise distribution in the simulation setup

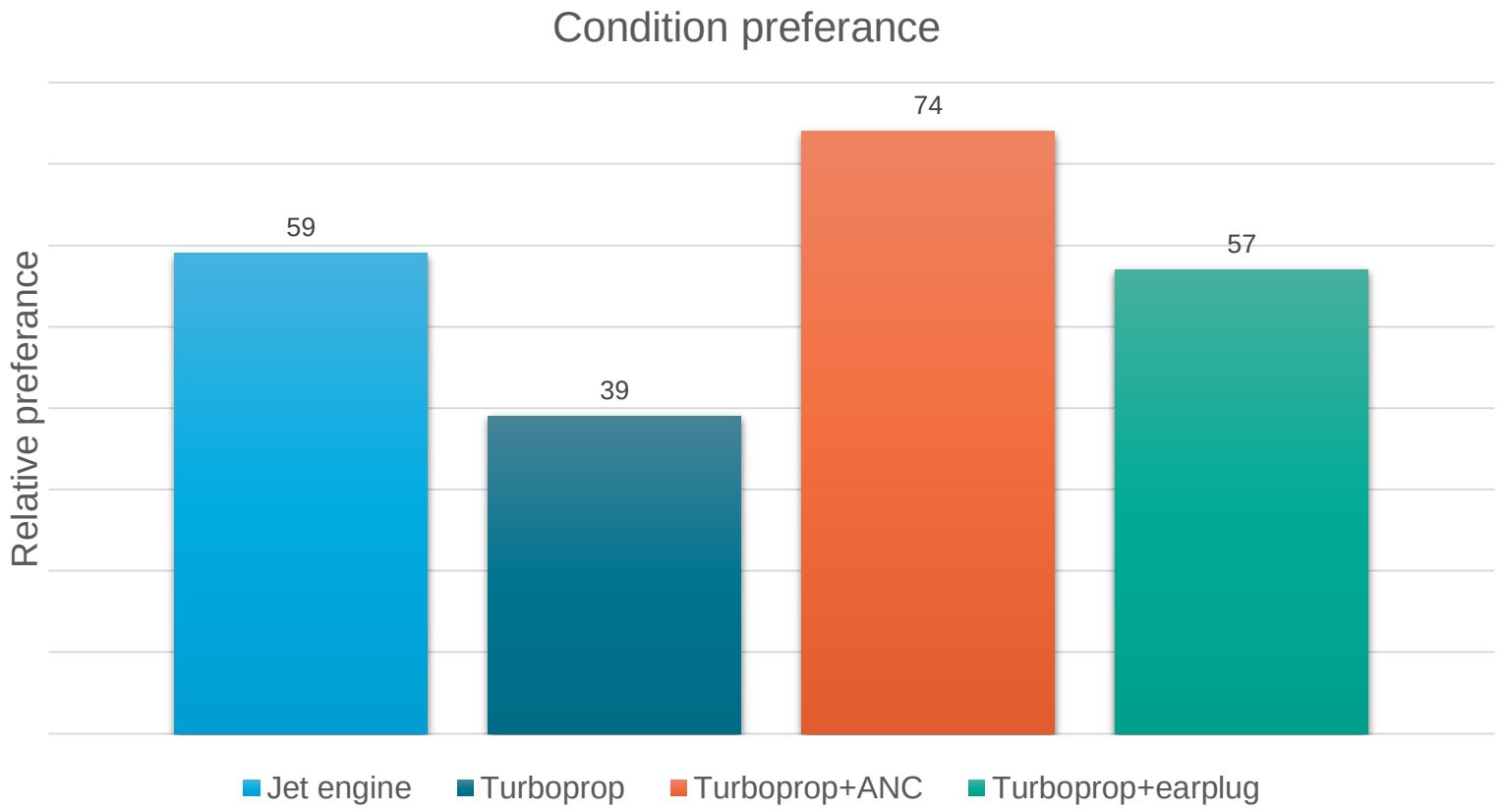
dB distribution across seats (average)

	9B	9C	9D	9E
B737	84,6	86,1	86,0	84,2
ATR	86,3	84,9	84,8	86,3

- Jet sound vs. Turboprop sound: difference in sound reflection in the interior.



Overall preference



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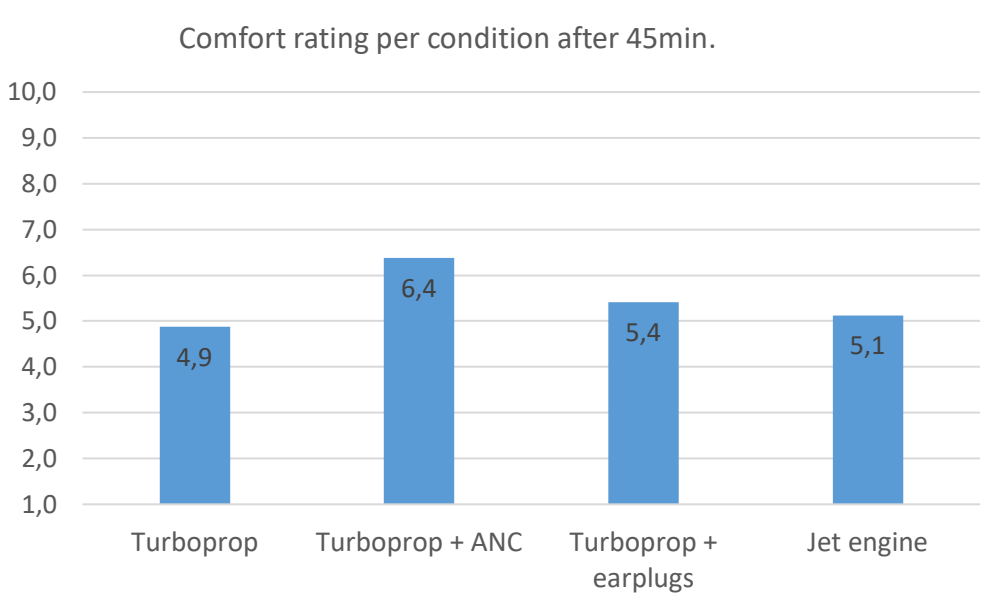
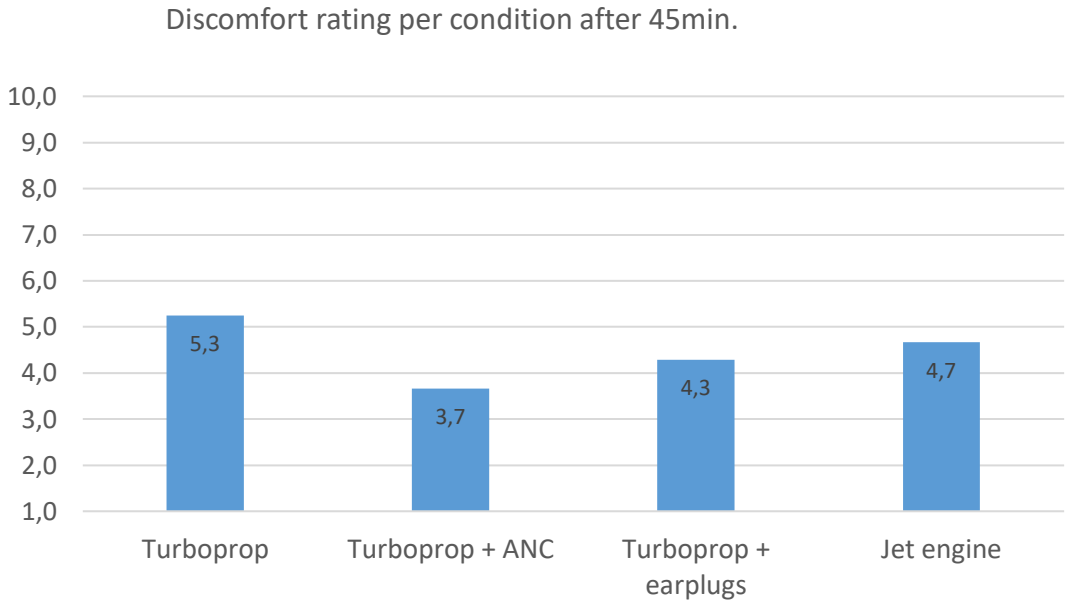
Comfort and Discomfort comparison





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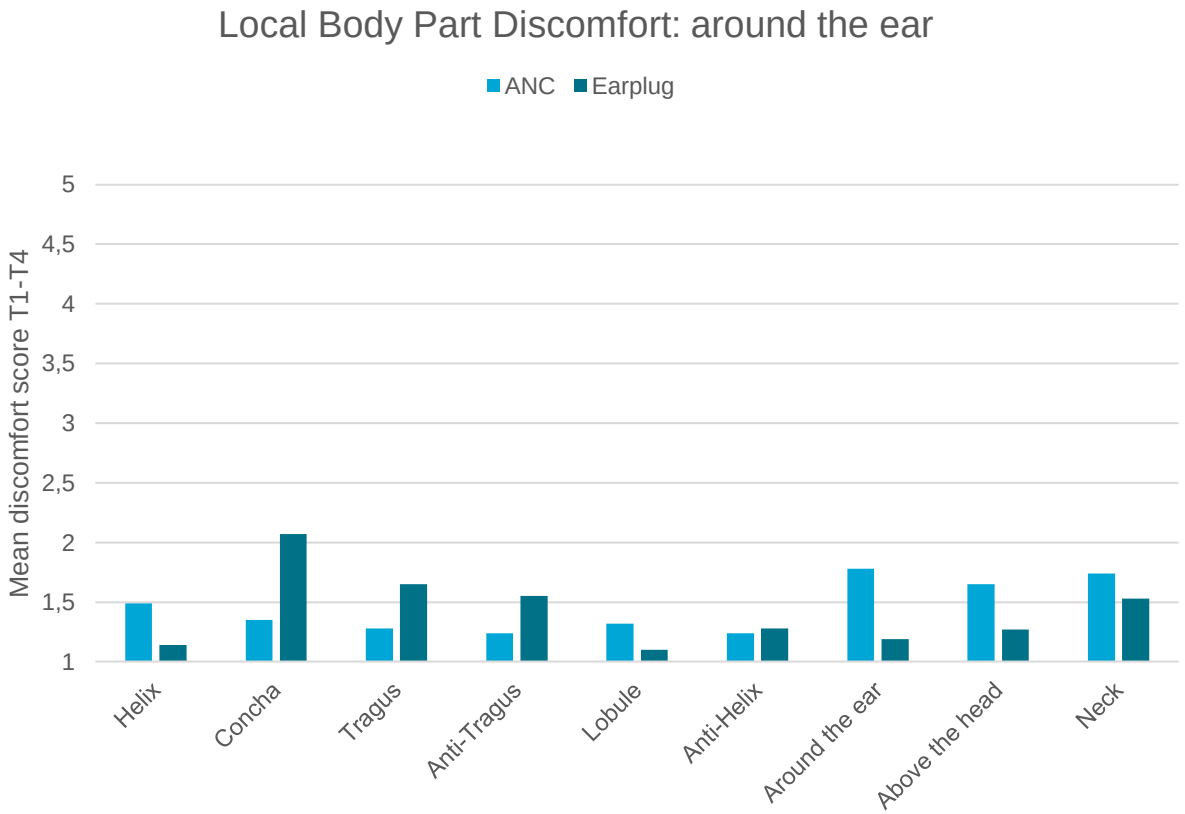
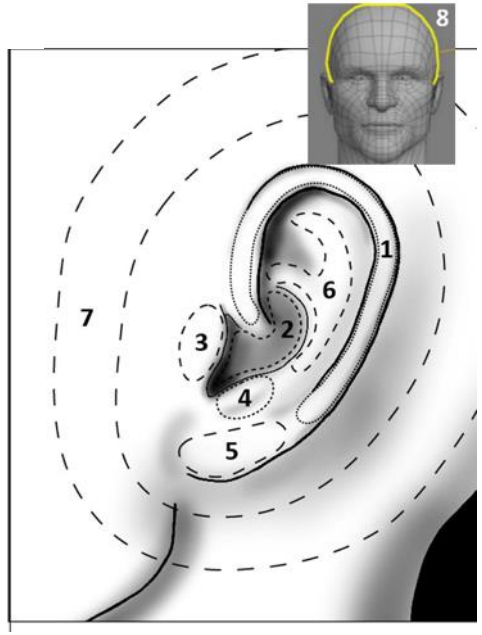
ANC vs. Earlugs





1	Helix
2	Concha
3	Tragus
4	Anti-tragus
5	Lobule
6	Anti-helix
7	Around the ear
8	Above the head
9	Neck

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ANC vs. Earplugs

Active Noise Cancelling headphones

- Heightened awareness of vibrations and heartbeat
- Feeling of air pressure change
- Gives option to play music
- Create a feeling of privacy

Earplugs

- Blocks out less noise
- Less heavy on the head
- Easy to implement measure

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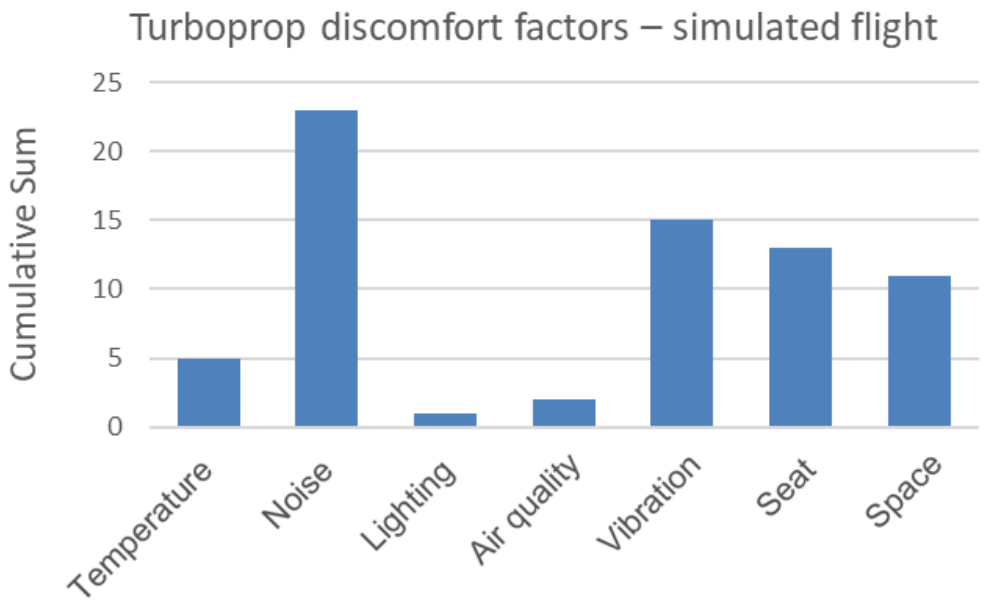
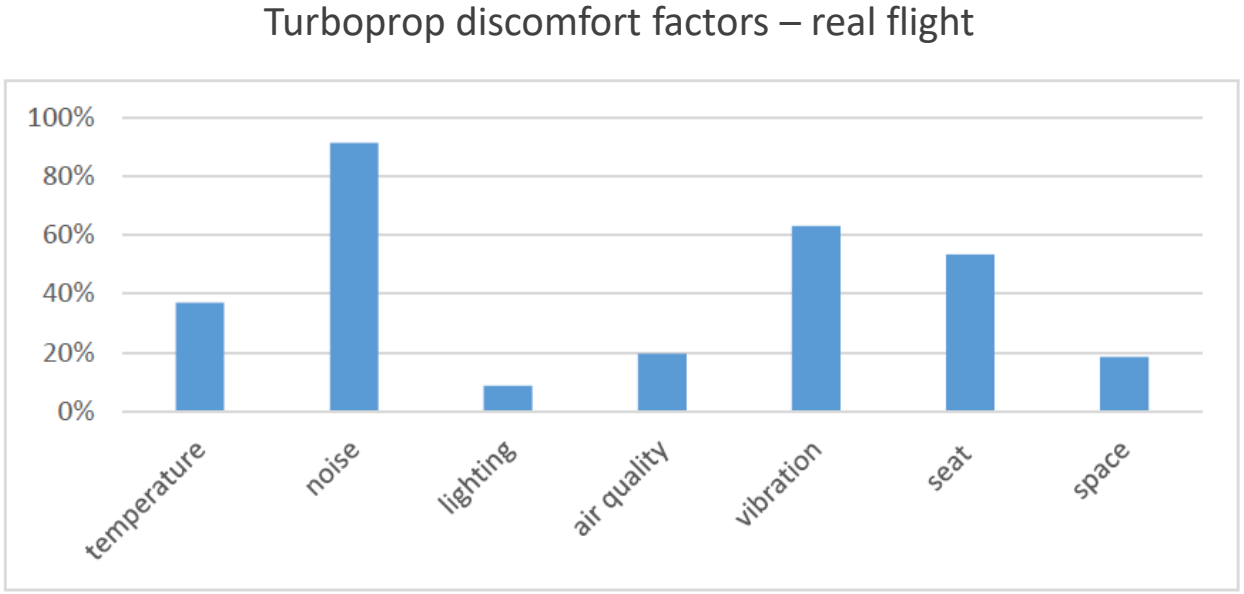
Discomfort factors compared





**Vink et al., 2022*

Key takeaways:

- Active Noise Cancelling Headphones are preferred over Earplugs.
- Jet sound is preferred over Turboprop sound.
- Valid research setup for acoustic comfort related studies.
- Sound reflection for jet sound is different then for turboprop sound.

Towards a comfort model of passenger comfort experience in turboprop aircraft

Prof. Dr. Neil Mansfield, Nottingham Trent University
Prof. Dr. Britta Herbig, Ludwig-Maximilians-Universität München

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Aim – to build a model(s) of passenger experience of turboprop aircraft

1. Concept model baseline factors
2. Comfort model from flight and lab tests
3. Numerical models from lab test

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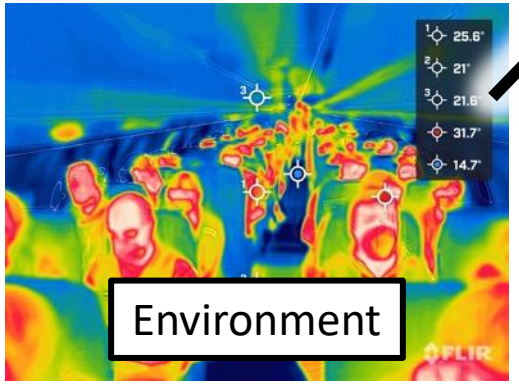
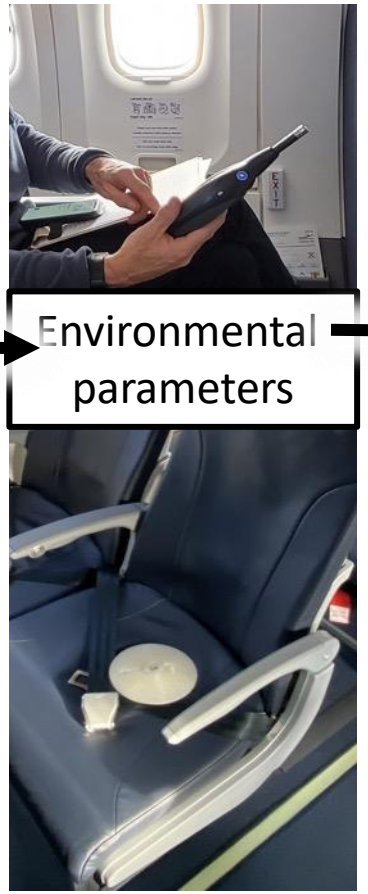
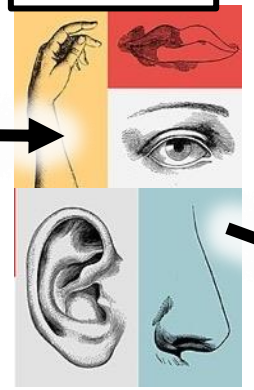
Starting point – baseline model



Interaction

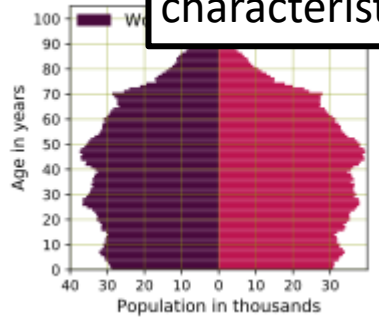




Current experience

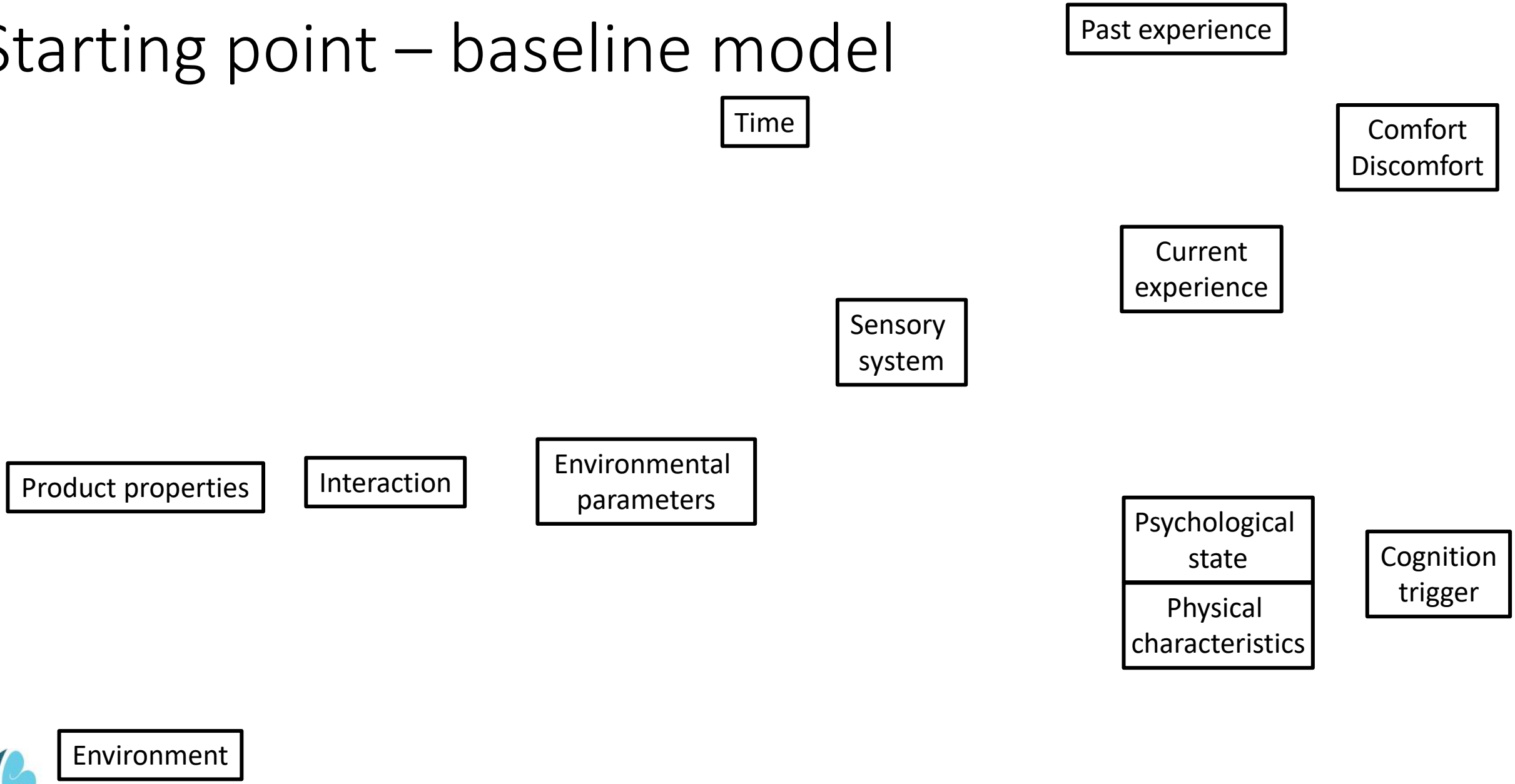
Psychological state

Physical characteristics

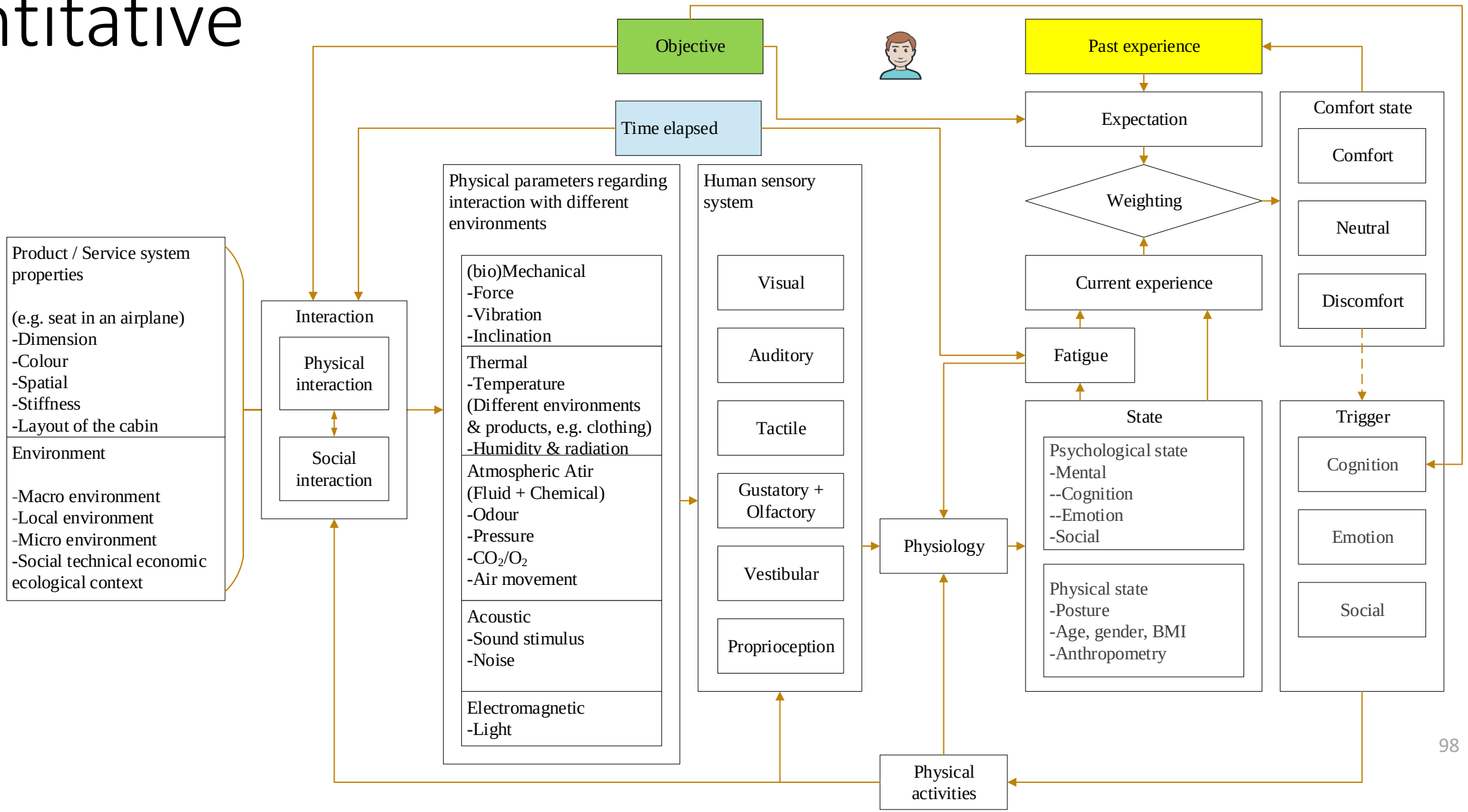


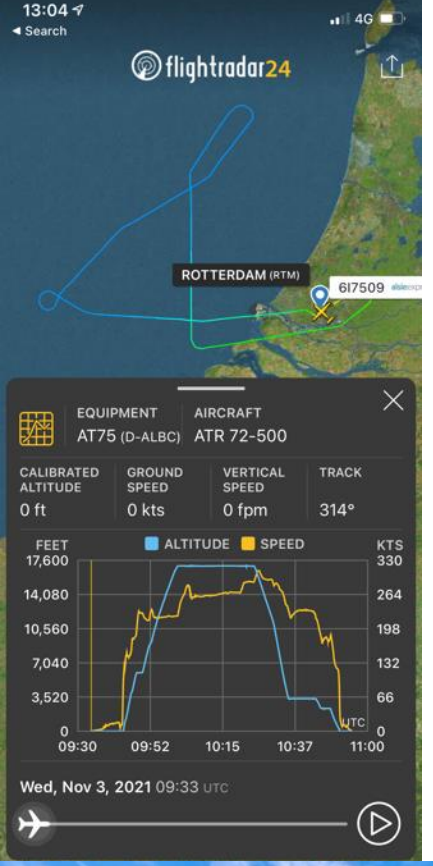
Cognition trigger

Starting point – baseline model

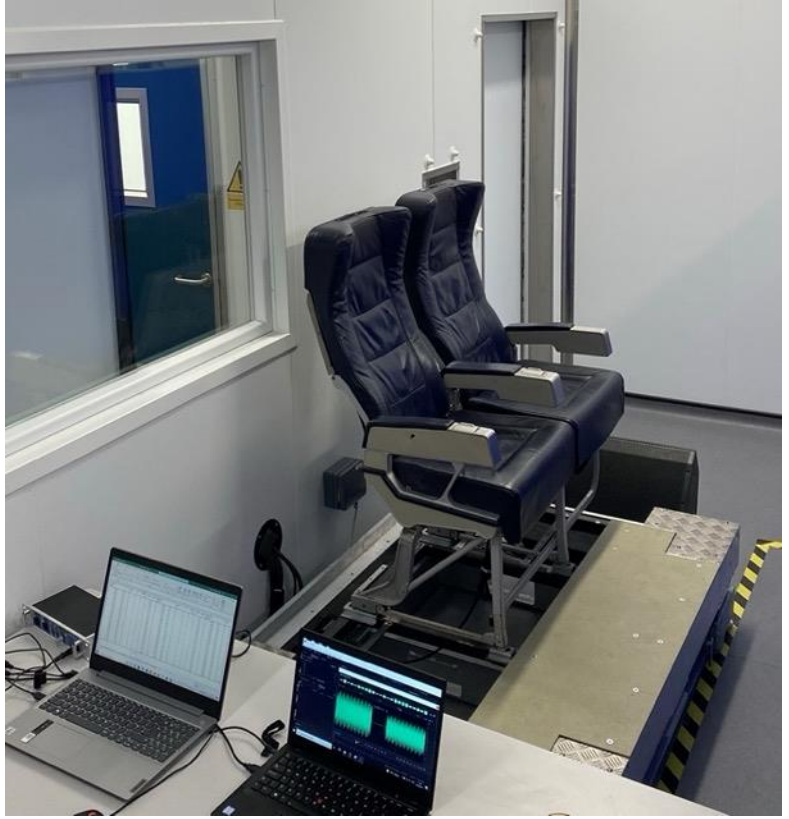


Starting point – baseline model – qualitative and quantitative





Flight test



Lab tests

Cabin simulators

KEY

Dimension measured during flight tests
Dimension measured during lab tests
Passenger responses
 Data supports association
 Data supports cross-flight phase effect

COMFDEMO

KEY

Dimension measured during flight tests
Dimension measured during lab tests
Passenger responses
Data supports association
Data supports cross-flight phase effect

Pre-boarding

Negative mood	Ascent discomfort
Positive past experience Positive attitude	Ascent comfort

Product properties			
Easy adjustment of seat	→	More comfort	Less discomfort
Sense of space	→	More comfort	Less discomfort
Restricted sitting	→	Less comfort	More discomfort

KEY

Dimension measured during flight tests
Dimension measured during lab tests
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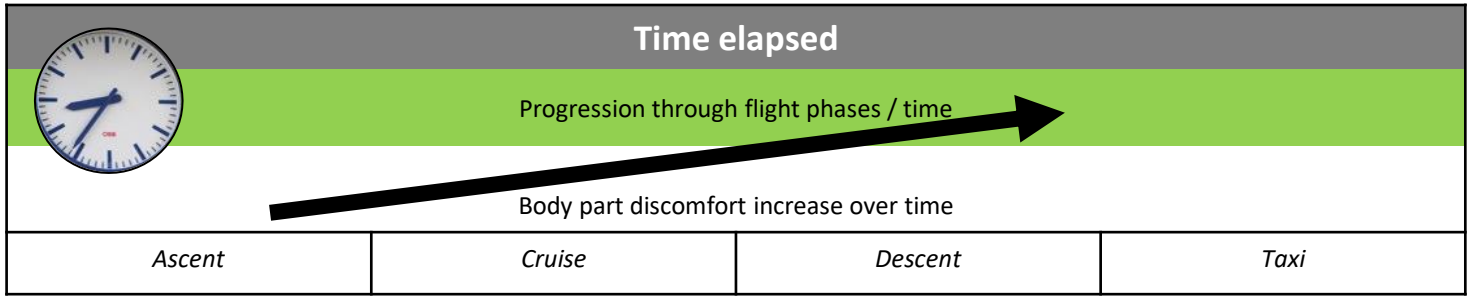

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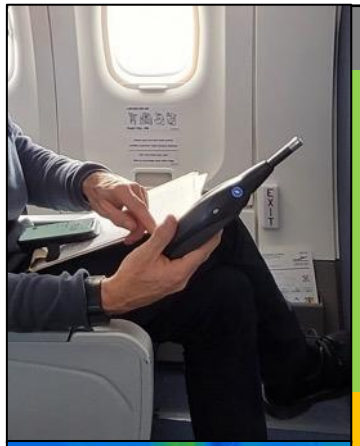
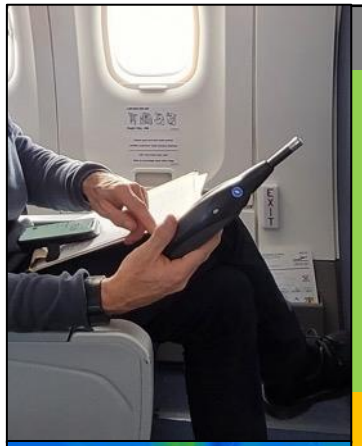


Physical / environmental parameters in cabin

Noise acceptability	More comfort	Less discomfort
Vibration acceptability	More comfort	Less discomfort
Overall pleasantness	More comfort	Less discomfort
Thermal acceptability (pre-flight & cruise)	More comfort at end of flight	
Air quality acceptability (cruise)	More comfort at end of flight Less discomfort at end of flight	
Noise level	More noise discomfort More overall discomfort Priority > 86 dB(A)	
Vibration magnitude	More vibration discomfort More overall discomfort	
Temperature	Priority at >30°C	

Product properties

Easy adjustment of seat	More comfort	Less discomfort
Sense of space	More comfort	Less discomfort
Restricted sitting	Less comfort	More discomfort



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Dimension measured during flight tests
Dimension measured during lab tests
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Post-flight

‘Would you consider flying with this type of aircraft again?’

Pre-boarding

Negative mood	→ Ascent discomfort
Positive past experience Positive attitude	→ Ascent comfort

Time elapsed

Progression through flight phases / time

Body part discomfort increase over time

Ascent	*Cruise*	*Descent*	*Taxi*

Product properties

Easy adjustment of seat	More comfort	Less discomfort
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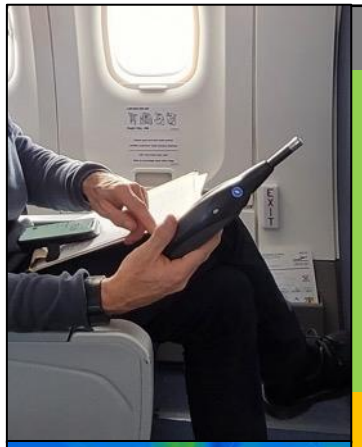

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KEY

- Dimension measured during flight tests
- Dimension measured during lab tests
- Passenger responses
- Data supports association
- Data supports cross-flight phase effect

Noise acceptability
Vibration acceptability
Overall comfort - descent
Overall pleasantness

Post-flight

'Would you consider flying with this type of aircraft again?'

+ve attribute

-ve attribute

Number of recent flights
Overall discomfort – ascent
Overall discomfort – descent
Overall discomfort - taxi

Pre-boarding

Negative mood	Ascent discomfort
Positive past experience Positive attitude	Ascent comfort

Time elapsed

Progression through flight phases / time

Body part discomfort increase over time

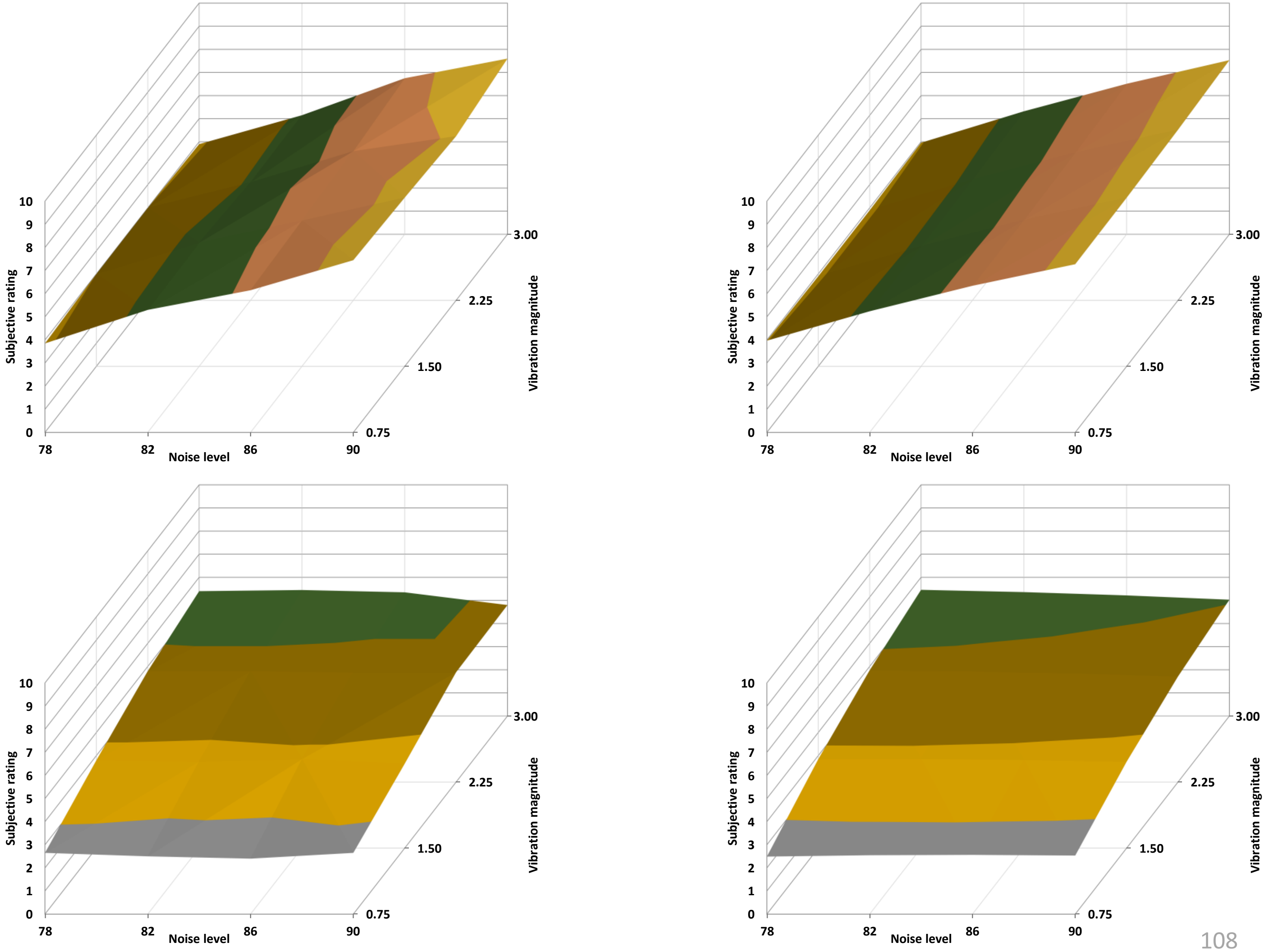
Ascent	*Cruise*	*Descent*	*Taxi*

Noise / vibration / thermal comfort models

Polynomial surface

- Top – Noise
- Bottom – Vibration

- Left – measured
- Right – modelled



Noise / vibration models

- Noise and vibration models were created using a polynomial function for *x* (noise) and *y* (vibration); one for each temperature. Curve fitted in MATLAB.

$$f(x,y) = p00 + p10x + p01y + p20x^2 + p11xy + p02y^2$$

Table 2. Descriptors for polynomial coefficients	
Coefficient	Description
p00	Constant value
p10	Linear coefficient (noise)
p20	Second order coefficient (noise)
p01	Linear coefficient (vibration)
p02	Second order coefficient (vibration)
p11	Coefficient of interaction between noise and vibration

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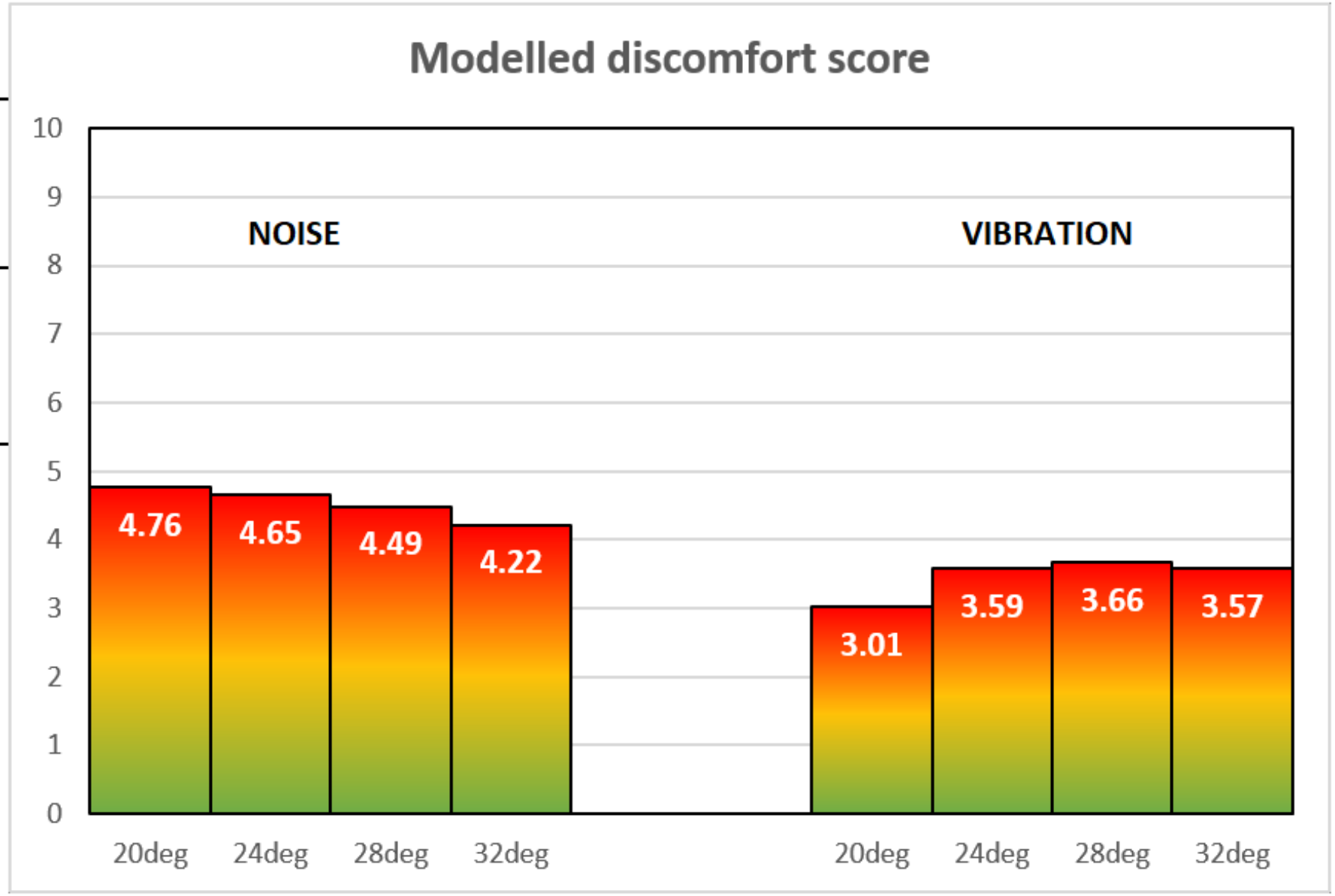
Noise 78-90
80.5
Vibration 0.75-3.00
1.00



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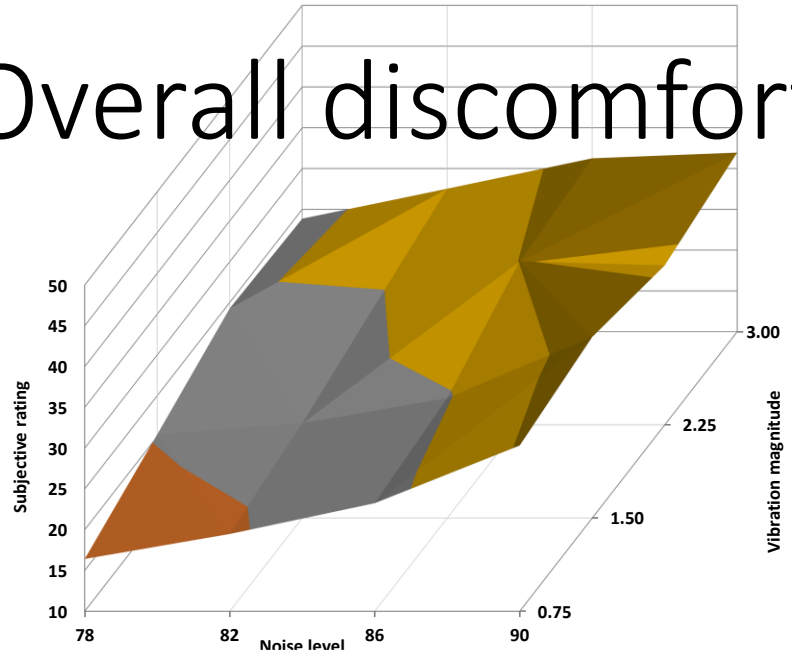
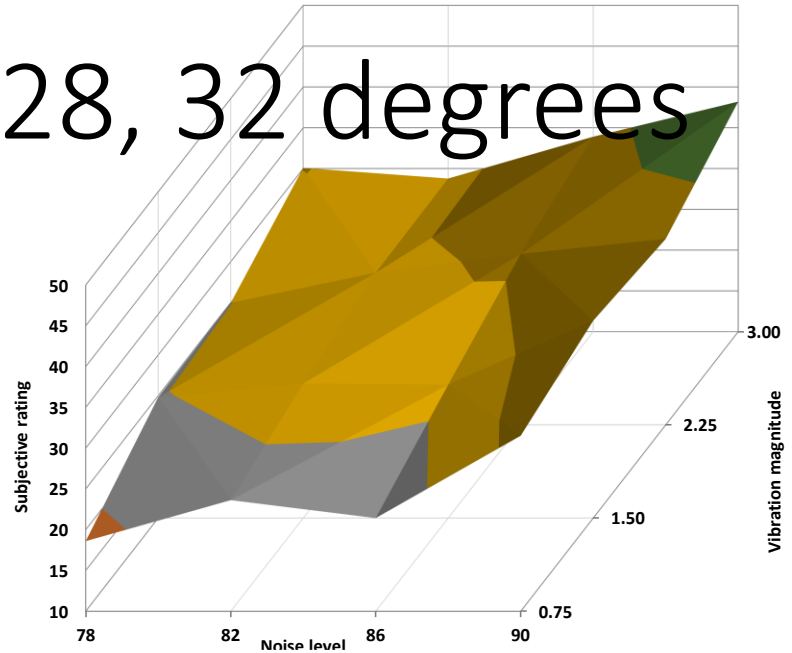
Overall discomfort – 20, 24, 28, 32 degrees

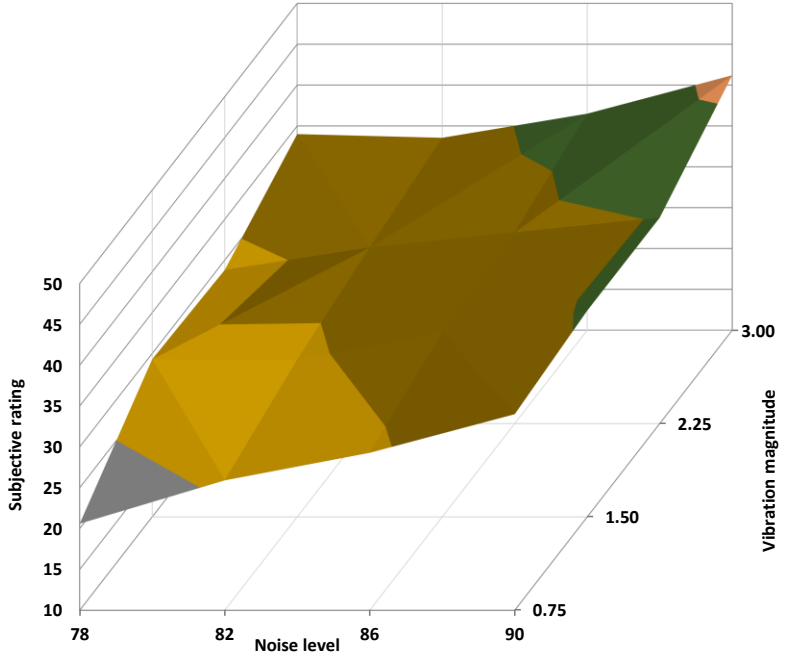
20º



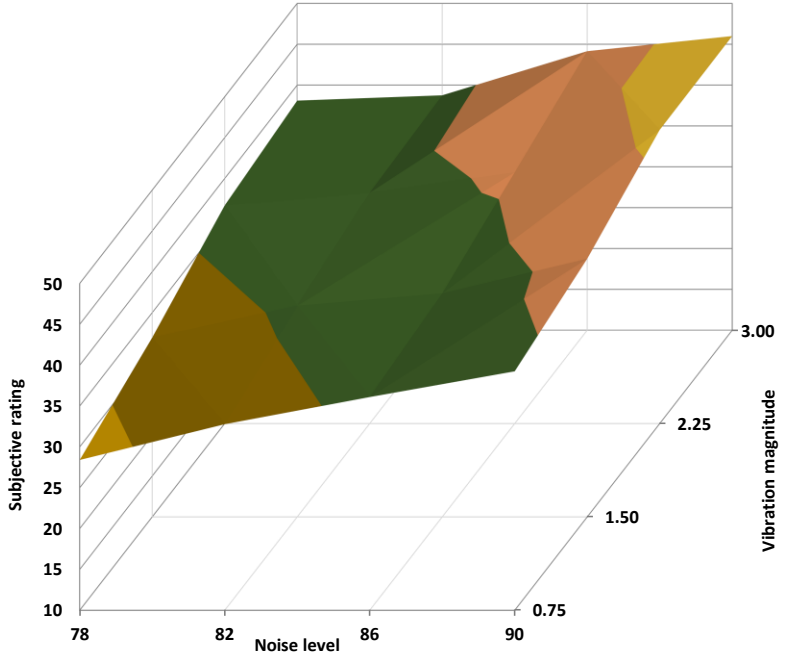
24º



28º



32º



Overall model – machine learning

- K-fold cross-validation method
- Inclusion of noise (*x*), vibration (*y*), temperature (*z*) as linear coefficients

- Data randomly assigned to one of 5 data sets, each comprising 256 test conditions
- 5 repeats of multiple linear regression in SPSS using 4 of 5 data sets as training set and one data set as test data

$$f(x, y, z) = q000 + q100x + q010y + q001z$$

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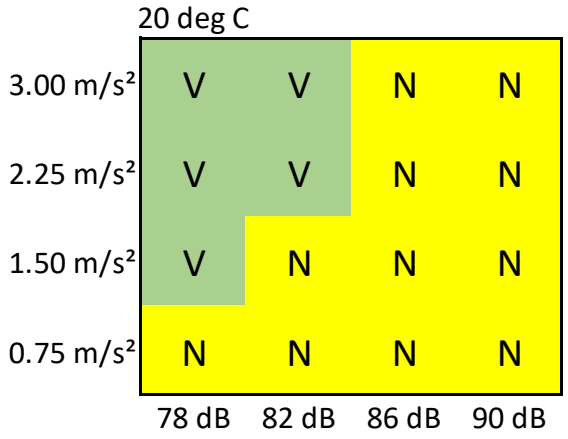
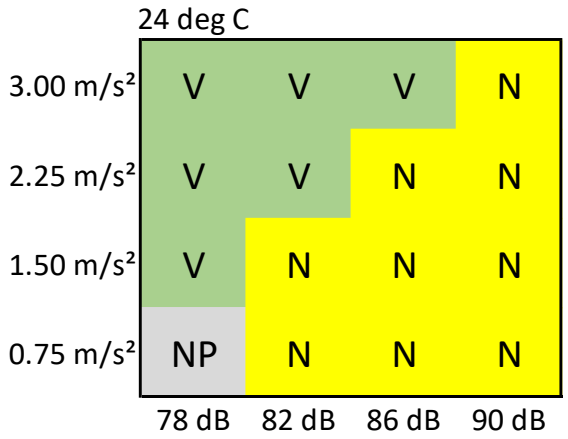
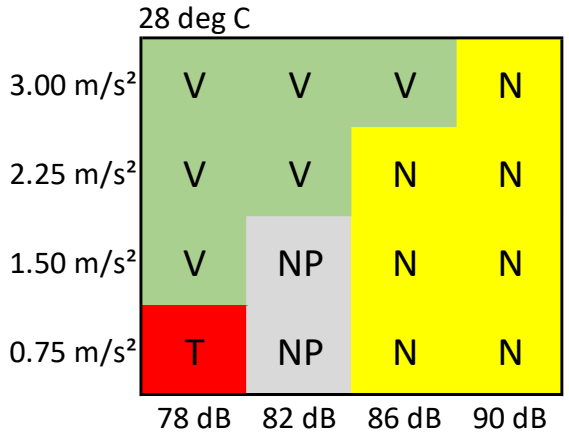
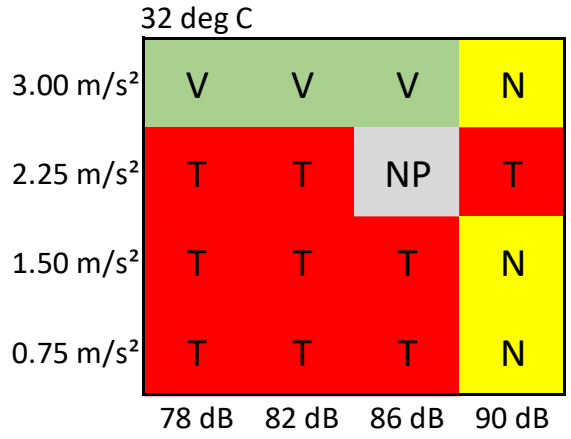
Preference

V	> 50% prefer to reduce vibration
N	> 50% prefer to reduce noise
T	> 50% prefer to reduce temperature
NP	no preference > 50%









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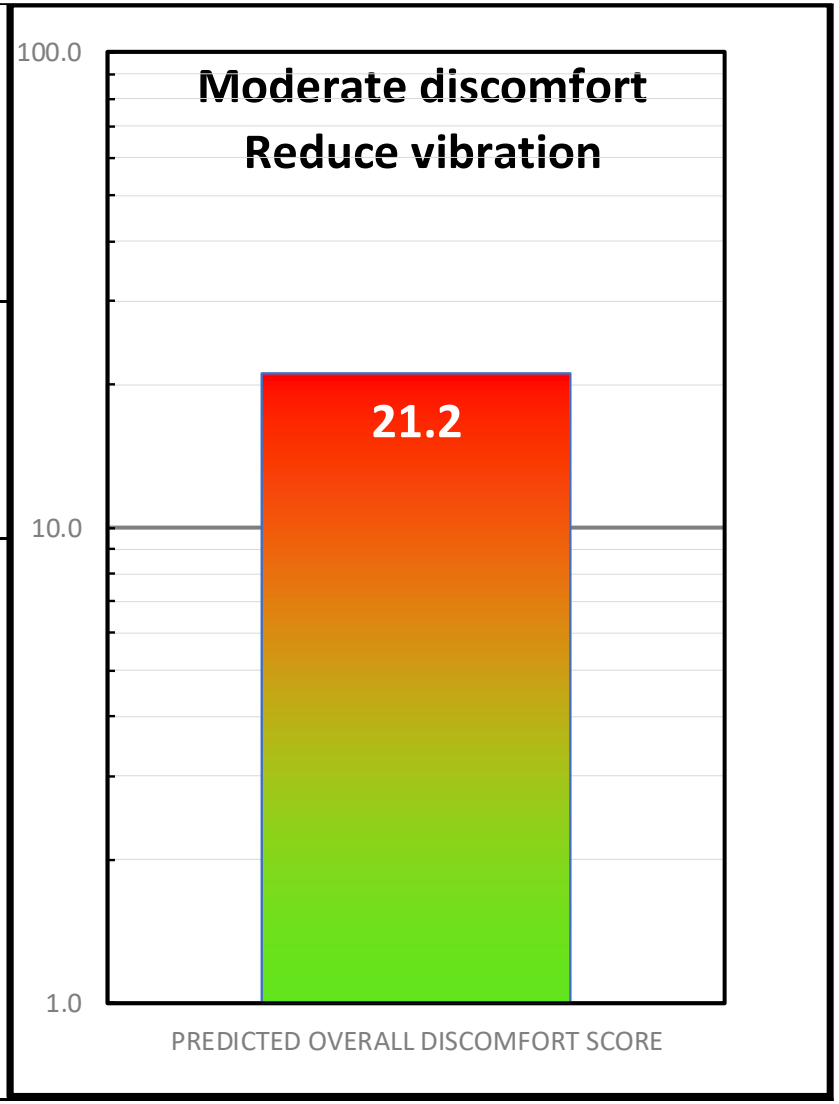
Machine learning overall / preference model

Vibration magnitude (0.75-3.00)	2.00	
Noise level (78-90)	78	
Temperature (20-32)	20	
PREDICTED OVERALL DISCOMFORT SCORE	21.2	
PREDICTED DESCRIPTOR	Moderate discomfort	
PREDICTED CHANGE	Reduce vibration	69%
SUM OF CHANGE PERCENTAGES		108%



Interaction and Questions

Interaction between attendees and speakers on webinar so far + discussion

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Acknowledgements

This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 831992. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.