Neuro-adaptive Architecture in Extreme Environments

Investigating Visual Quality as Countermeasure to Stressor Exposure affecting Heart Rate Variability

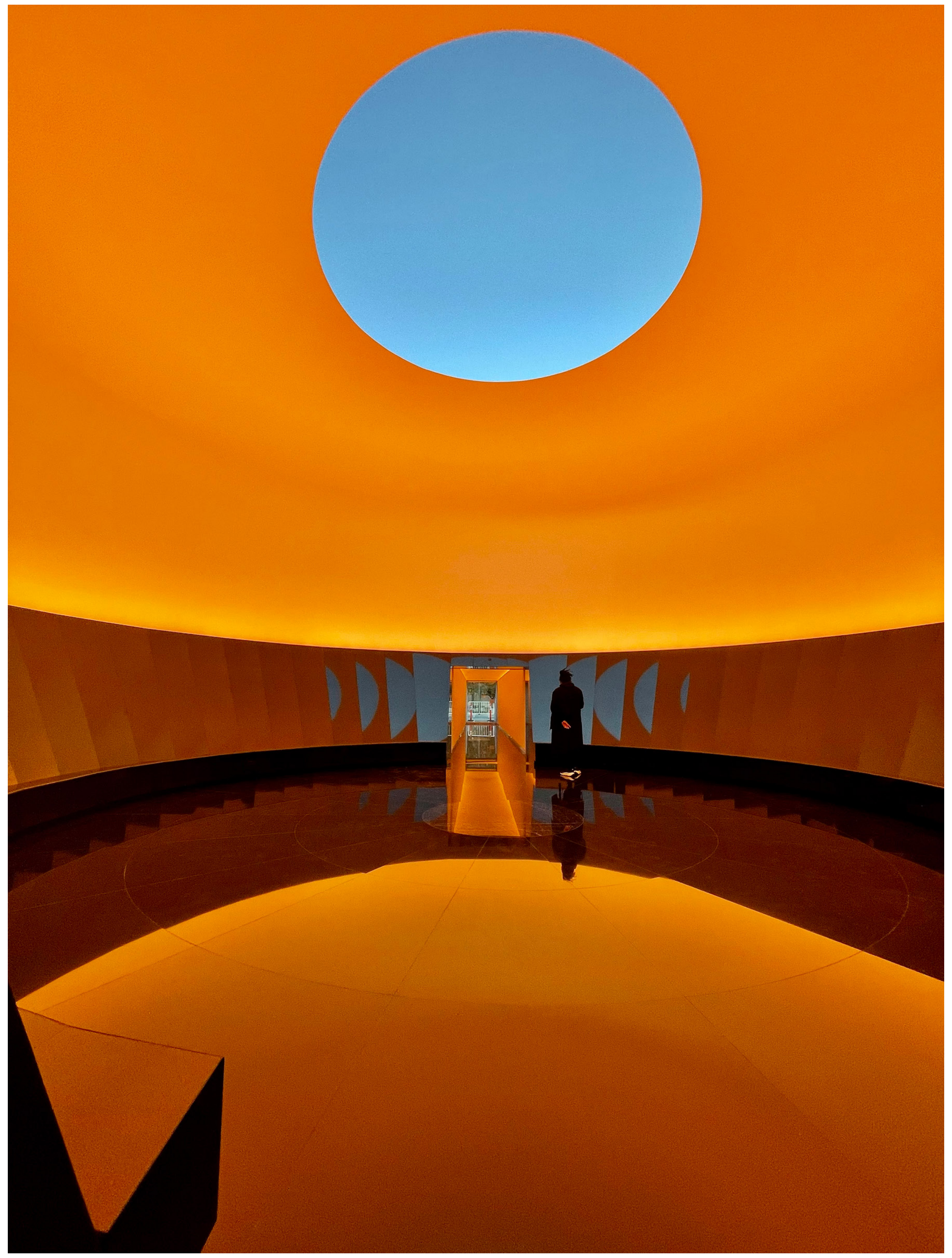
Master's Thesis Defense

Antonia Sattler

Supervisors

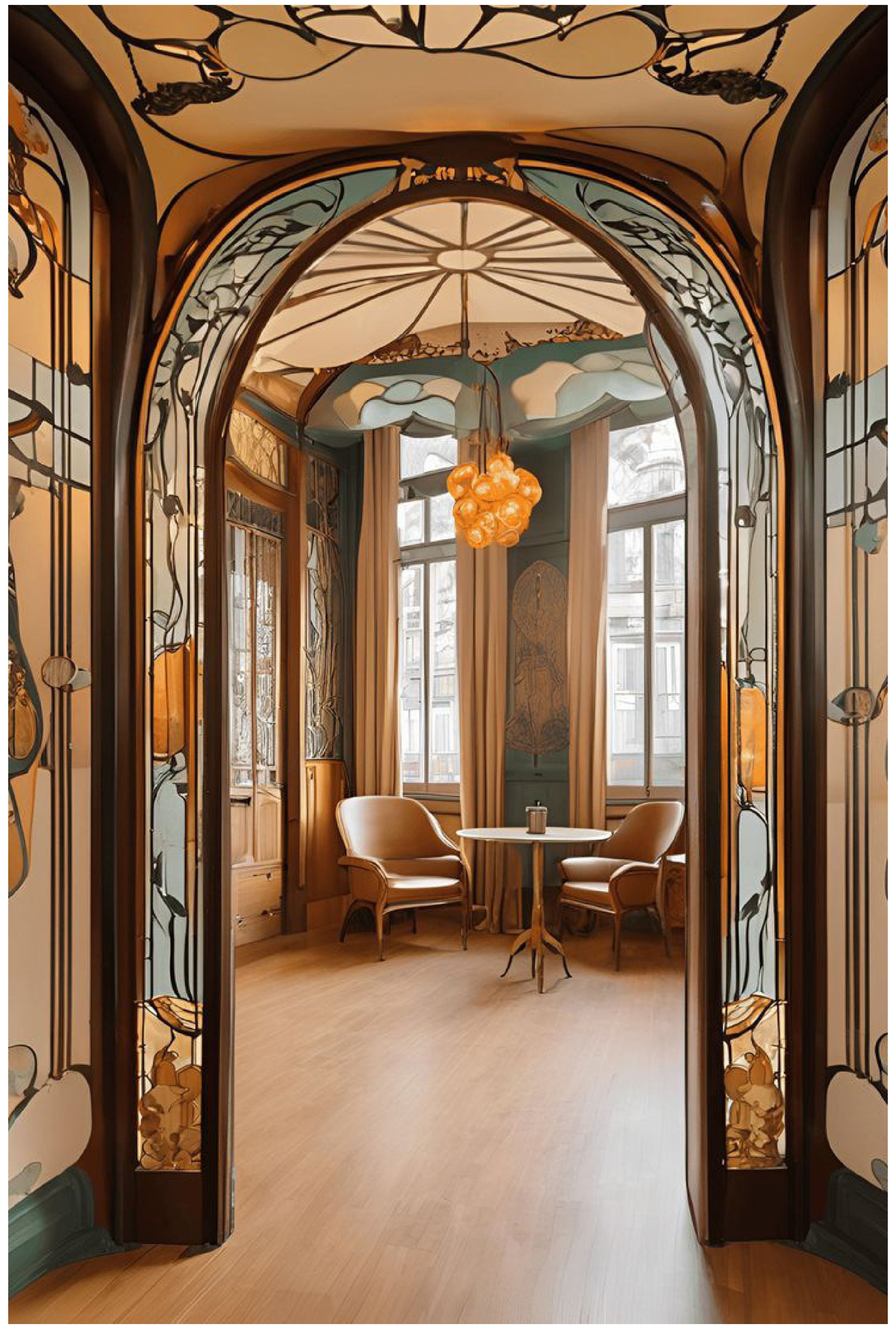
Dr. Michela Turrin
Dr. Henriette Bier

30th of June 2025

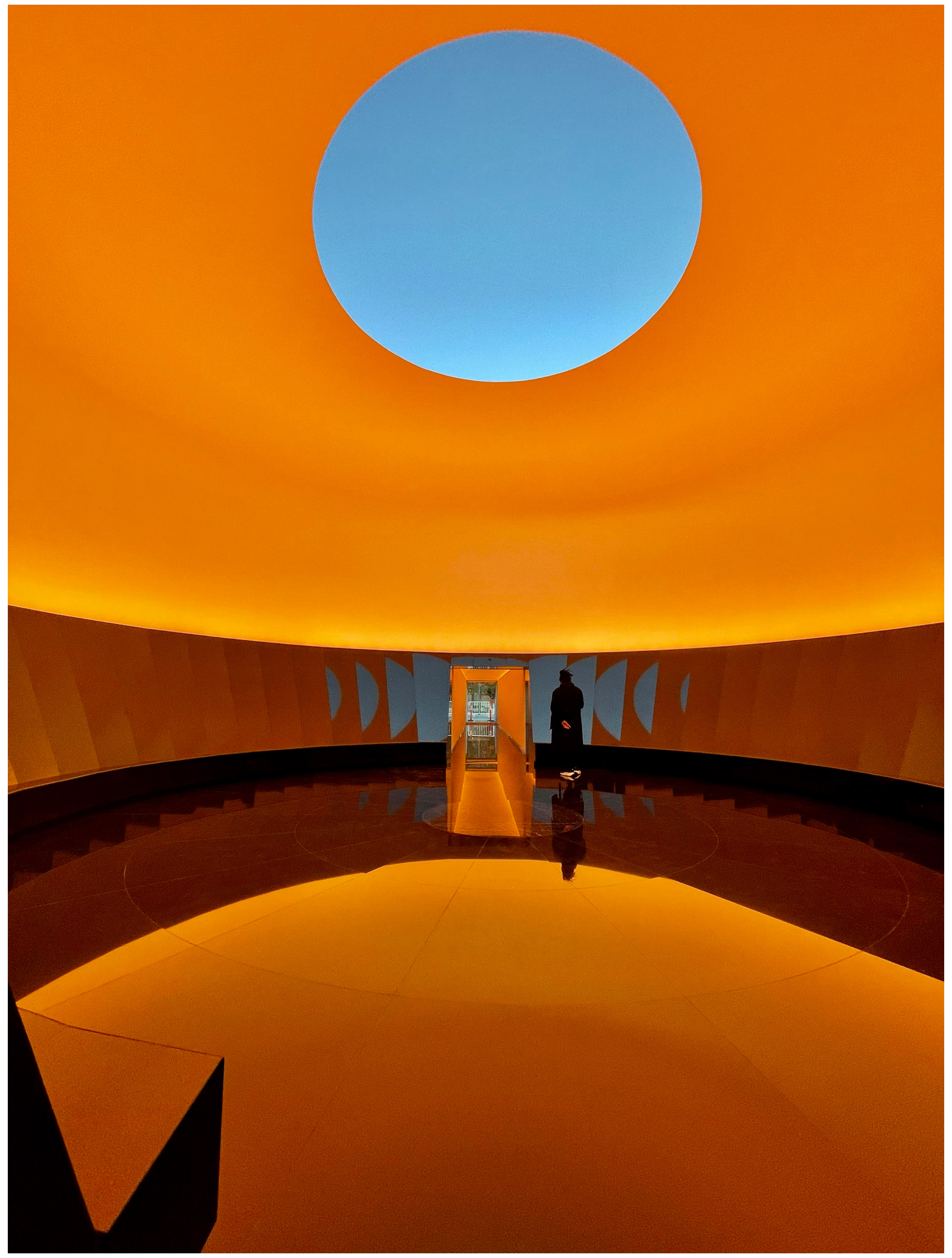


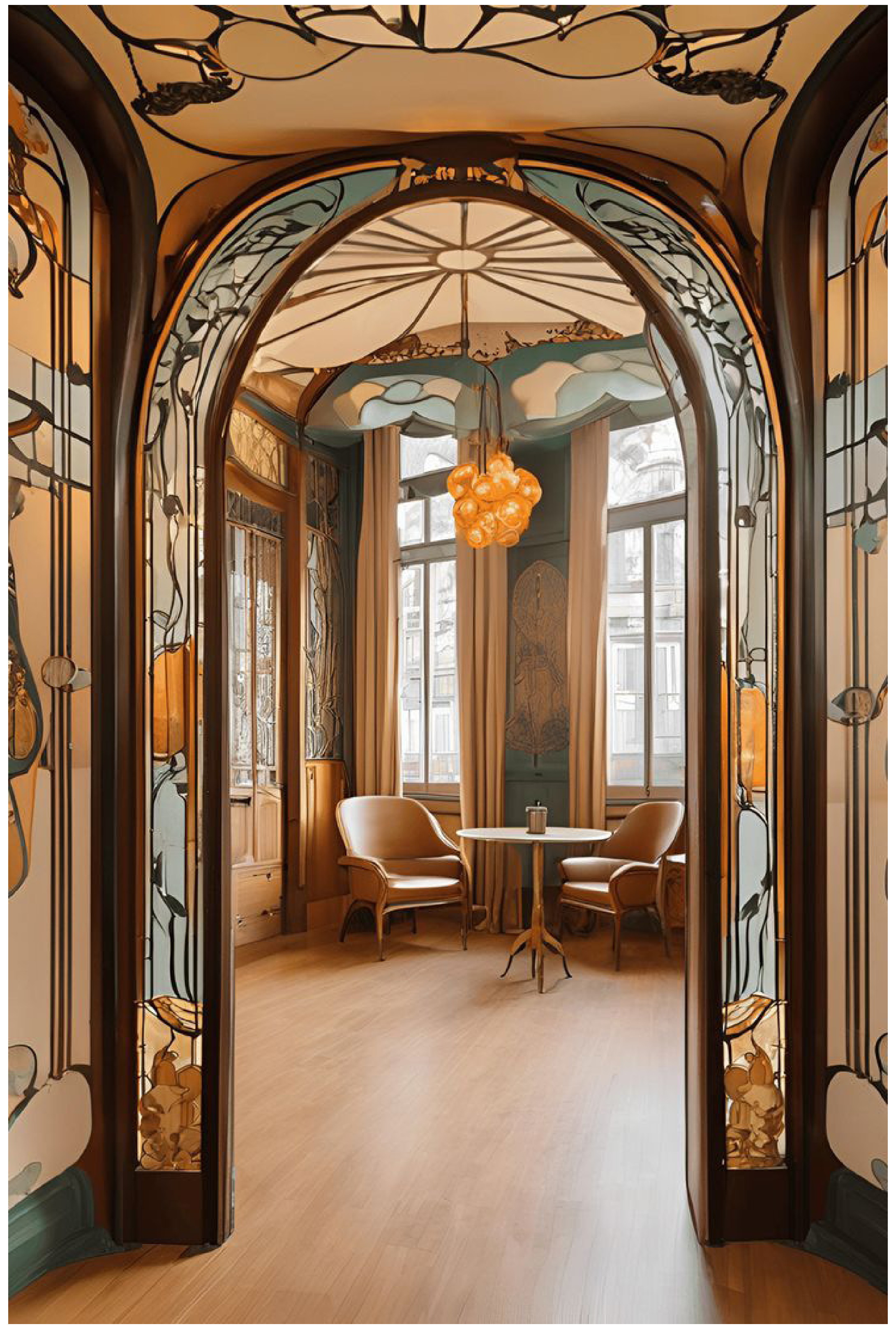
« Skyspace Espíritu de Luz», 2022
Instituto Tecnológico, Monterrey,
Mexiko | ©James Turrell, Photo:
Andrea Alonso

Zeitz MOCAA – Cape Town,
South Africa | © Heatherwick
Studio London



Art Nouveau Living Room
Interior





while we can imagine the effects of architecture on our wellbeing...

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Art Nouveau Living Room
Interior

Neuroarchitecture

Built Environment → Neuroarchitecture ← **Public and Individual Health**

investigates the effects of architecture on the human brain through biomarkers

Assem, H. M., Khodeir, L. M., & Fathy, F. (2023). Designing for human wellbeing: The integration of neuroarchitecture in design–A systematic review. Ain Shams Engineering Journal, 14(6), 102102. https://doi.org/10.3389/fcomp.2023.1237531
Valentine, C. (2024). The impact of architectural form on physiological stress: a systematic review. Frontiers in Computer Science, 5, 1237531.

Why is this relevant?

Built Environment

Valentine, C. (2023). Architectural allostatic overloading: exploring a connection between architectural form and allostatic overloading. International Journal of Environmental Research and Public Health, 20(9), 5637
Piao, X., Xie, J., & Managi, S. (2024). Continuous worsening of population emotional stress globally: Universality and variations. BMC Public Health, 24(1), 3576. https://doi.org/10.1186/s12889-024-20961-4
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Why is this relevant?

people spend up to 90 % of their time indoors

TU Delft

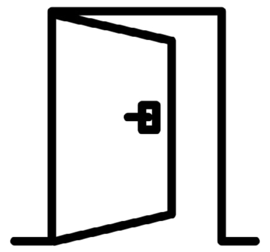
Why is this relevant?

resourcal limitations in the built environment (space in cities and natural resources)

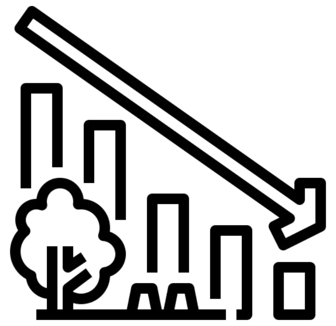
Why is this relevant?

Built Environment

people spend up to 90 % of their time indoors



resourcal limitations in the built environment



Public and Individual Health

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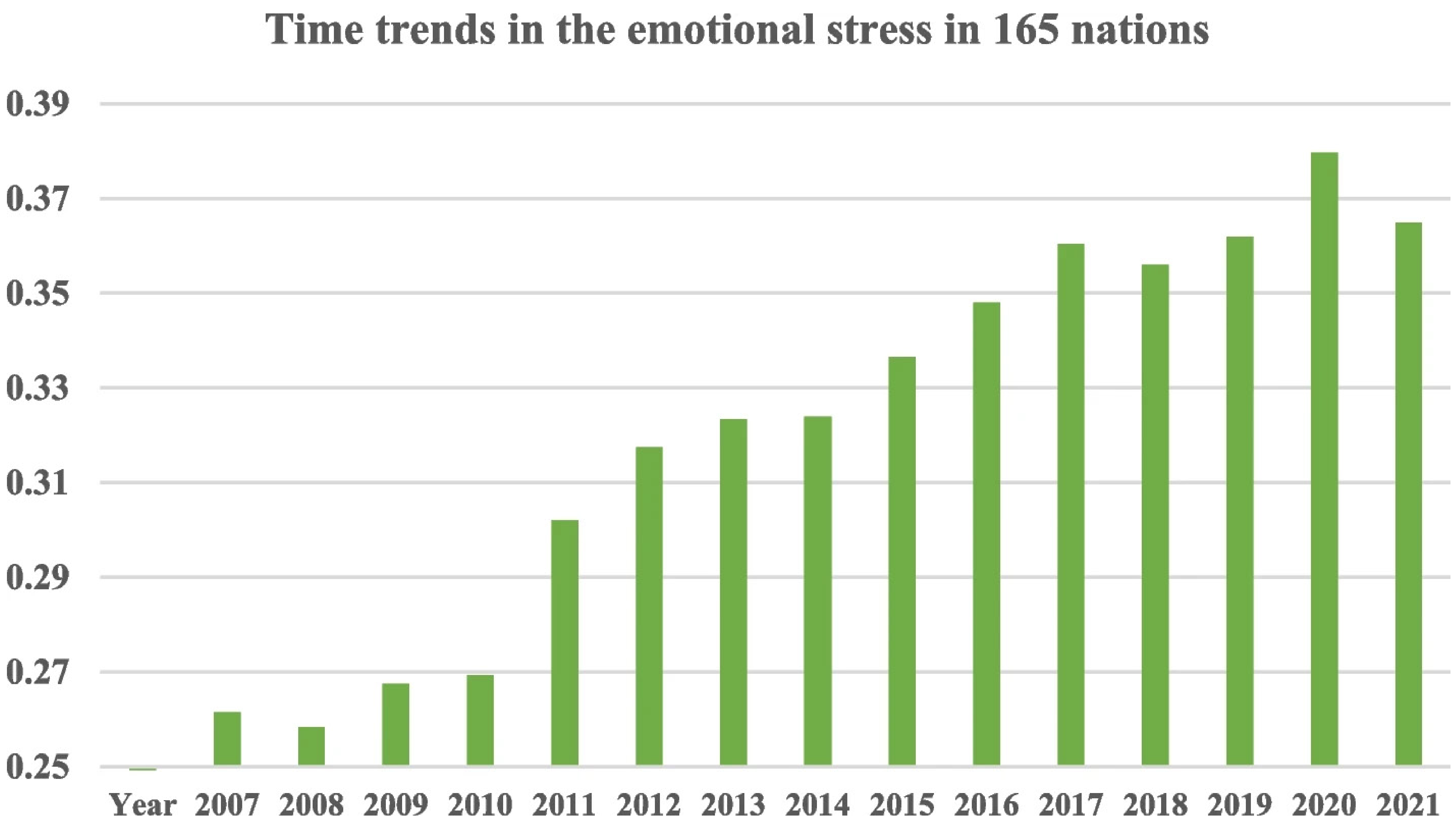
Why is this relevant?

widespread rise in chronic stress

which can lead to a range of short- and long-term health conditions



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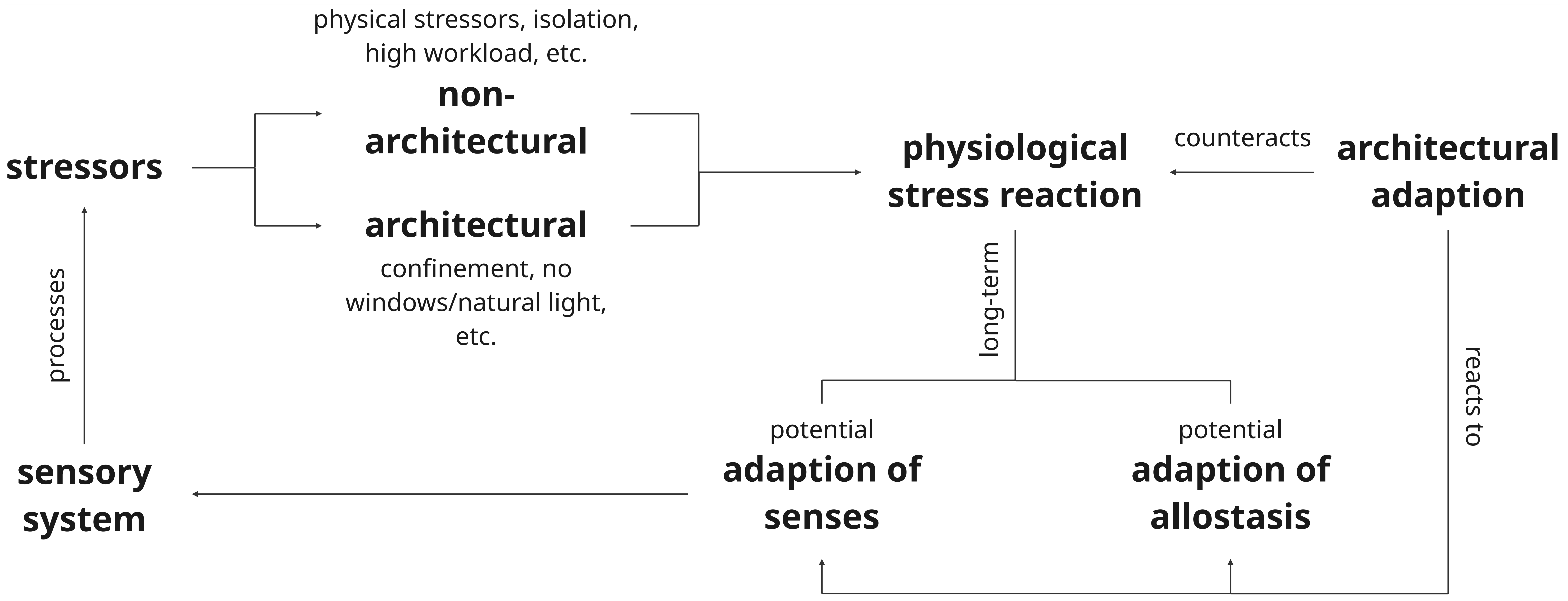
Longterm Vision



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State of the Research

indoor environmental quality (acoustic, air, temperature and light) as cause of negative health effects

healing architecture (supporting physical recovery) and post-stress recovery

architectural features/shapes as acute stress-cause

Bluyssen, P. M. (2019). The need for understanding the indoor environmental factors and its effects on occupants through an integrated analysis. IOP Conference Series: Materials Science and Engineering, 609(2), 022001. https://doi.org/10.1088/1757-899X/609/2/022001
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Research Gaps

→ **longterm health consequences of architecture**

→ **architecture as countermeasure (= decrease of relative biomarker-change during stressor exposure)**

→ **in alignment with functionality and limited resources**

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PROOF OF CONCEPT METHODOLOGY

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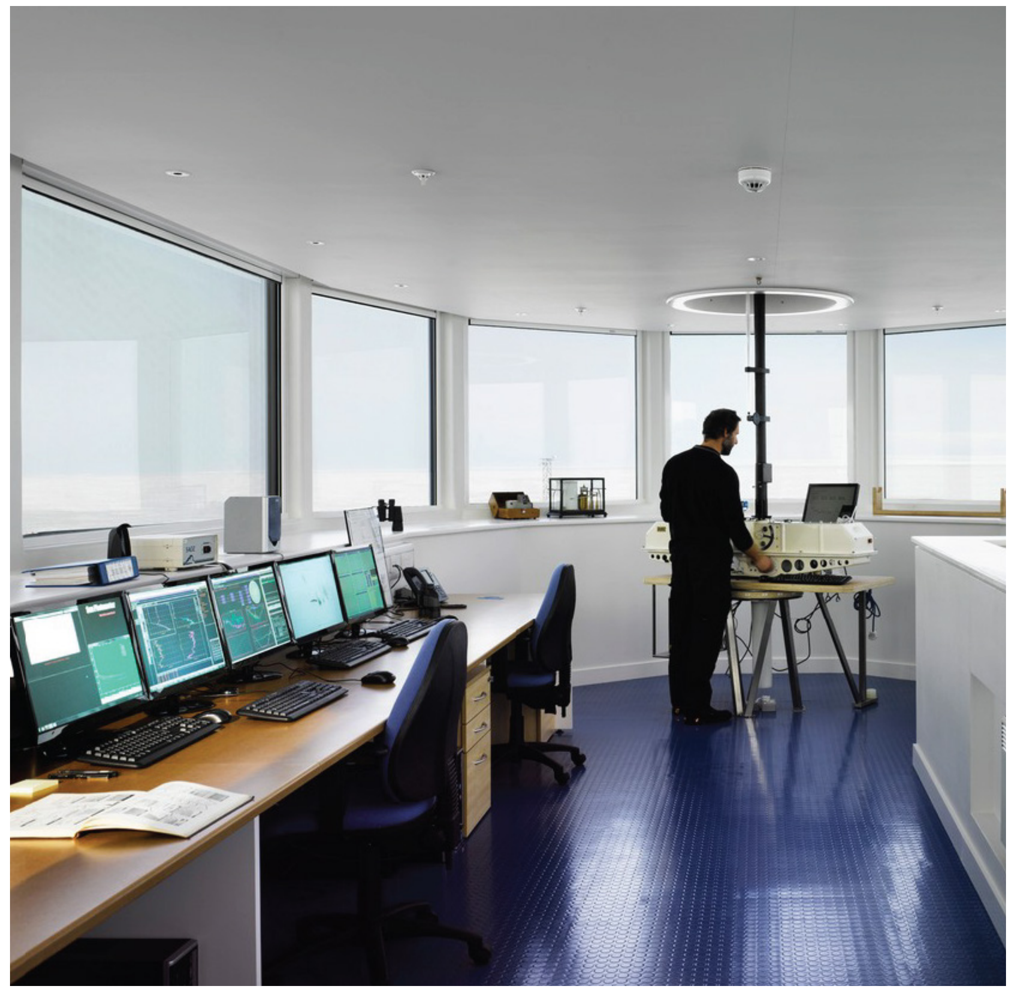
Research Gaps

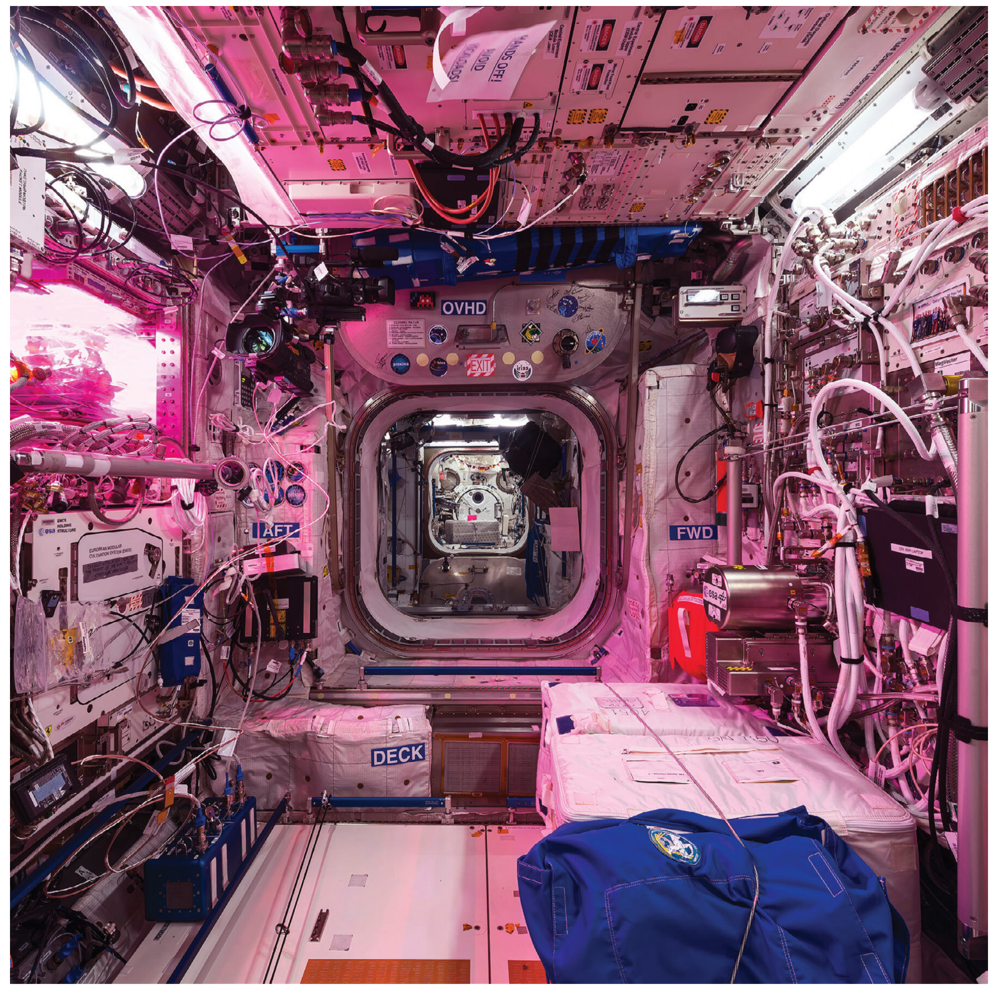
challenges are amplified in extreme environments:

↑ **stressor exposure**

↑ **alignment with functionality**

↑ **limited resources**





Challenges in their Investigation

in cross-sectional research:

individual biomarker-baselines

Challenges in their Investigation

in cross-sectional research:

individual biomarker-baselines

influence of confounding variables

Challenges in their Investigation

in cross-sectional research:

individual biomarker-baselines

influence of confounding variables

reliable transient stressor simulation

Research Questions

1. How can neuroarchitecture be used in the investigation and application of visual quality as countermeasure to stressors in alignment with functional requirements of architecture in extreme environments?

- **1.1** How can dynamic biomarkers and their inter-individuality in combination with stress be investigated in cross-sectional design studies?
- **1.2** How can computational analysis be used to manage cause-effect ambiguity resulting from the dynamic nature of biomarkers for an increasement of result reliability?
- **1.3** How can the findings be further developed in longitudinal research and applied in extreme environments?

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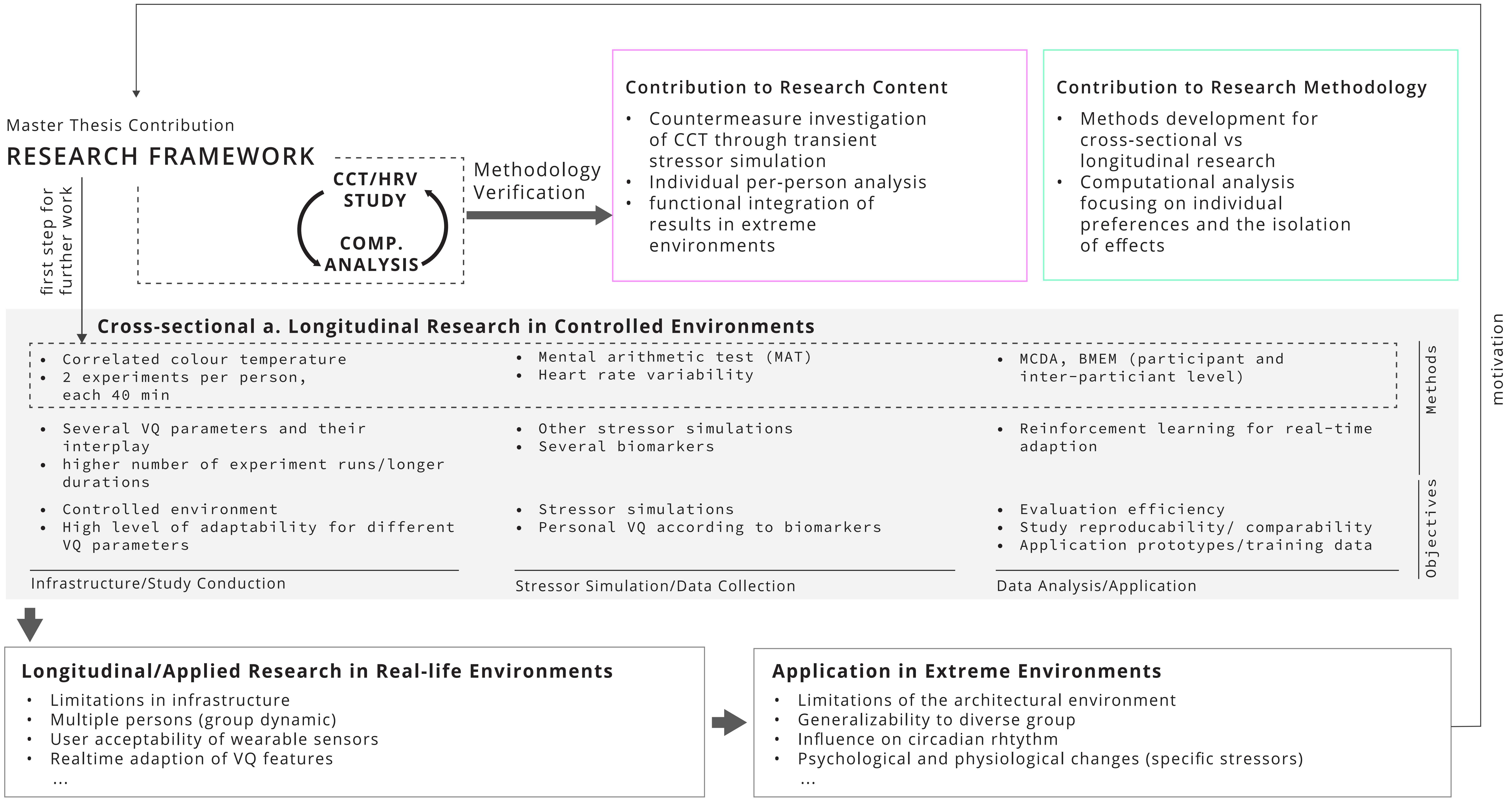
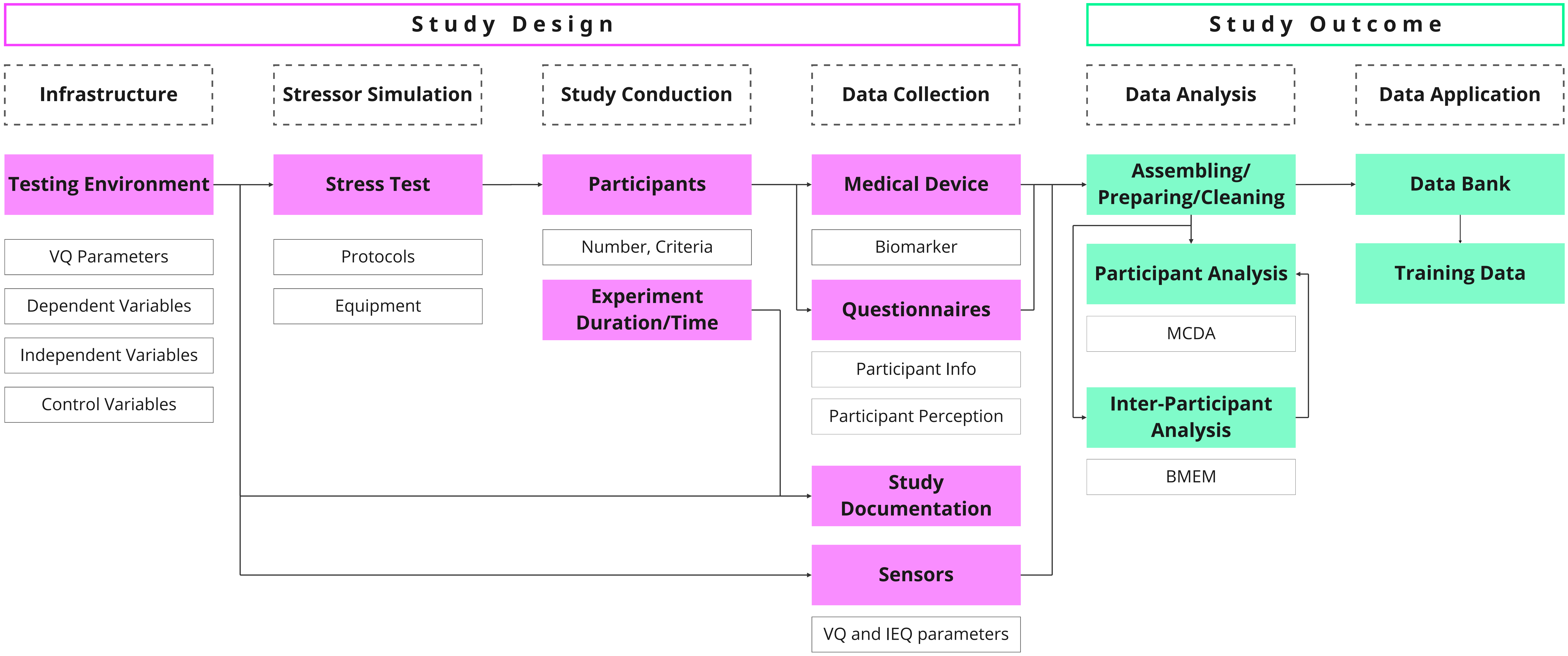
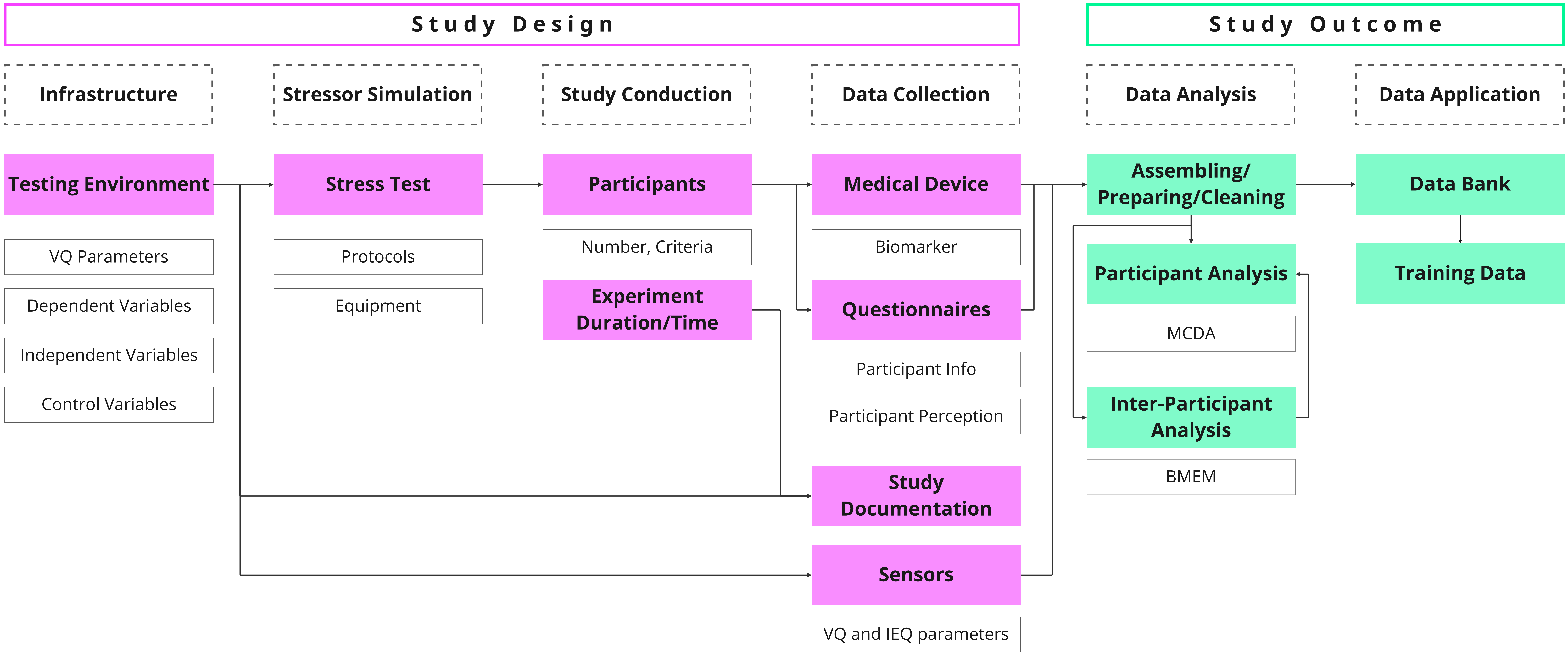
Research Framework



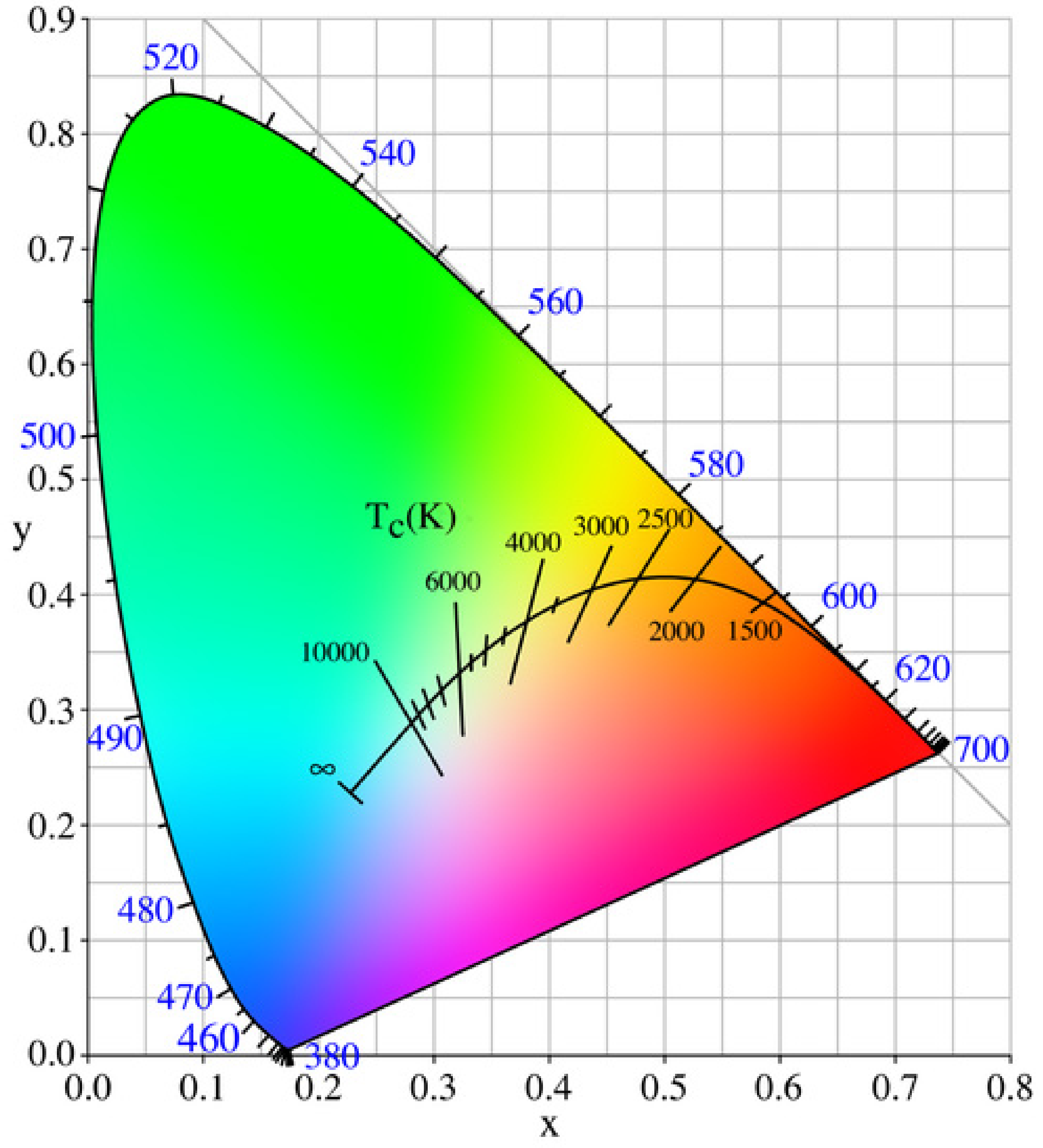
Research Framework Applied



Research Framework Applied to CCT and HRV



Colour Correlated Temperature (CCT)



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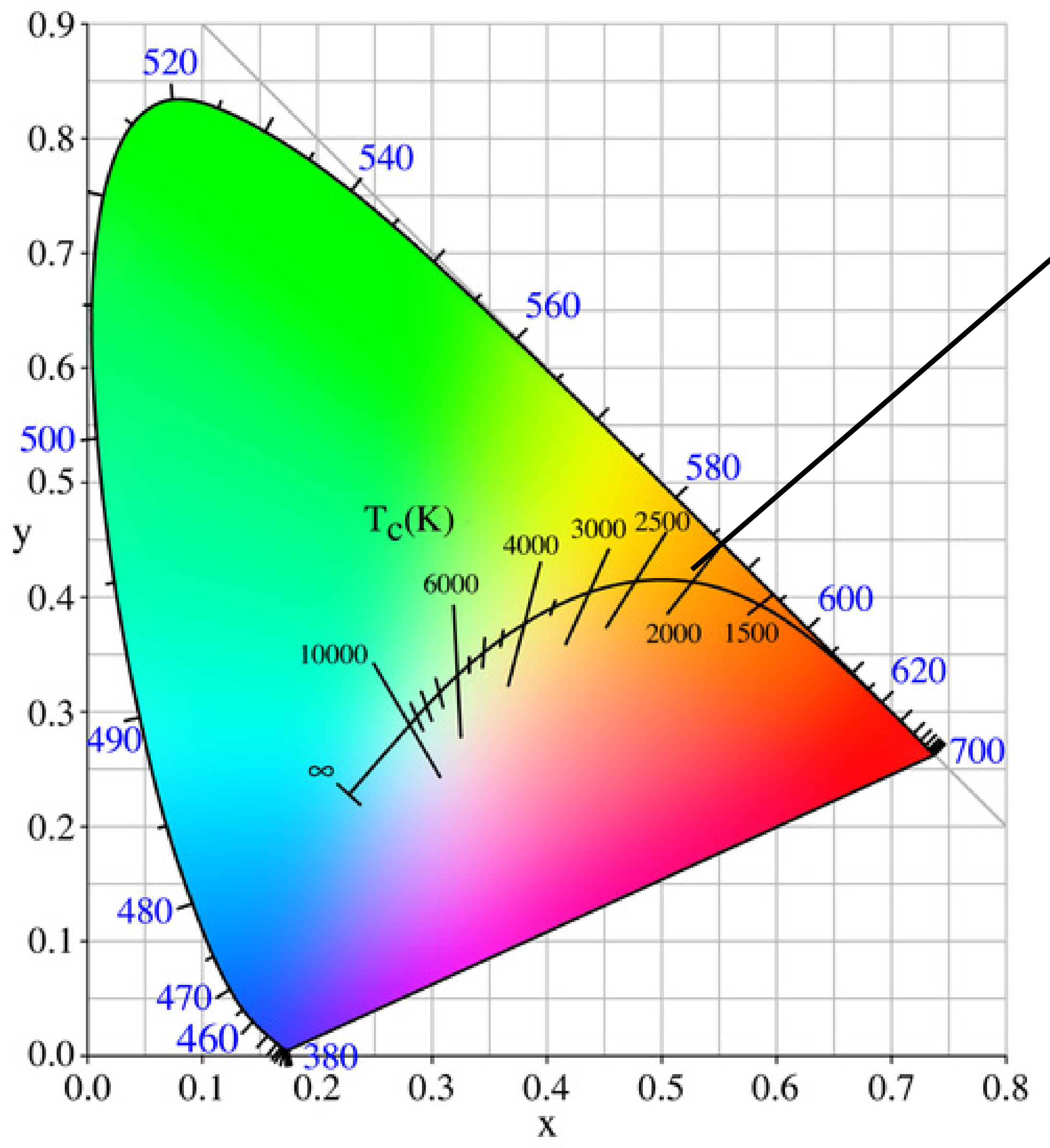
Colour Correlated Temperature (CCT)

Colour Correlated Temperature (CCT)

- colour appearance of a light source (one-dimensional from warm to cold)
- ~ 1000K to ~12000K



6000 K **2700 K**

part of IEQ as well as architectural design feature

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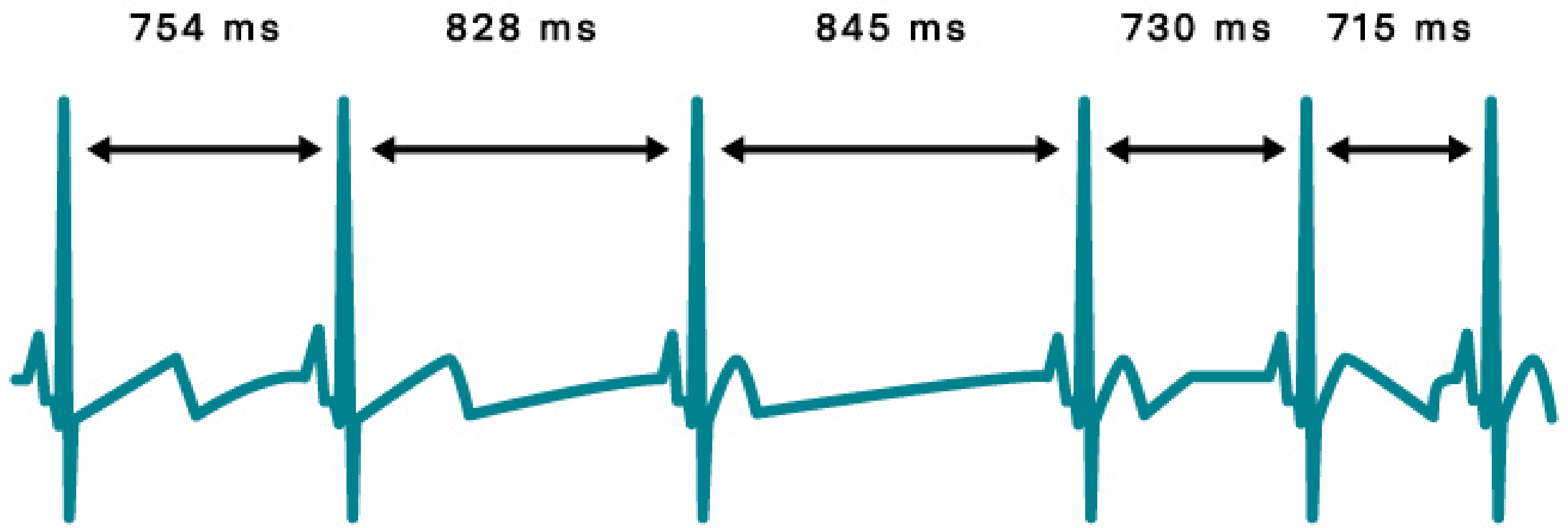
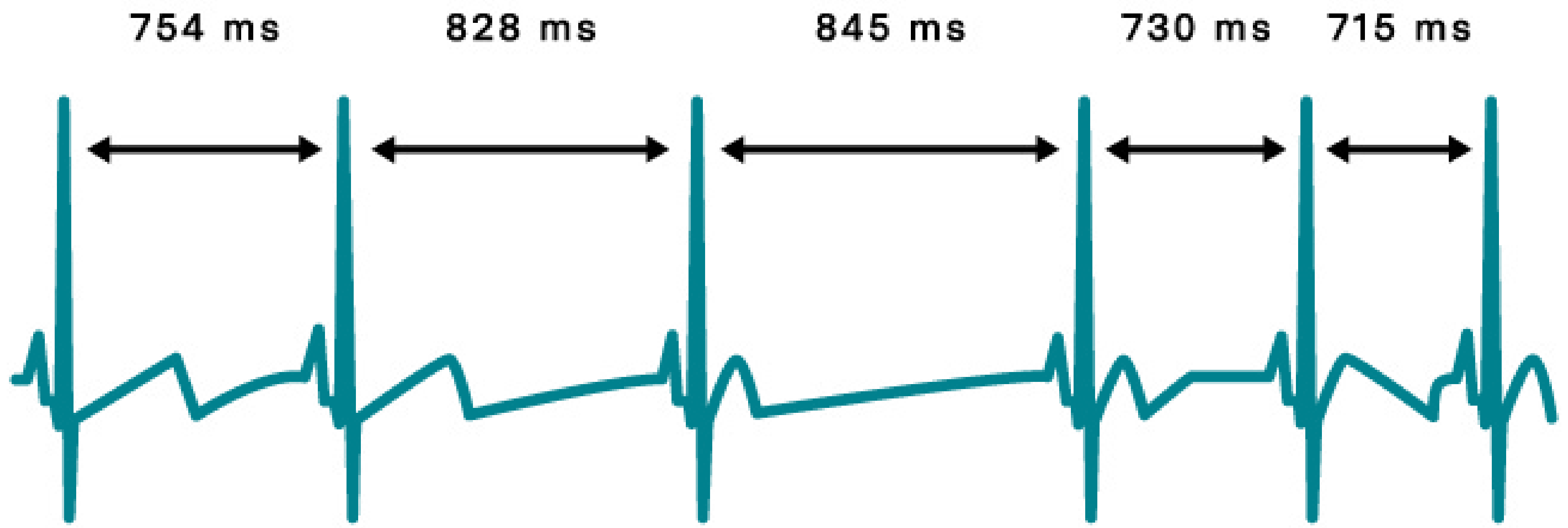
Heart Rate Variability (HRV)



Heart Rate Variability (HRV)

- HRV: variation in time between successive heartbeats (time-domain measures, frequency-domain measures, non-linear measures)
- indicator for the adaptability of the autonomic nervous system



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Heart Rate Variability (HRV)

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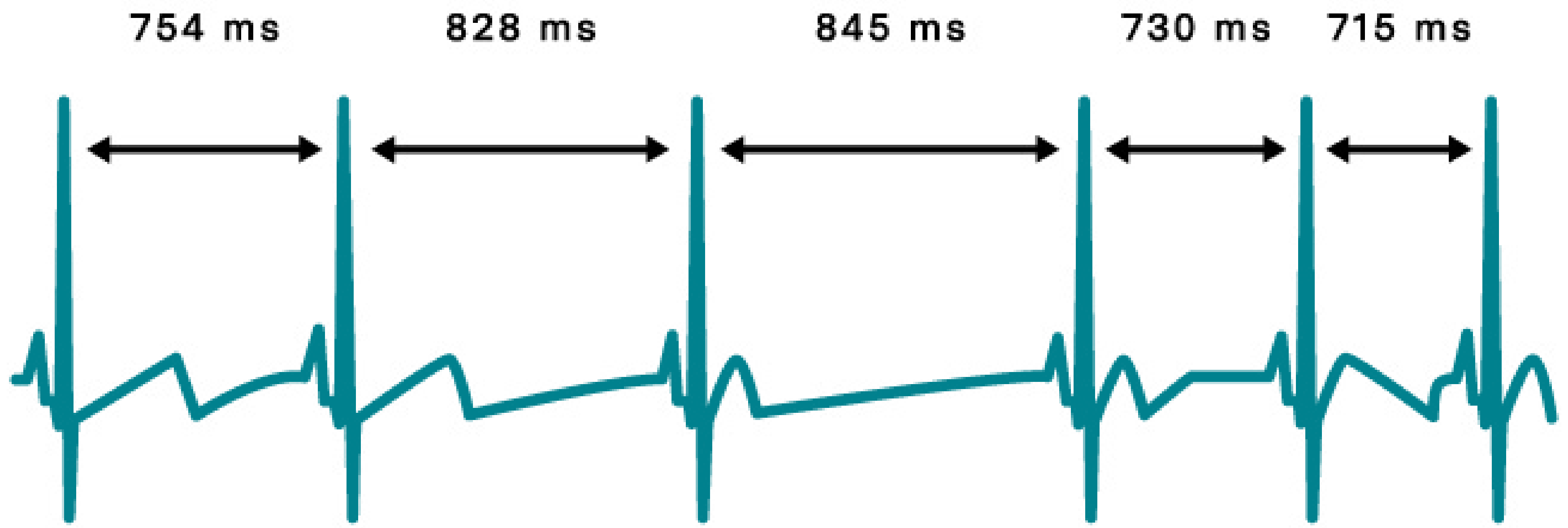
Spectral Features

- High Frequency: 0.15–0.40 Hz
- Low Frequency: 0.04–0.15 Hz
- LF/HF: ratio between them



Statistical Features

- SDSD: Standard Deviation of Successive Differences
- RMSSD: Root Mean Square of Successive Differences
- pnn50: % of successive NN intervals that differ by more than 50 ms

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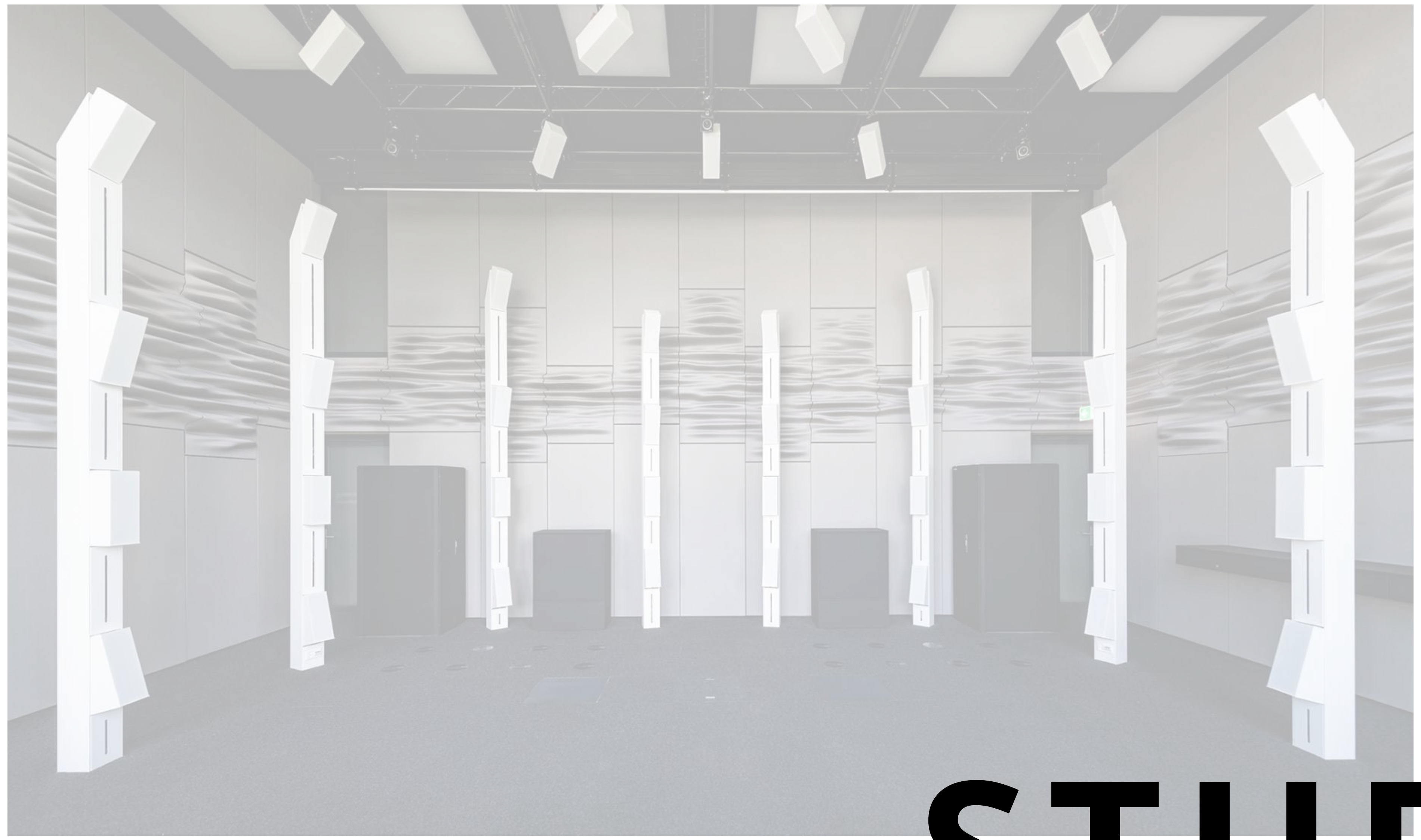
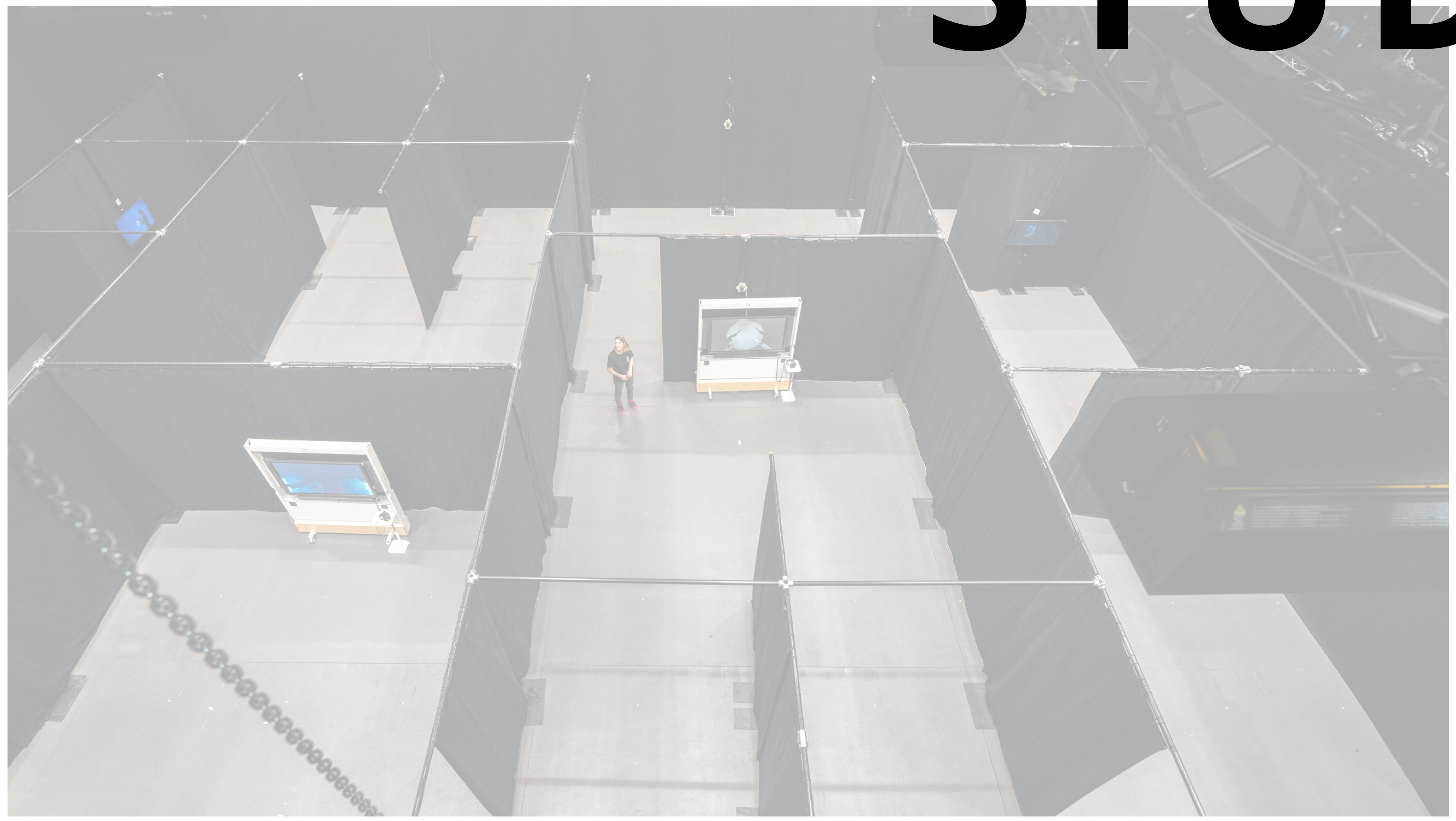
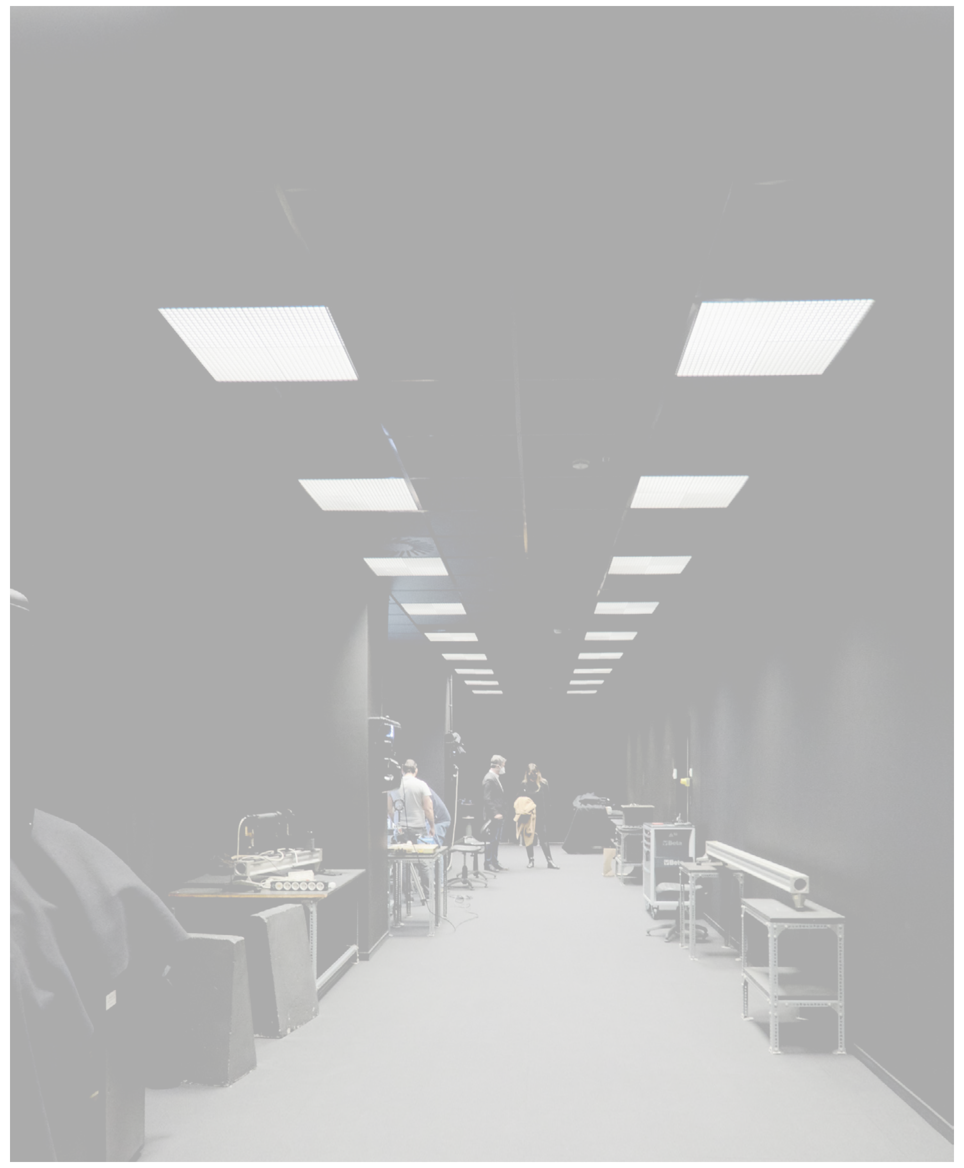
Building Technology
2025



STUDY DESIGN

Infrastructure

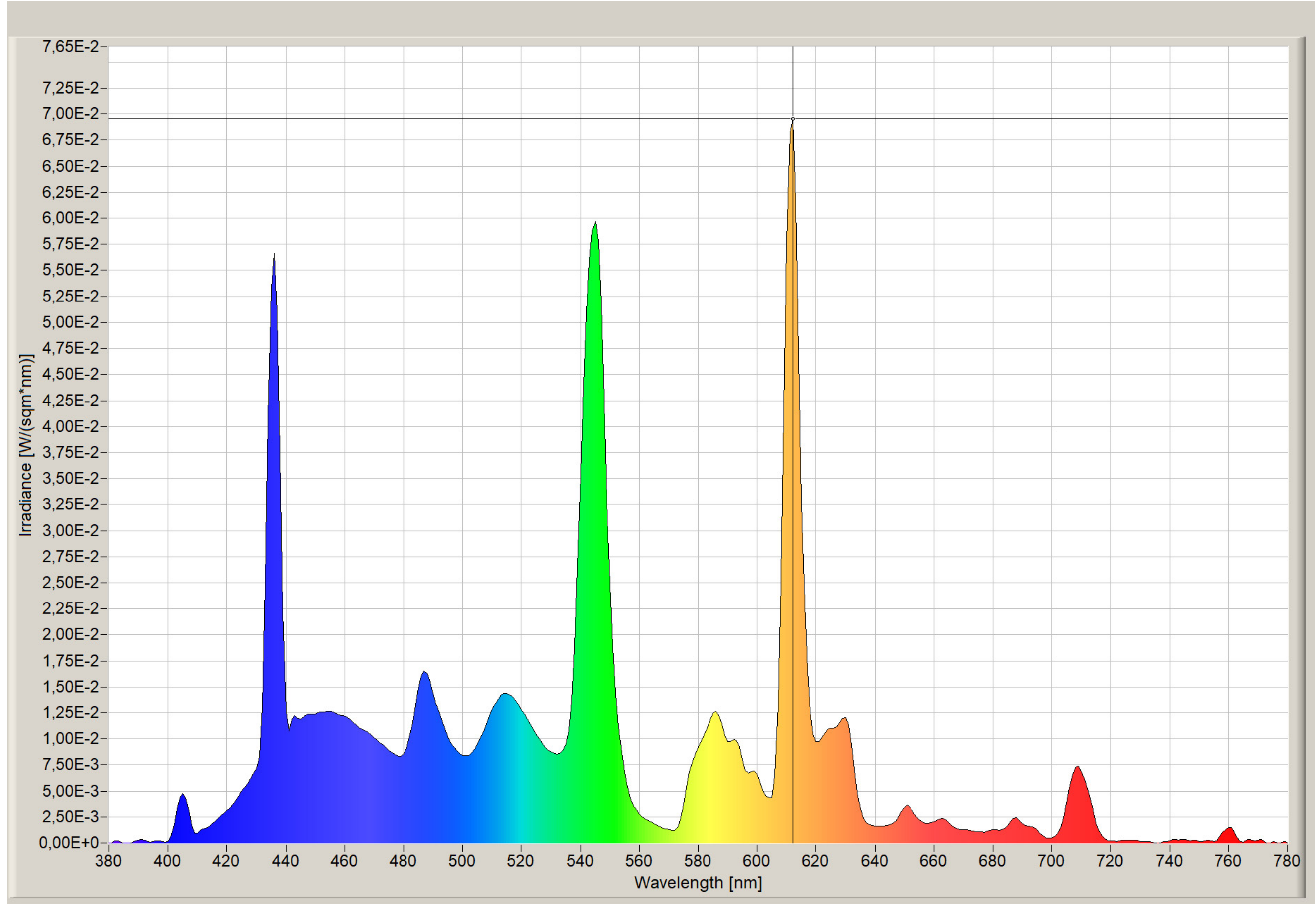
Lighting Lab - TU Eindhoven

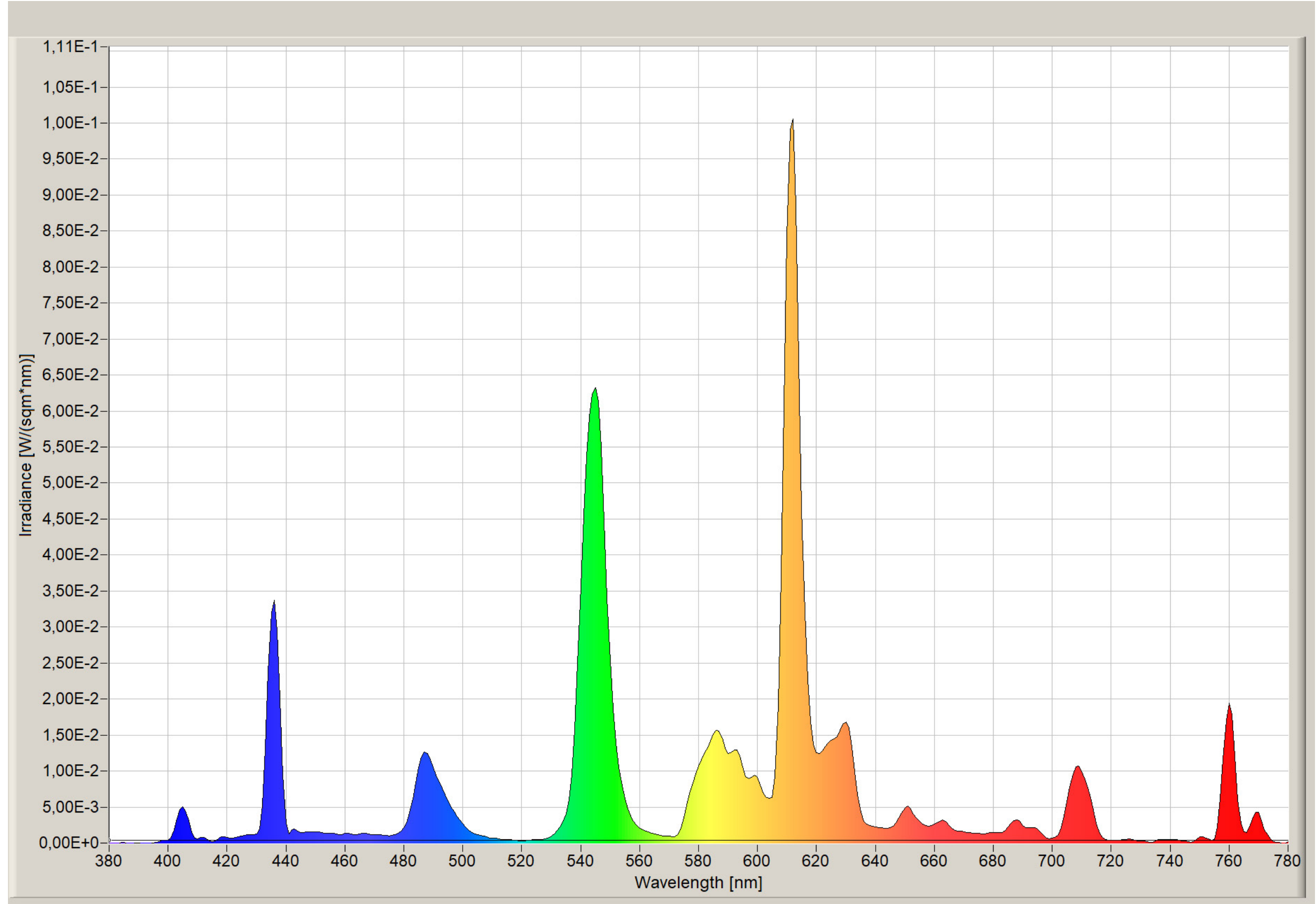
Infrastructure

Lighting Lab - TU Eindhoven

Illuminance: 1000 lx (vertically measured on table height) = recommended for high-precision work (ISO 8995 / CIE S 008 and EN 12464-1)

CCT: 6000 K (blue) and 2700 K (yellow)





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Building Technology
2025

Stressor Simulation

Space Medicine

- Head-Down Tilt Bed Rest
- Lower Body Positive Pressure
- Dry Immersion

Extended Reality

- VR, MR, AR
- Physical Mock-ups

Psychology

- Trier Social Stress Test (TSST)
- Maastricht Acute Stress Test (MAST)
- Mannheim Multicomponent Stress Test (MMST)
- Cold Pressor Test (CPT)
- Mental Arithmetic Test (MAT)

Fernandez-Gonzalo, R., Deane, C. S., & Bailey, D. M. (2024). Experimental bed rest as a model to investigate mechanisms of, and countermeasures against, microgravity and disease-free inactivity. Experimental Physiology, 109(5), 647–649. https://doi.org/10.1113/EP091795
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Xie, L., Liu, B., Wang, X., Mei, M., Li, M., Yu, X., & Zhang, J. (2017). Effects of different stresses on cardiac autonomic control and cardiovascular coupling. Journal of Applied Physiology, 122(3), 435–445. https://doi.org/10.1152/japplphysiol.00245.2016

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Feasibility + HRV Effect

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Psychology

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- Maastricht Acute Stress Test (MAST)
- Mannheim Multicomponent Stress Test (MMST)
- Cold Pressor Test (CPT)
- Mental Arithmetic Test (MAT) → Sympathetic activation, reduced vagal tone and parasympathetic withdrawal, decrease in baroreflex sensitivity

Feasibility + HRV Effect

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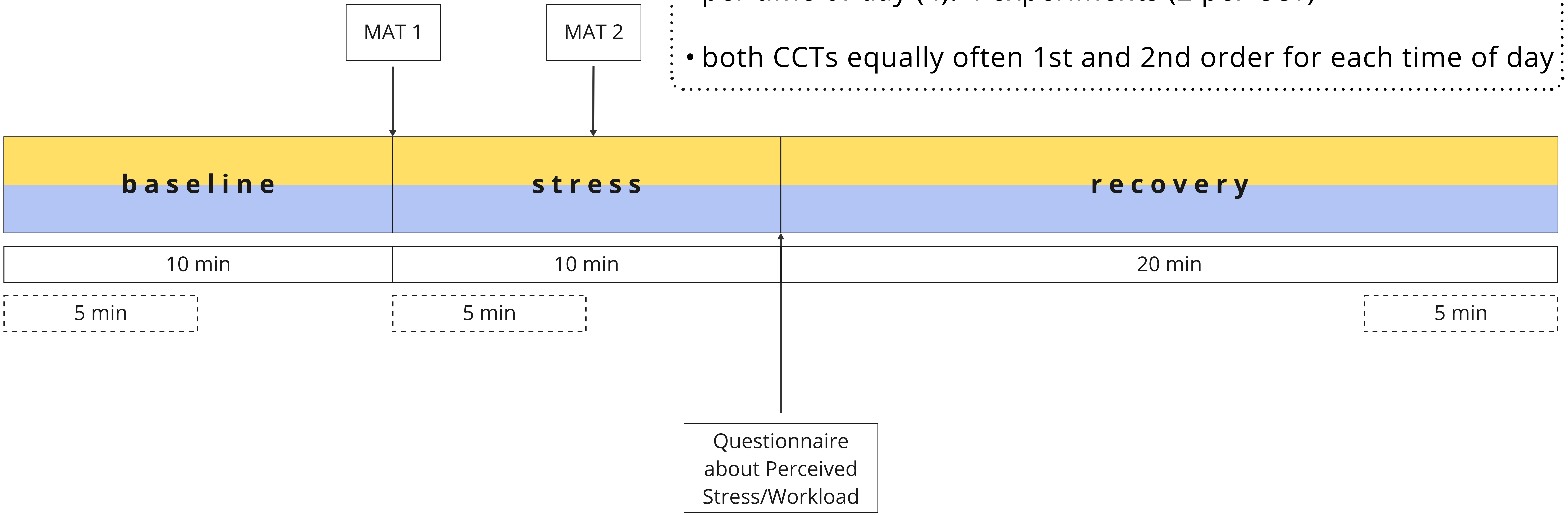
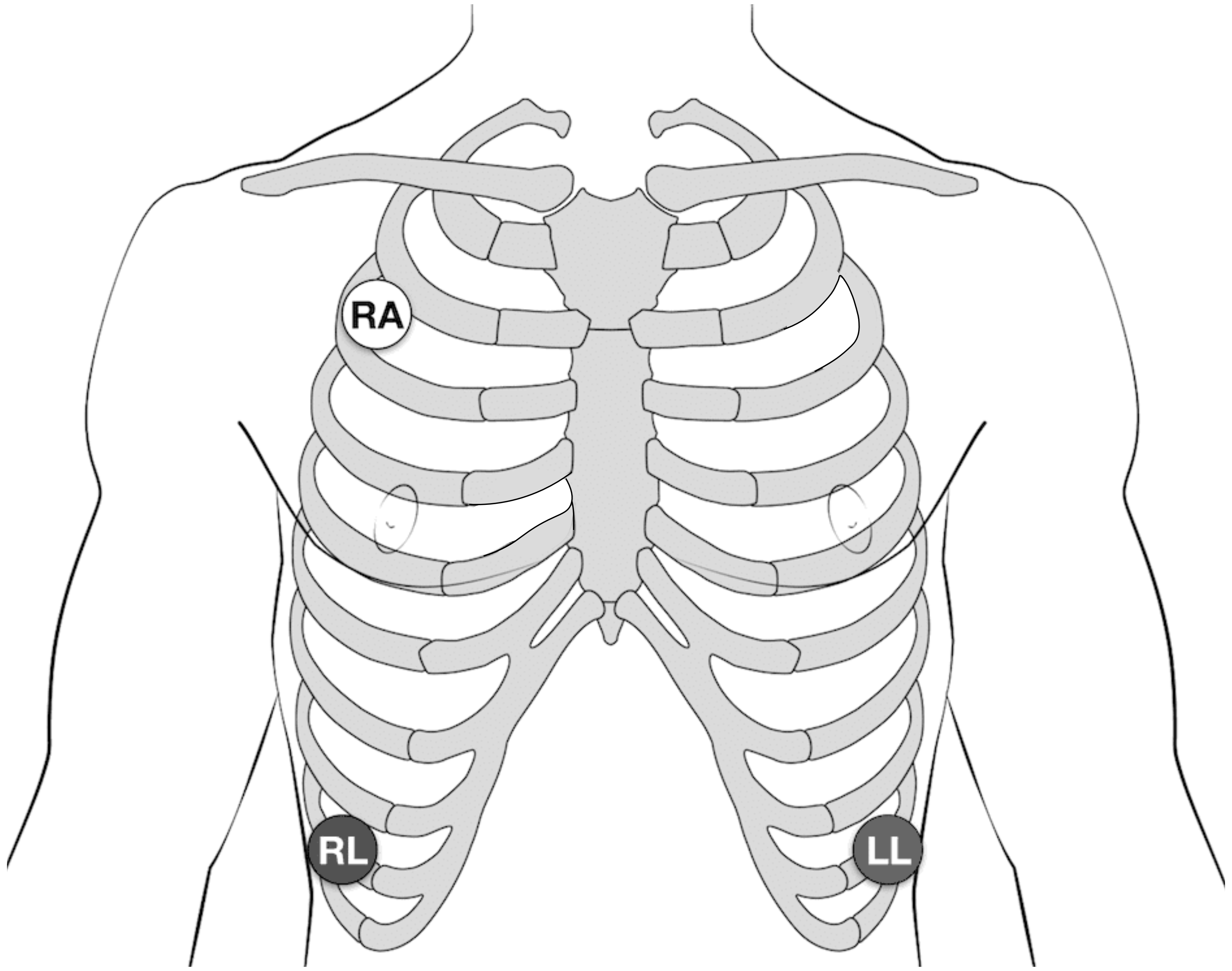
Study Conduction

- 8 participants, 3 women and 5 men (23.6 ± 2.6 years old)
- per time of day (4): 4 experiments (2 per CCT)
- both CCTs equally often 1st and 2nd order for each time of day



Data Collection

Electrocardiogramm (ECG) with
three electrodes
(Biopac Systems from BioNomadix)



Heart Rate Variability

Statistical Features

- **RMSSD**: higher values indicate higher vagal activity (rest state)
- pnn50: higher values indicate higher variability (rest state)

Spectral Features

- **High Frequency**: strong parasympathetic control
- LF/HF: balance between sympathetic and parasympathetic nervous system activity (simplified)

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Data Collection

Heart Rate Variability (HRV)

Electrocardiogram

Pedersen, H. S., Christensen, K. S., Prior, A., & Christensen, K. B. (2024). The dimensionality of the Perceived Stress Scale: The presence of opposing items is a source of measurement error. Journal of Affective Disorders, 344, 485–494. https://doi.org/10.1016/j.jad.2023.10.109
Shahid, A., Wilkinson, K., Marcu, S., & Shapiro, C. M. (2011). State-Trait Anxiety Inventory (STAI). In A. Shahid, K. Wilkinson, S. Marcu, & C. M. Shapiro (Eds.), STOP, THAT and One Hundred Other Sleep Scales (pp. 367–368). Springer New York. https://doi.org/10.1007/978-1-4419-9893-4_90
Hart, S. G., & Field, M. (n.d.). Nasa-Task Load Index (NASA-TLX); 20 Years Later.

Data Collection

Heart Rate Variability (HRV)

Perceived stress last month (PSS)

Perceived stress/workload during experiment (PSW)

Electrocardiogram

Perceived Stress Scale (PSS-10)

NASA Task Load Index (TLX), Stait Trait Anxiety Inventory (STAI), Subjective Units of Distress (SUD)

Pedersen, H. S., Christensen, K. S., Prior, A., & Christensen, K. B. (2024). The dimensionality of the Perceived Stress Scale: The presence of opposing items is a source of measurement error. Journal of Affective Disorders, 344, 485–494. https://doi.org/10.1016/j.jad.2023.10.109
Shahid, A., Wilkinson, K., Marcu, S., & Shapiro, C. M. (2011). State-Trait Anxiety Inventory (STAI). In A. Shahid, K. Wilkinson, S. Marcu, & C. M. Shapiro (Eds.), STOP, THAT and One Hundred Other Sleep Scales (pp. 367–368). Springer New York. https://doi.org/10.1007/978-1-4419-9893-4_90
Hart, S. G., & Field, M. (n.d.). Nasa-Task Load Index (NASA-TLX); 20 Years Later.

Data Collection

Heart Rate Variability (HRV)	Perceived stress last month (PSS)	Perceived stress/workload during experiment (PSW)	Cognitive performance (CP)	Chronotype (CHT)
Electrocardiogram	Perceived Stress Scale (PSS-10)	NASA Task Load Index (TLX), Stait Trait Anxiety Inventory (STAI), Subjective Units of Distress (SUD)	Performance in the Mental Arithmetic Test (MAT)	Morningness Eveningness Questionnaire (MEQ)

Pedersen, H. S., Christensen, K. S., Prior, A., & Christensen, K. B. (2024). The dimensionality of the Perceived Stress Scale: The presence of opposing items is a source of measurement error. Journal of Affective Disorders, 344, 485–494. https://doi.org/10.1016/j.jad.2023.10.109
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Limitations

General

- small number of participants
- per time of day (4): 4 experiments (2 per CCT)

Biomarker - HRV

- short-term measurements (2 x)
- potentially influenced by factors outside the researcher‘s control

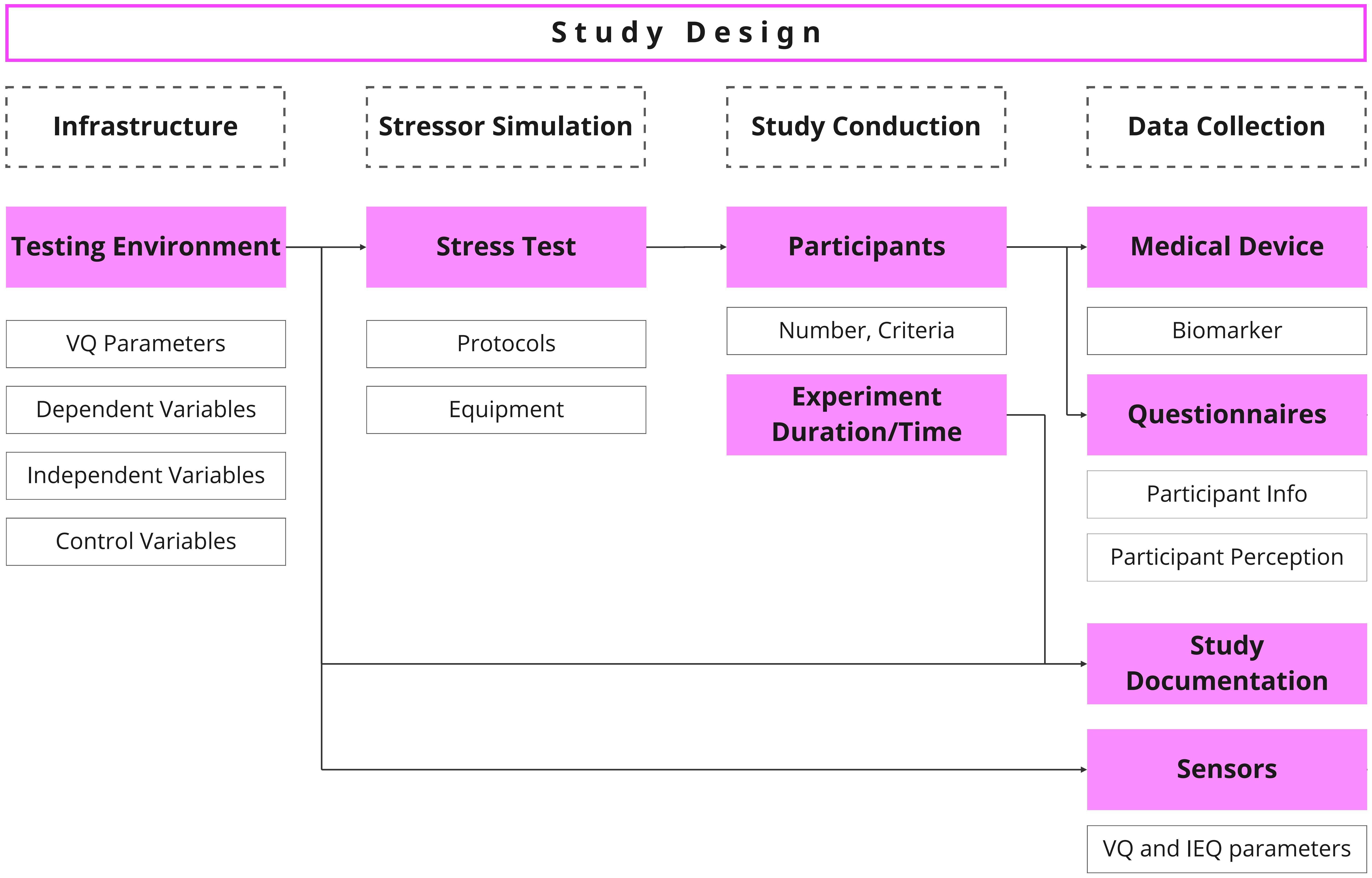
Stressor Simulation

- psychological tests leave room for subtle execution differences
- individual reactions to that type of task

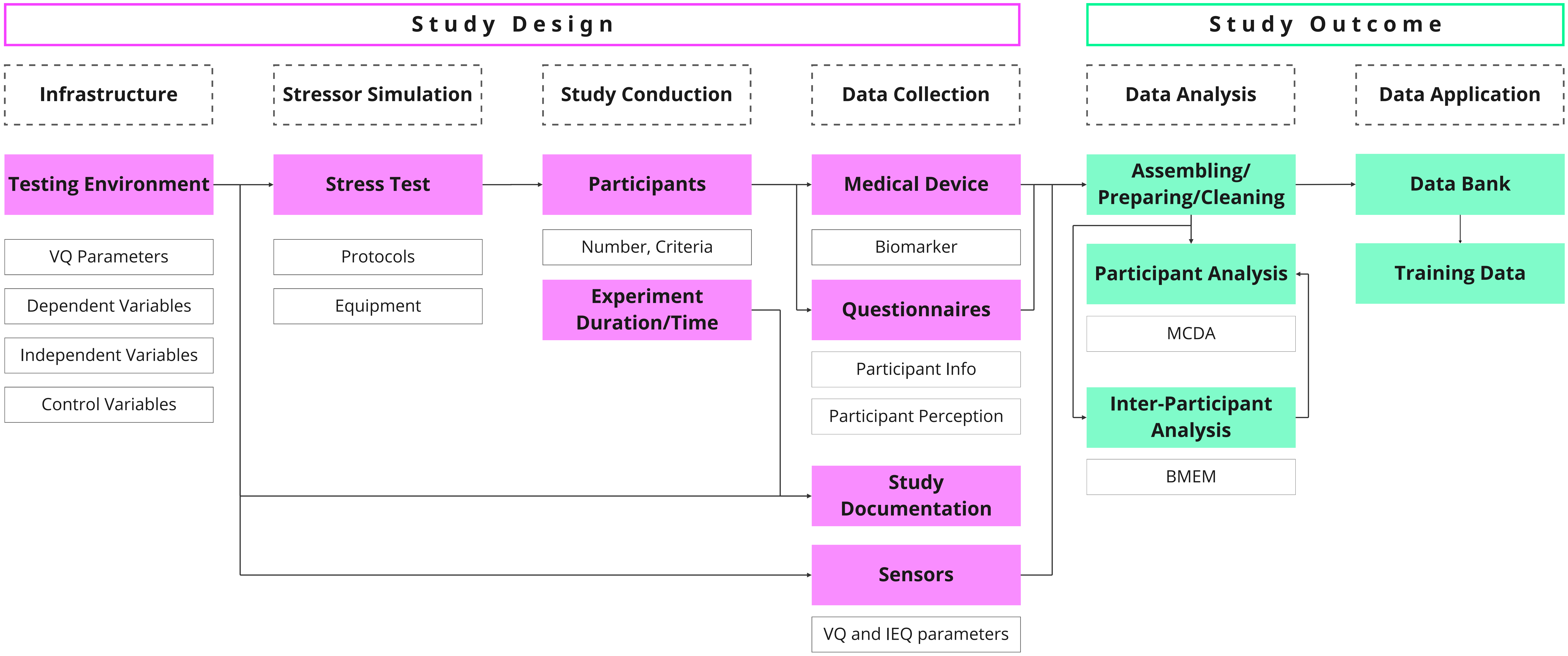
Visual Quality - CCT

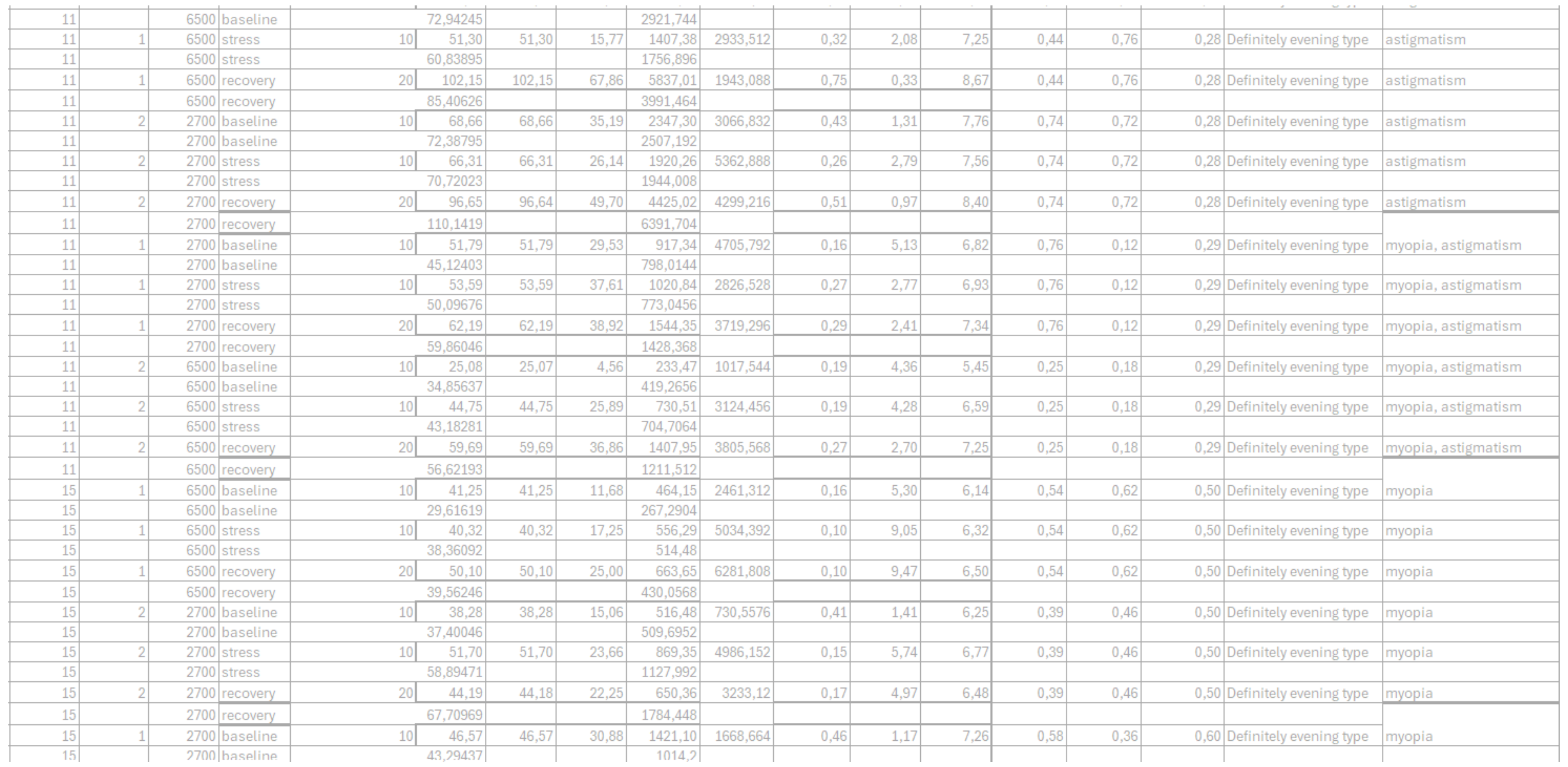
- influence of CCT on circadian rhythm
- baseline-HRV recorded in the corresponding CCT
- potential fluroscent light fluctuations in the lab

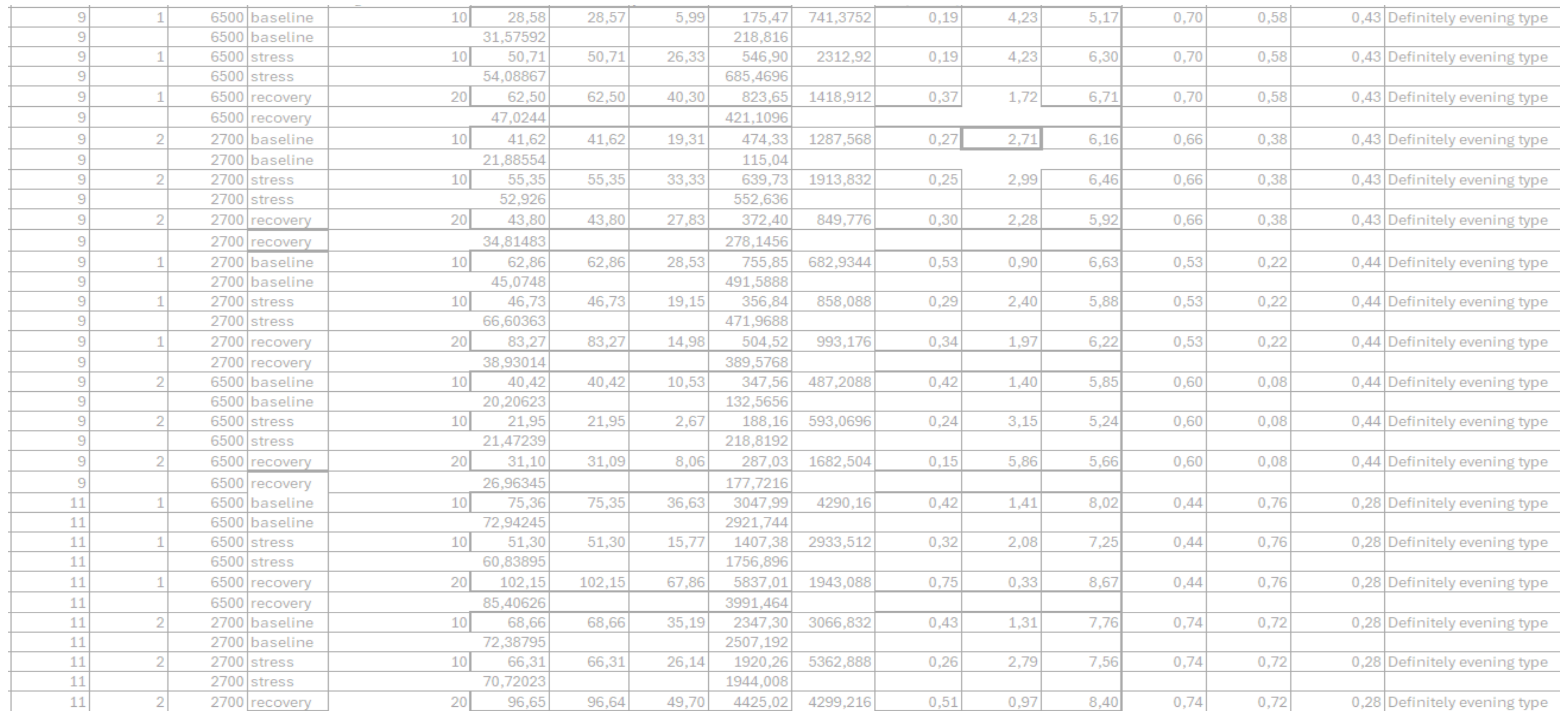
Research Framework Applied on CCT and HRV

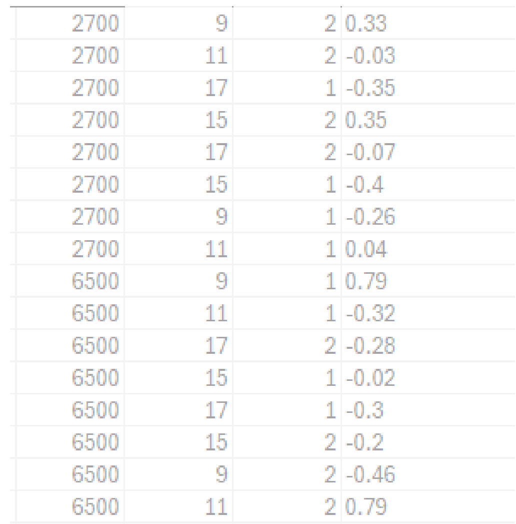


Research Framework Applied on CCT and HRV

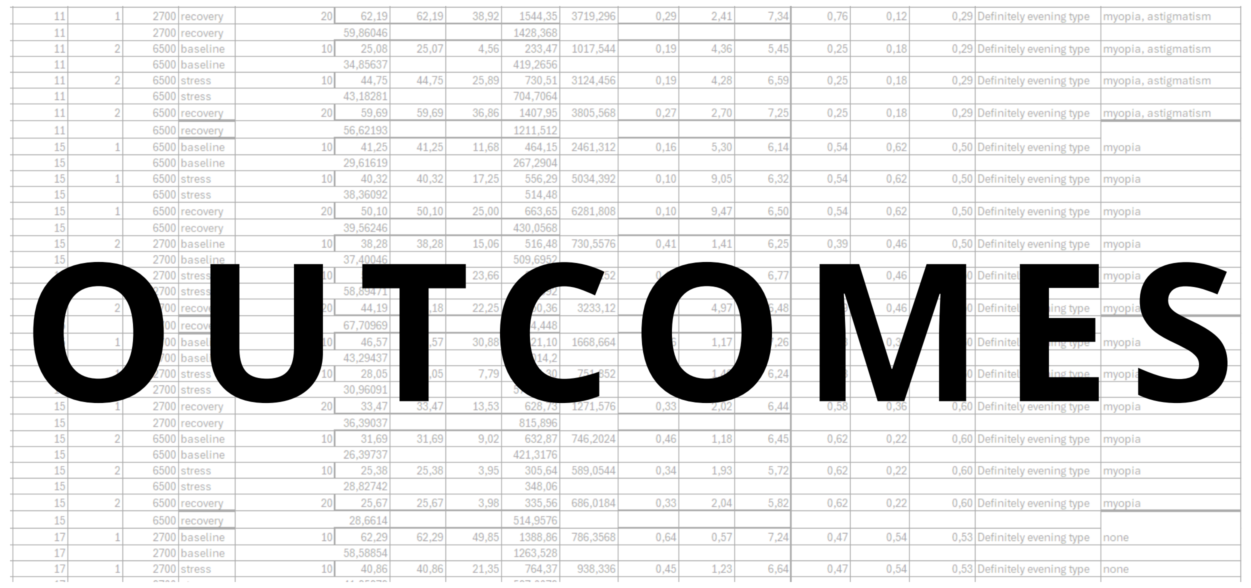


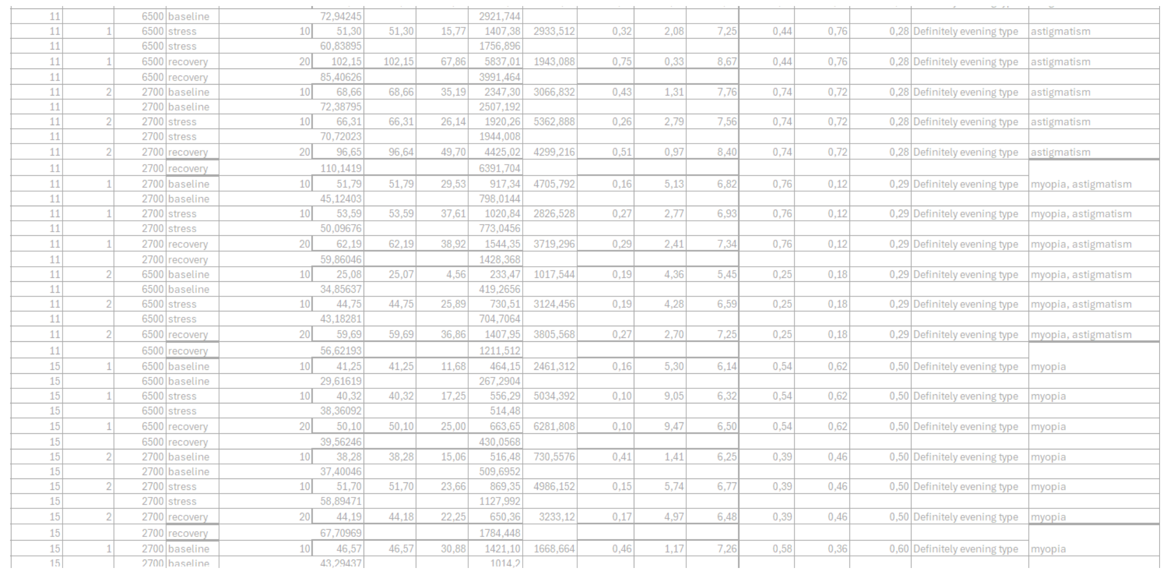


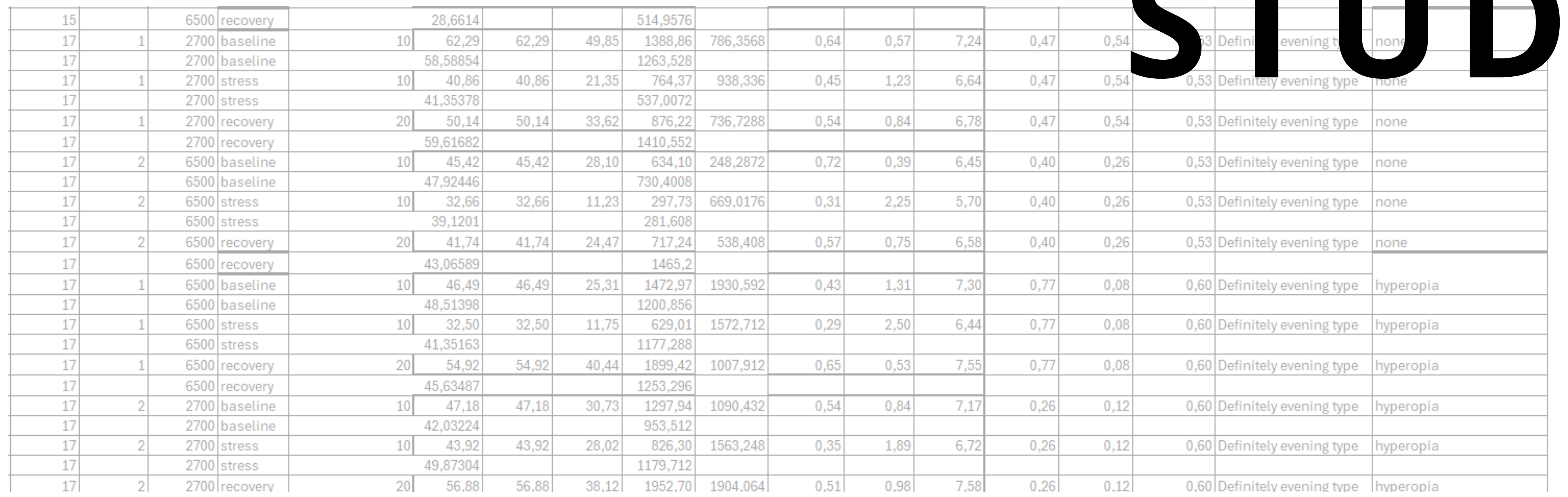




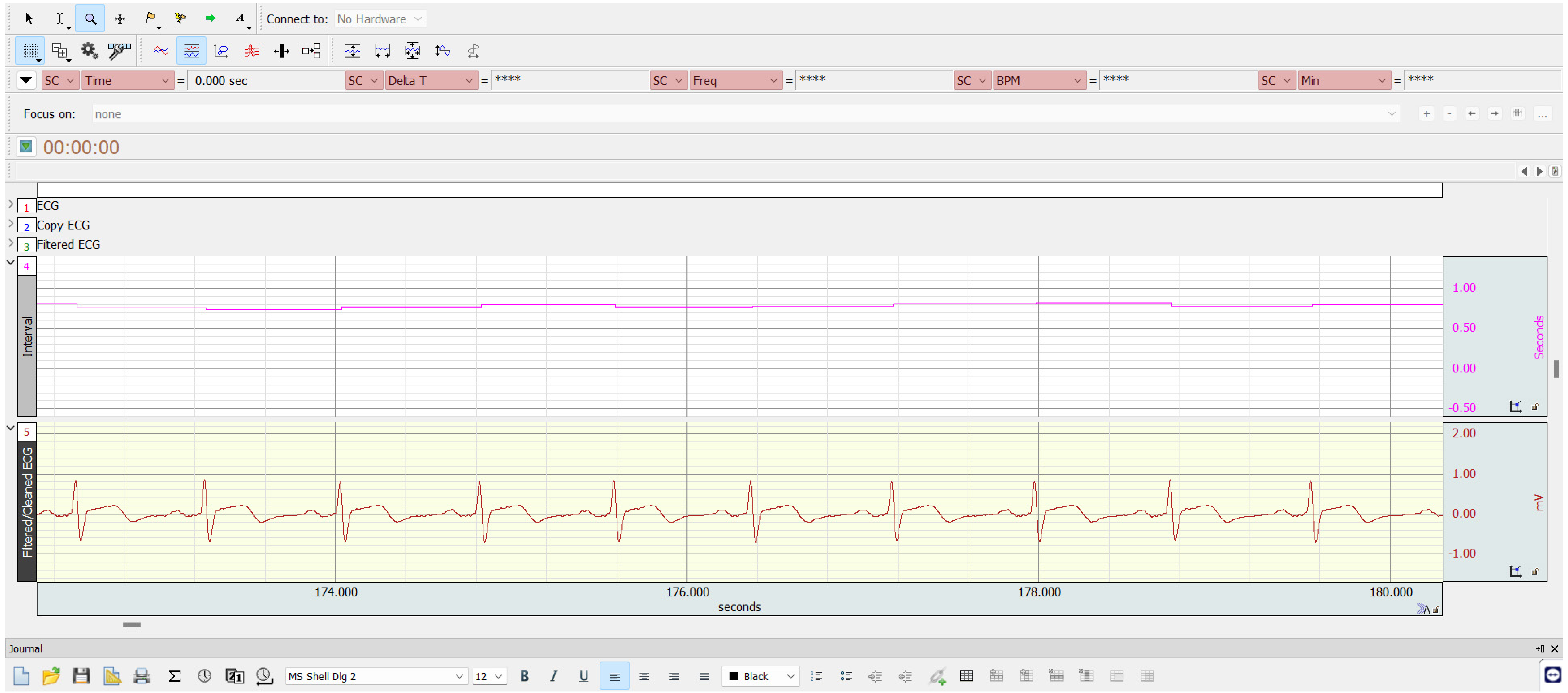
STUDY OUTCOMES







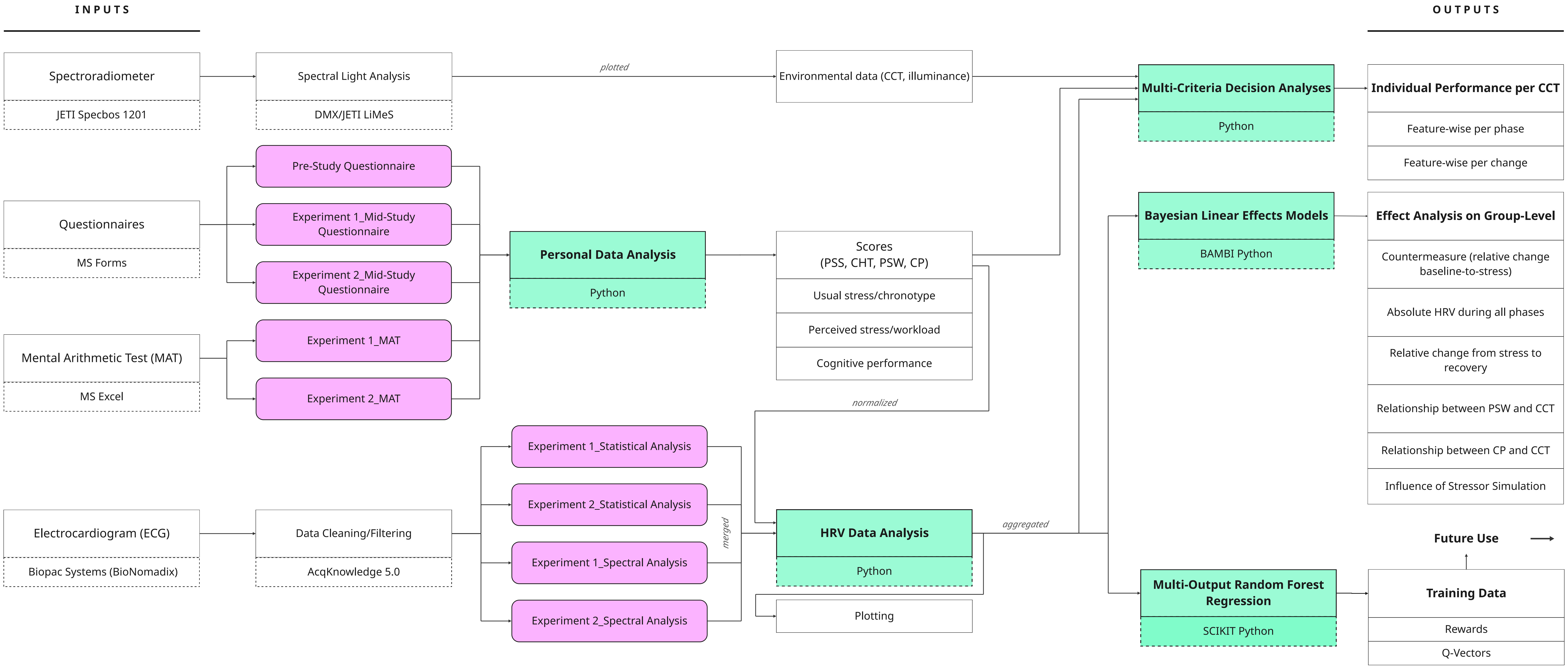
Data Preparation



AcqKnowledge 5.0

- bandpassfilter (between 0.5 and 35 Hz)
- artifact removal
- statistical and spectral analysis in 5-min sequences

Data Analysis



Data Overview

6/8
participants

HRV-**decrease** during stress in both experiments

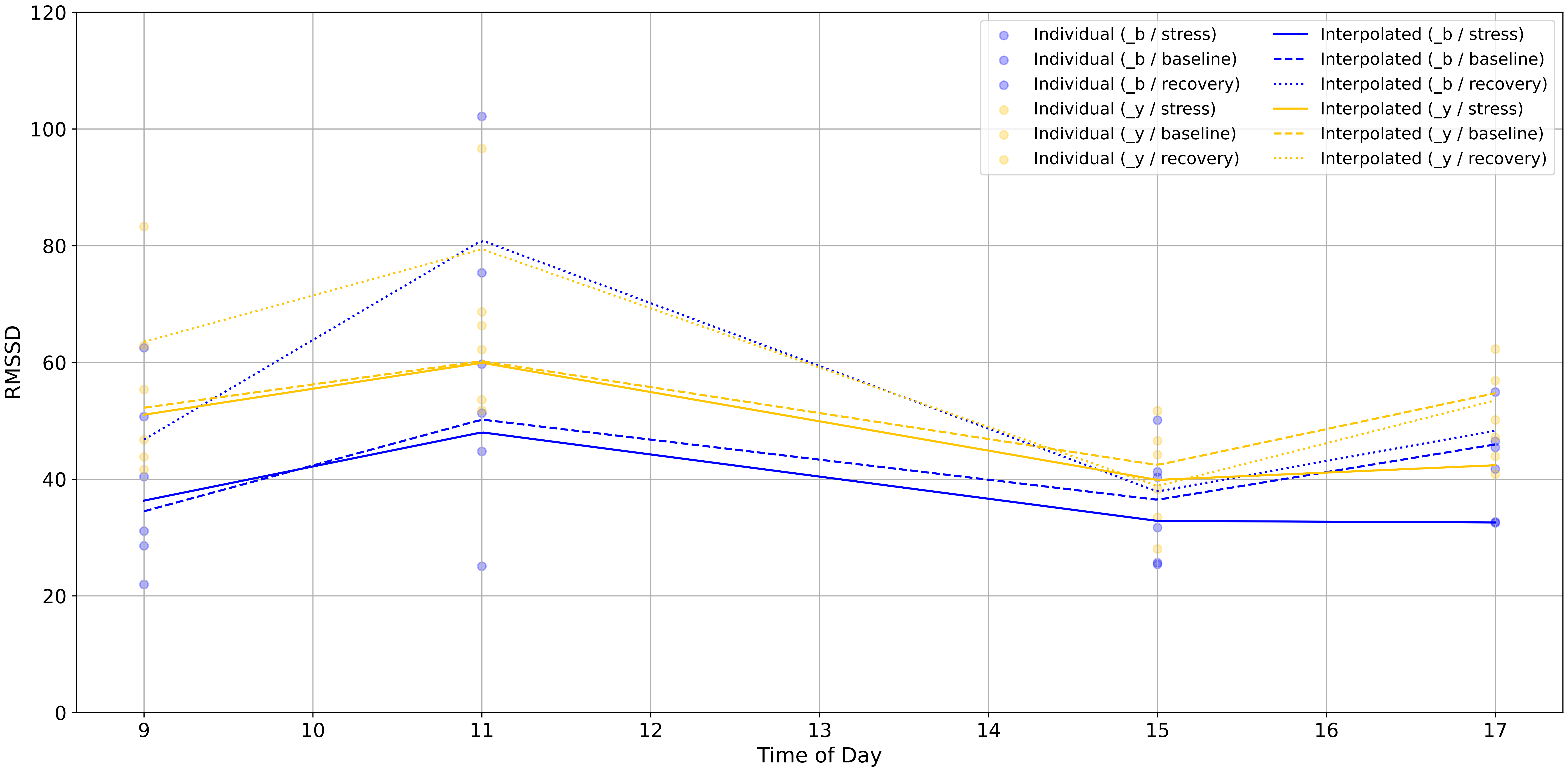
1/8
participants

HRV-**increase** during stress in both experiments

1/8
participants

HRV-**decrease** during stress in the first experiment,
HRV-**increase** in the second experiment

Data Overview



RMSSD fluctuations depending on the Time of Day and three phases (baseline, stress and recovery) in both CCTs (2700 K and 6000 K)

wide range of baseline- HRVs (but consistent per person in both experiments)

Data Overview

	Phase	CCT		Time of Day		Order	
		2700 K	6000 K	Morning	Afternoon	1	2
RMSSD [ms]	baseline	52.41 ± 11.01	41.79 ± 15.68	49.30 ± 18.51	44.90 ± 8.82	51.90 ± 14.61	42.30 ± 12.86
	stress	48.3 ± 11.34	37.45 ± 11.10	48.84 ± 12.67	36.92 ± 8.81	43.01 ± 9.26	42.75 ± 15.28
	recovery	58.82 ± 21.39	53.48 ± 23.65	67.67 ± 24.79	44.64 ± 10.75	62.34 ± 21.42	49.97 ± 22.06
PSW [-]	stress	0.55 ± 0.18	0.54 ± 0.17	0.59 ± 0.17	0.50 ± 0.16	0.60 ± 0.13	0.49 ± 0.19
CP [-]	stress	0.36 ± 0.21	0.35 ± 0.27	0.38 ± 0.27	0.33 ± 0.20	0.41 ± 0.25	0.30 ± 0.21

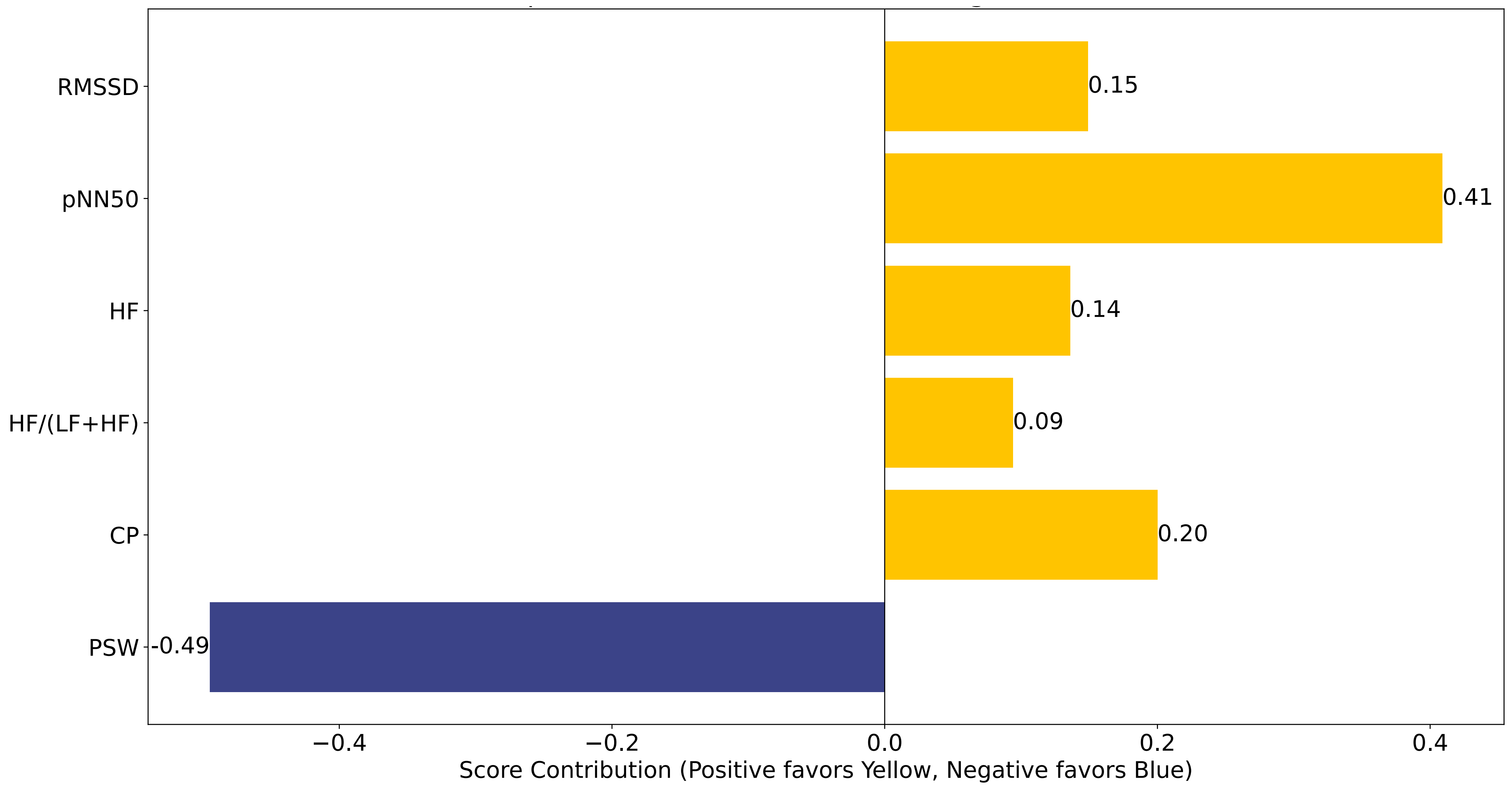
Summary of Iterative Subgroup Analysis for RMSSD, PSW and CP keeping two out of the three categories constant, while comparing the two variables within the remaining category

- PSW/CP largely uneffected
- tendency towards effects of three variables (CCT, time of day, order)
- high standard deviations

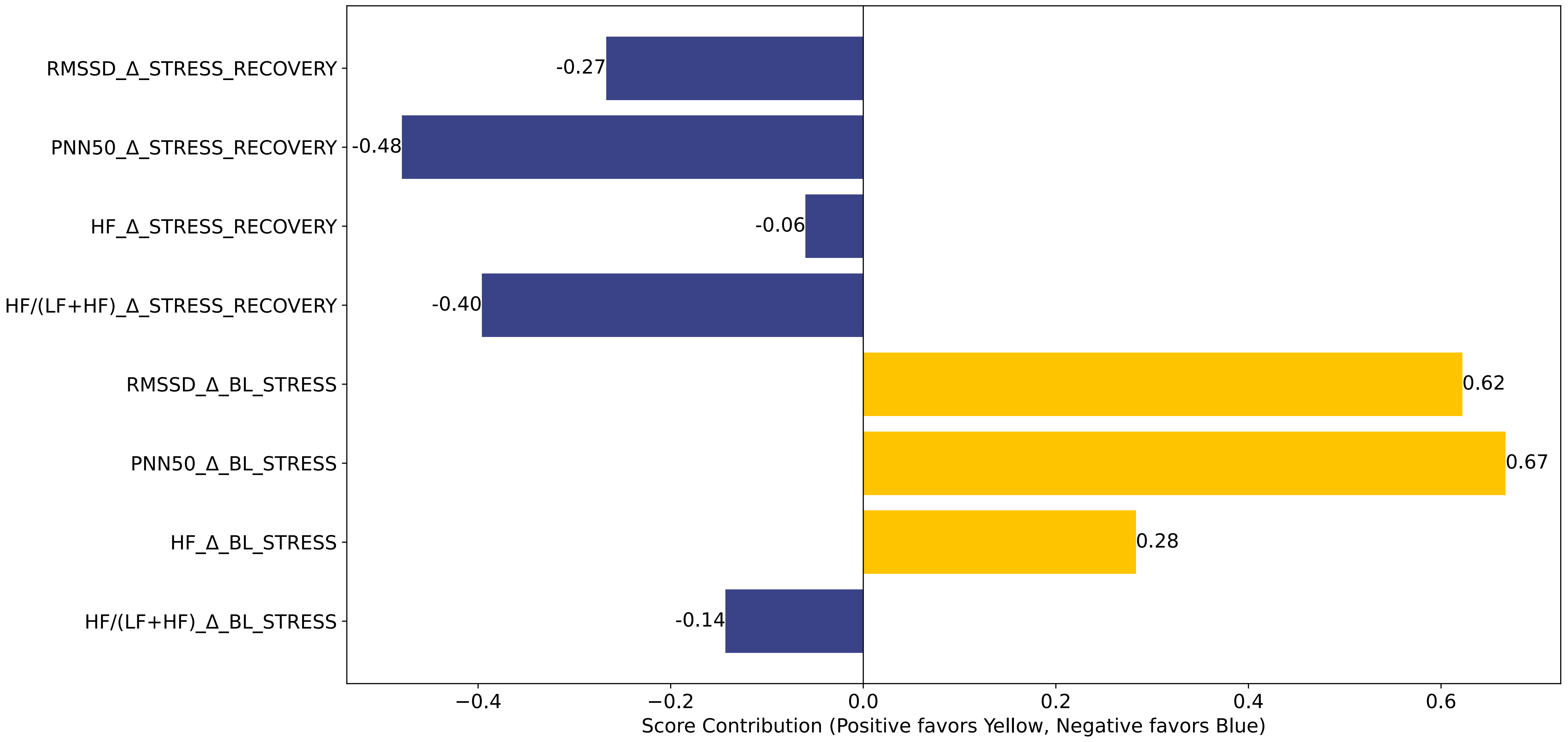
Individual-Level Analysis

Multi-Criteria Decision Analysis

- individual level
- feature level
- interpretation in the study context



HRV Feature Comparison (incl. CP and PSW) during Stress



HRV Feature-Change Comparison between Phases

Individual-Level Analysis

8/8
participants

higher score in the absolute stress-HRV in yellow CCT

4/8
participants

total change-score - considering the change from baseline to stress and change from stress to recovery - was more favourable in yellow CCT

→ **no strong indication**

5/8
participants

perceived stress/workload lower in blue CCT

→ **no strong indication**

Group-Level Analysis

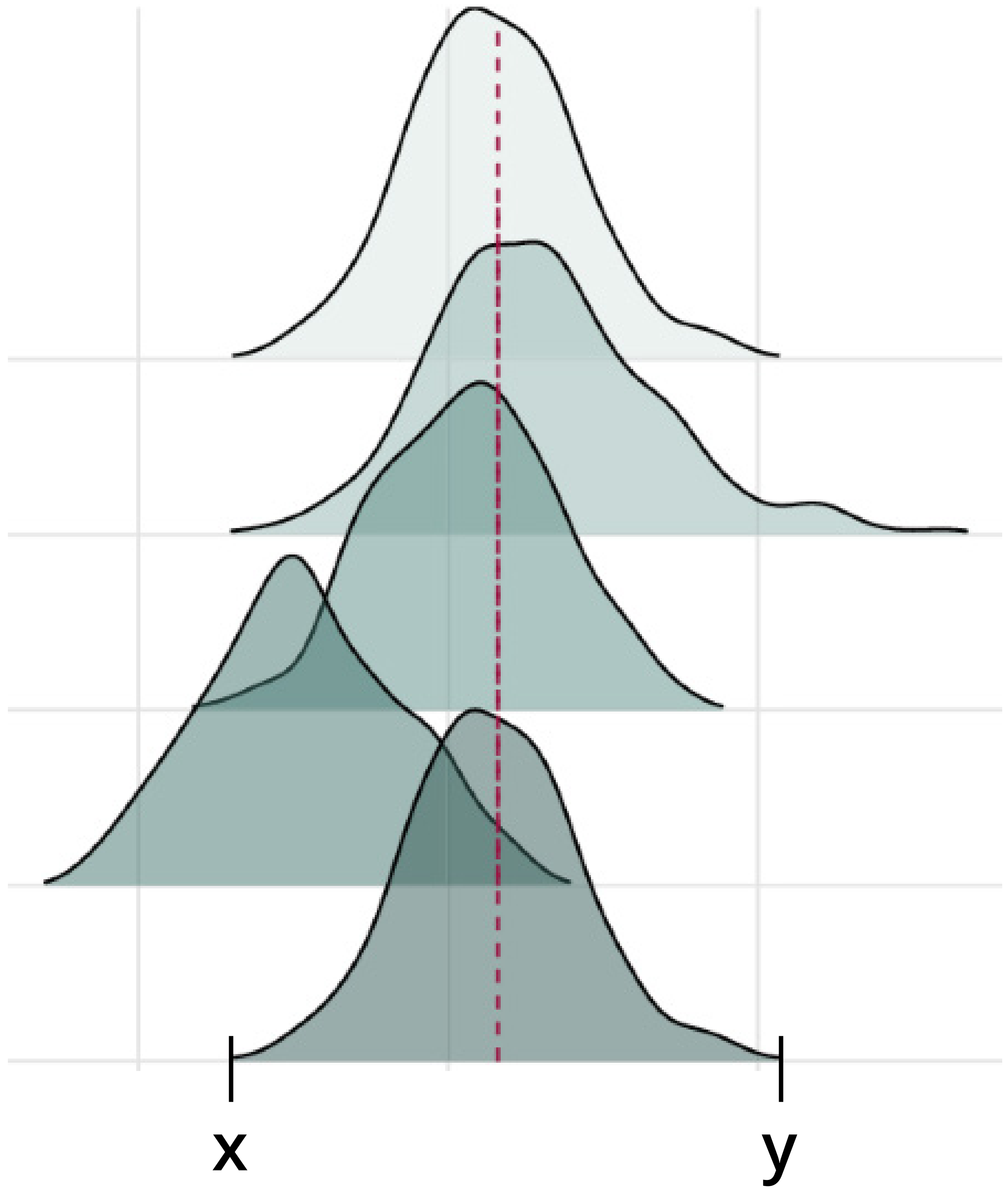
Bayesian Linear Effects Models

RMSSD ~ CCT + ToD + Order

instead of p-value (likelihood of obtaining the observed data):

probability distribution
(with 94 % certainty the value lies between x and y)

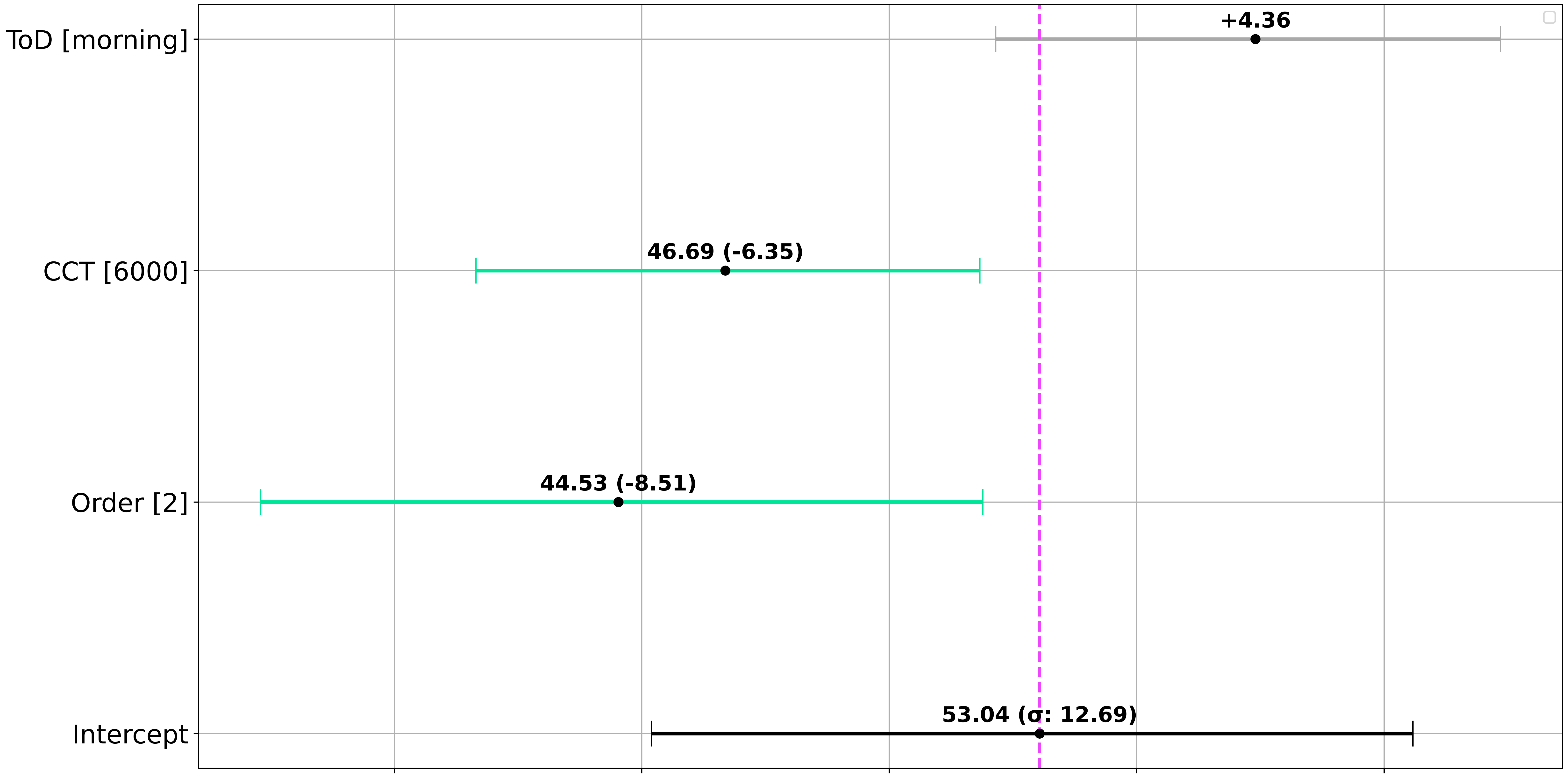
→ effect of variable a, if b and c are already accounted for



Song, Y., Nathoo, F. S., & Masson, M. E. J. (2017). A Bayesian approach to the mixed-effects analysis of accuracy data in repeated-measures designs. Journal of Memory and Language, 96, 78–92. https://doi.org/10.1016/j.jml.2017.05.002

Antonia Sattler
Building Technology
2025

Group-Level Results - Baseline

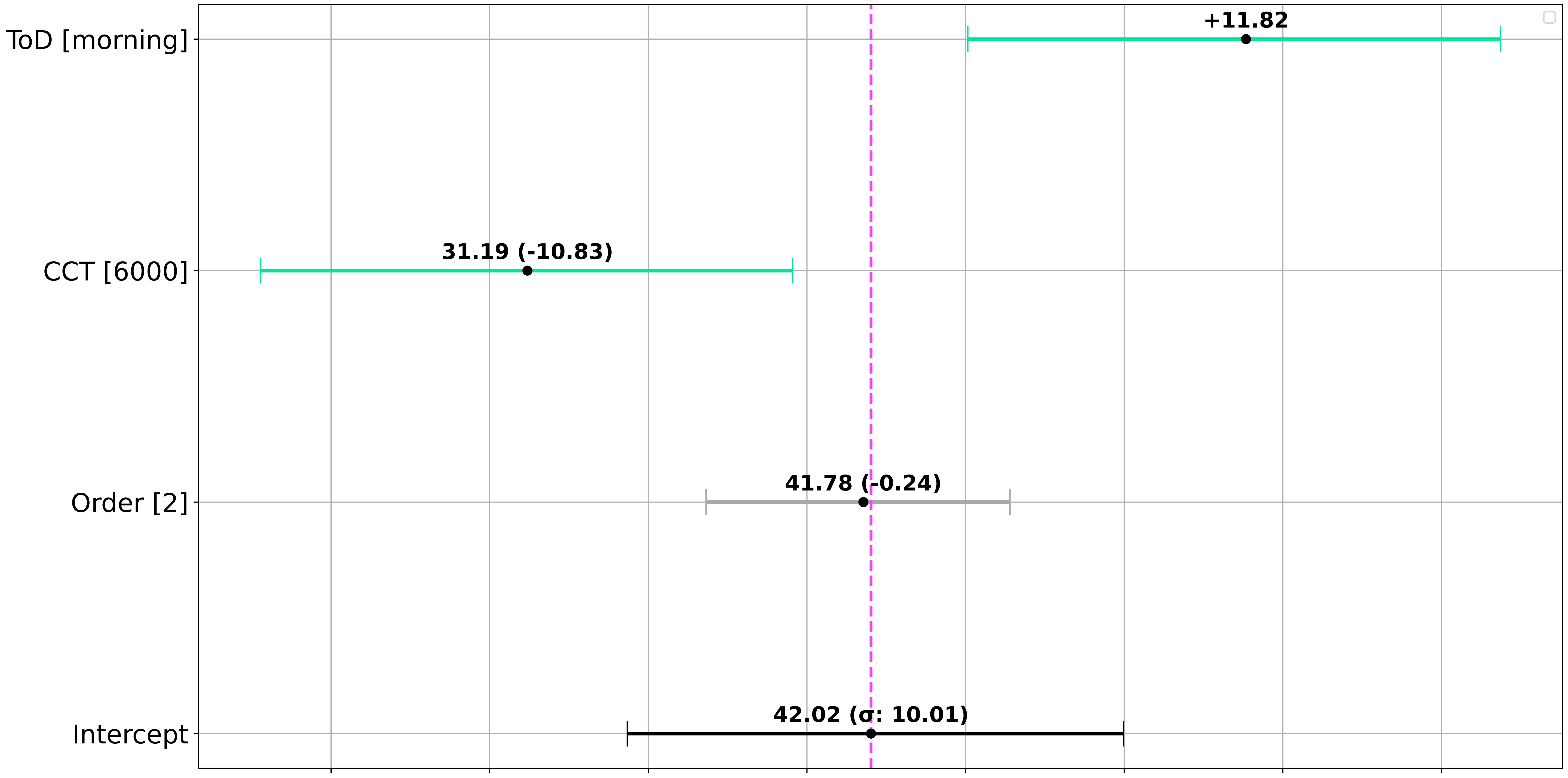


Posterior Estimate for Absolute RMSSD during Baseline (using CCT 2700 K, Order 1 and Afternoon as Time of Day as reference)

94% HDI:

- **clear effect of CCT (lower RMSSD in blue CCT)**
- **clear effect of order (lower RMSSD)**
- **potential effect of time of day**
- **high residual standard error**

Group-Level Results - Stress

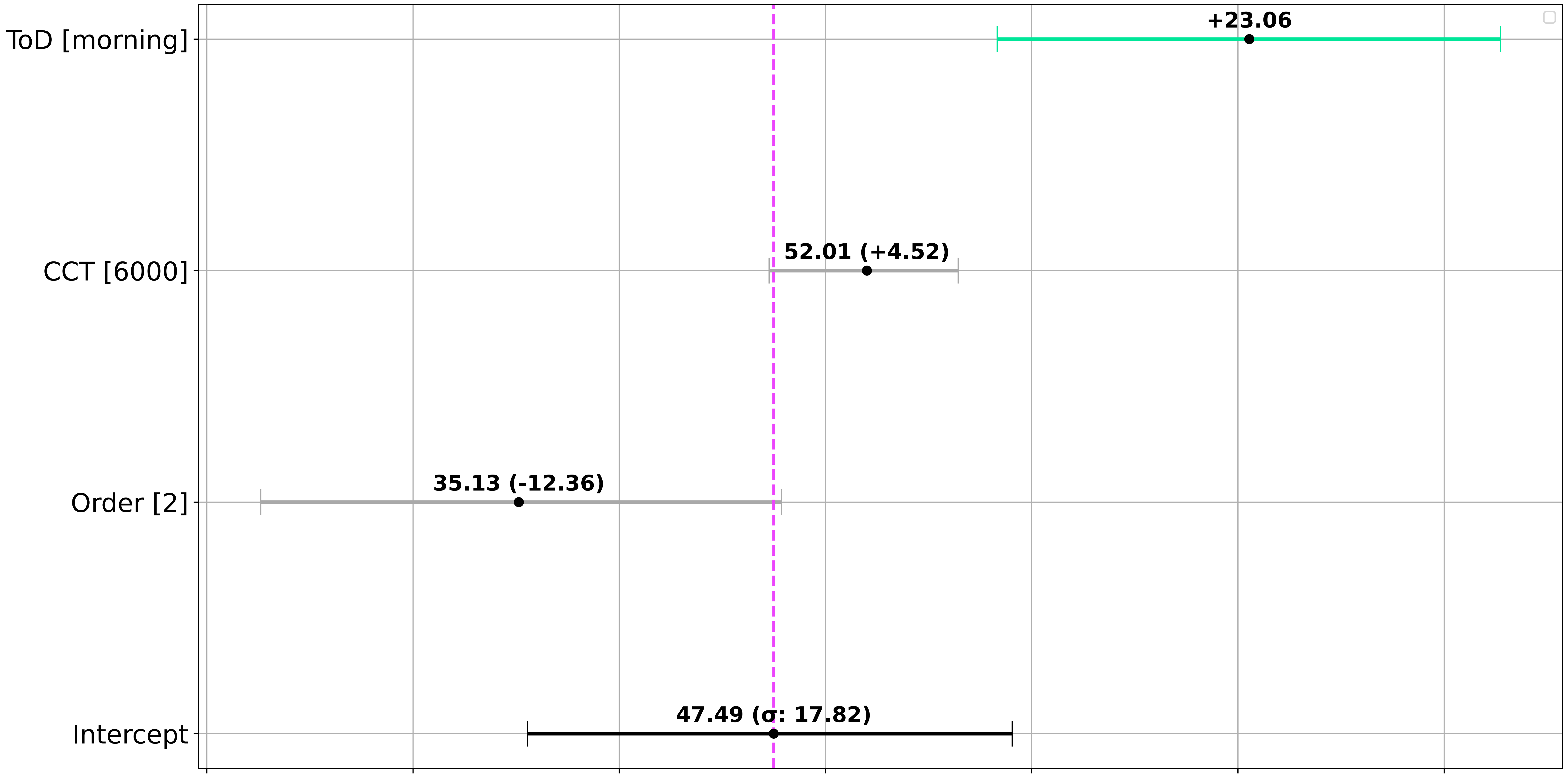


Posterior Estimate for Absolute RMSSD during Stress (using CCT 2700 K, Order 1 and Afternoon as Time of Day as reference)

94% HDI:

- **clear effect of CCT (lower RMSSD in blue CCT)**
- **clear effect of time of day (higher RMSSD in the morning)**
- **unclear effect of order**
- **high residual standard error**

Group-Level Results - Recovery



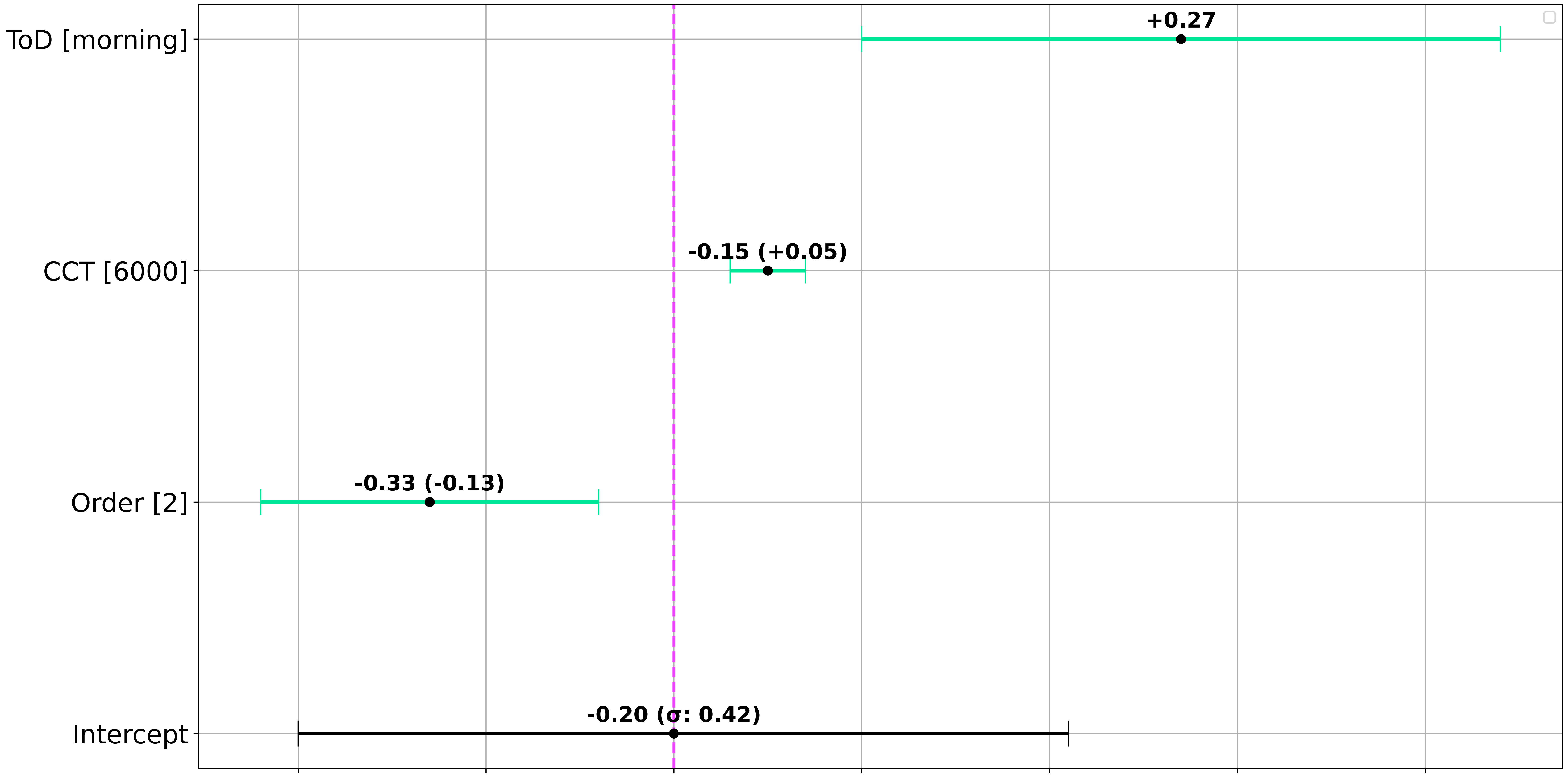
Posterior Estimate for Absolute RMSSD during Recovery (using CCT 2700 K, Order 1 and Afternoon as Time of Day as reference)

94% HDI:

- **clear effect of time of day (higher RMSSD in the morning)**
- **potential effect of CCT**
- **potential effect of order**
- **very high residual standard error**

But what about stress-decrease and recovery-increase?

Group-Level Results - Rel. Change from Baseline to Stress

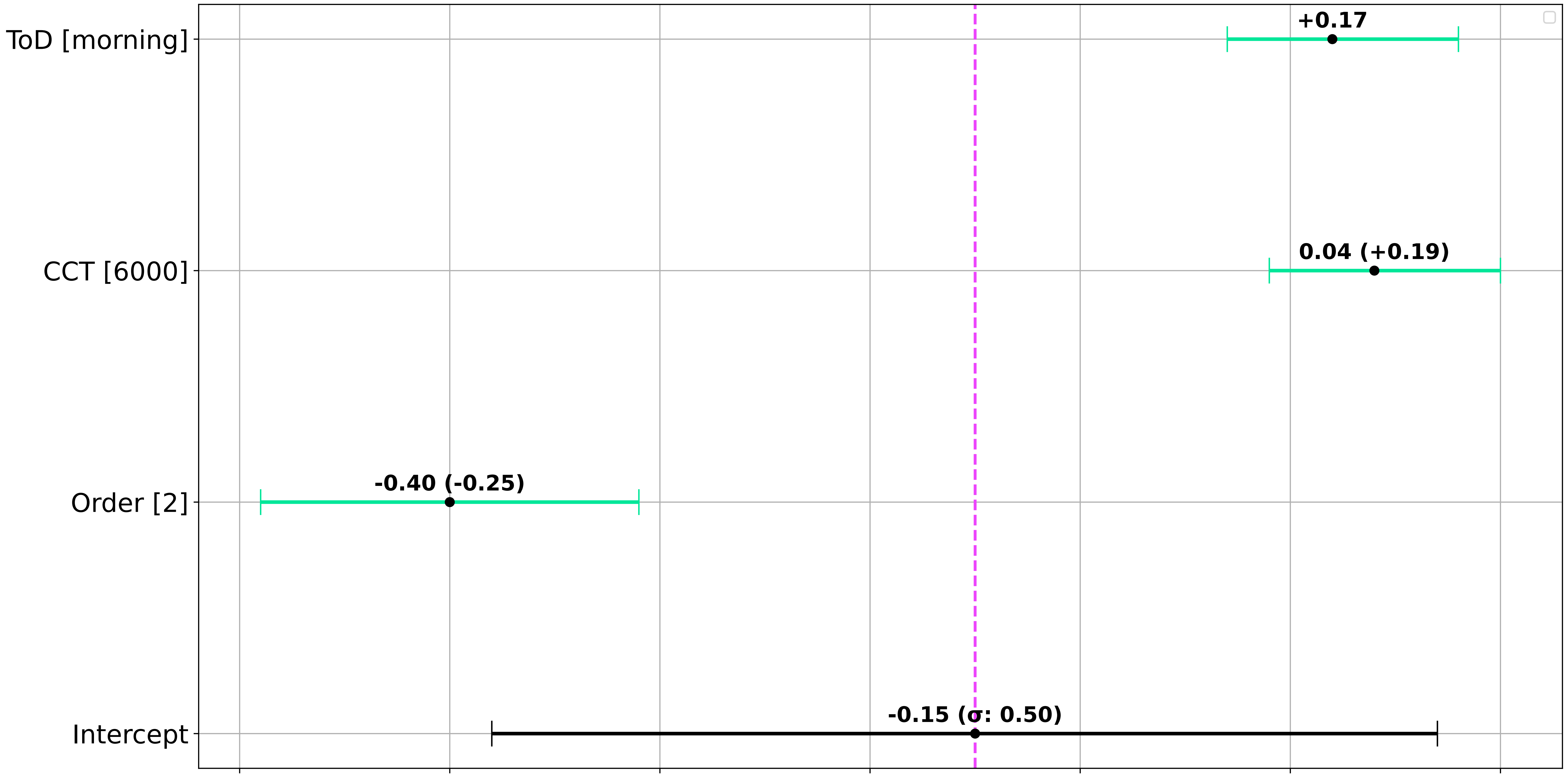


Posterior Estimate for Relative RMSSD Change from Baseline to Stress (using CCT 2700 K, Order 1 and Afternoon as Time of Day as reference)

94% HDI:

- clear effect of time of day (27 % higher RMSSD change in the morning)
- clear effect of CCT (5 % higher RMSSD change in cold CCT)
- clear effect of order (13 % smaller RMSSD change the second time)
- very high residual standard error

Group-Level Results - Rel. Change from Stress to Recovery



Posterior Estimate for Relative RMSSD Change from Stress to Recovery (using CCT 2700 K, Order 1 and Afternoon as Time of Day as reference)

94% HDI:

- **clear effect of time of day (17 % higher RMSSD change in the morning)**
- **clear effect of CCT (19 % higher RMSSD change in cold CCT)**
- **clear effect of order (25 % smaller RMSSD change the second time)**
- **very high residual standard error**

Results - Summary

Effect Analysis

Aggregated Data

Absolute Phase Values

higher baseline-HRV, stress-HRV, recovery-HRV

warm CCT

2700 K

Countermeasure
function not fulfilled

5 % compared to

= relative decrease in baseline-to-stress drop

Post-Stress Support

19 % higher stress-to-recovery change

cold CCT

6000 K

Future Studies

Factor

the probability distribution can be applied to the data of the individual

Stressor Simulation

13 %

less severe stress-response the 2nd time

Individual Data

experiment **2**

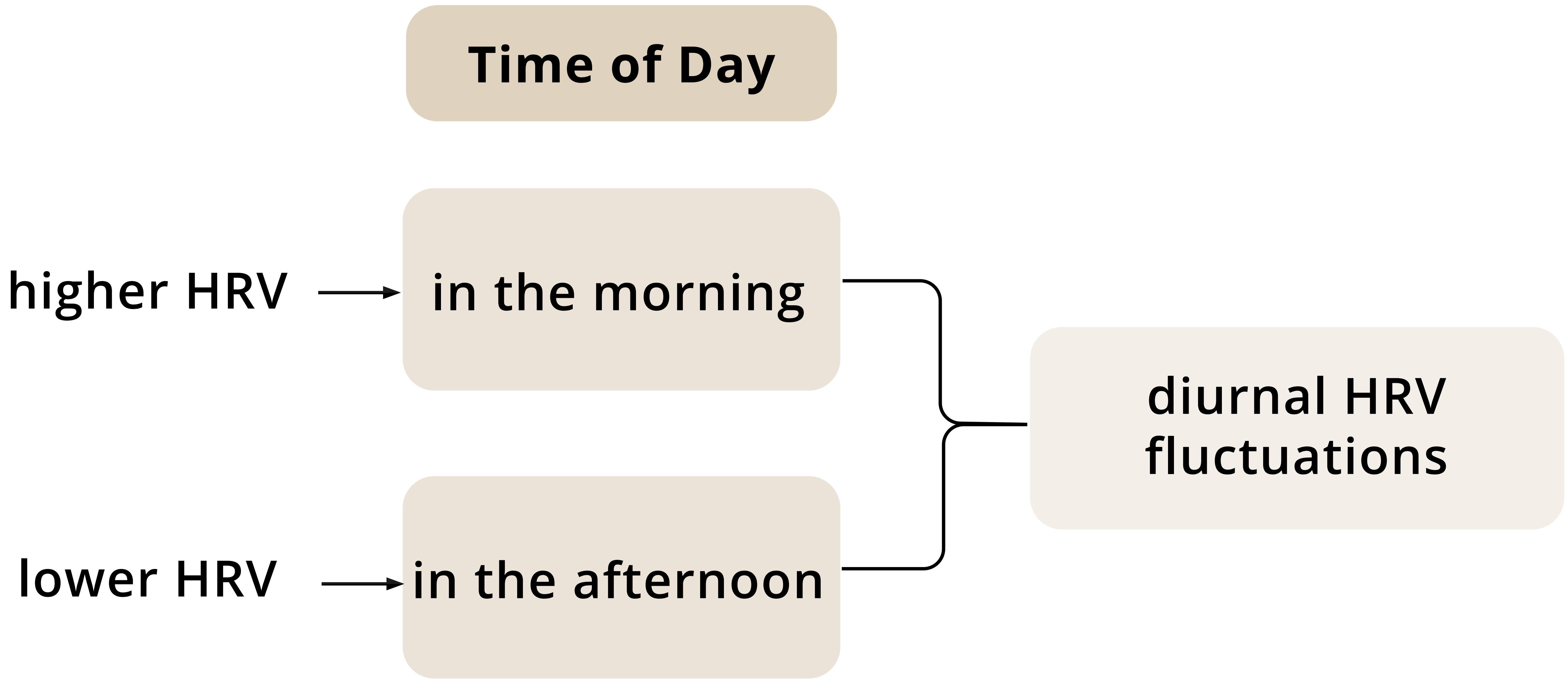
experiment **1**

1. higher HRV in warm CCT
2. No clear countermeasure to stress, (only 5% reduction)
3. Higher relative increase in HRV from stress to recovery in blue CCT
4. HRV responses to stress test varied strongly between individuals/time of day (= original assumption: comparing results per-person)
5. Repeated exposure to the same stress test reduced its effectiveness (more influential than CCT)
6. With more data: probabilities for variables' influence can be used for individual data

Result Interpretation

Influence of Time of Day

coincidental correlation between PSS score (perceived stress during the last month) and time of day of the experiment



Immanuel, S., Teferra, M. N., Baumert, M., & Bidargaddi, N. (2023a). Heart Rate Variability for Evaluating Psychological Stress Changes in Healthy Adults: A Scoping Review. Neuropsychobiology, 82(4), 187–202. https://doi.org/10.1159/000530376
Sammito, S., Sammito, W., & Böckelmann, I. (2016). The circadian rhythm of heart rate variability. Biological Rhythm Research, 47(5), 717–730. https://doi.org/10.1080/09291016.2016.1183887

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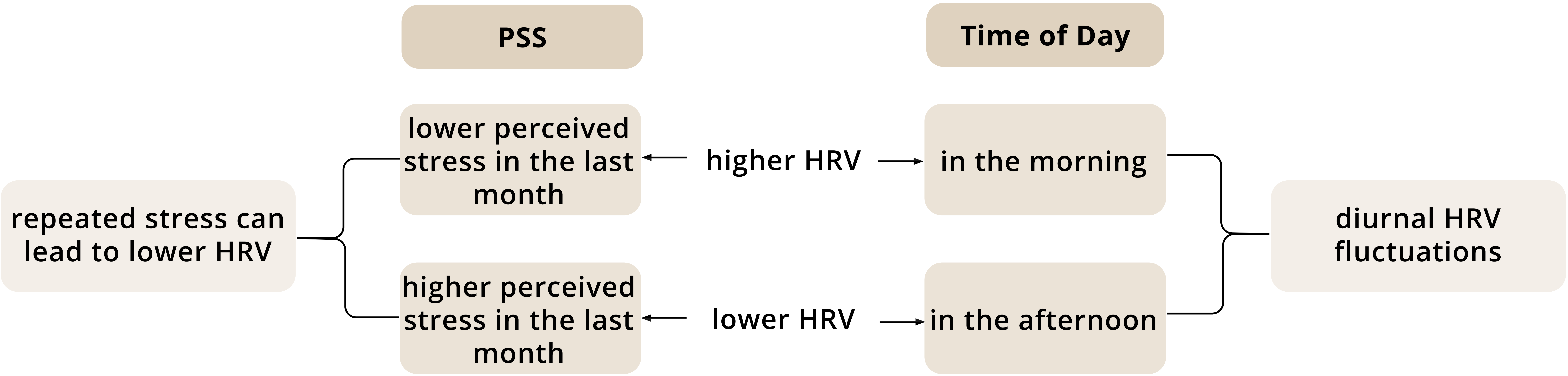

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Result Interpretation

Influence of Order

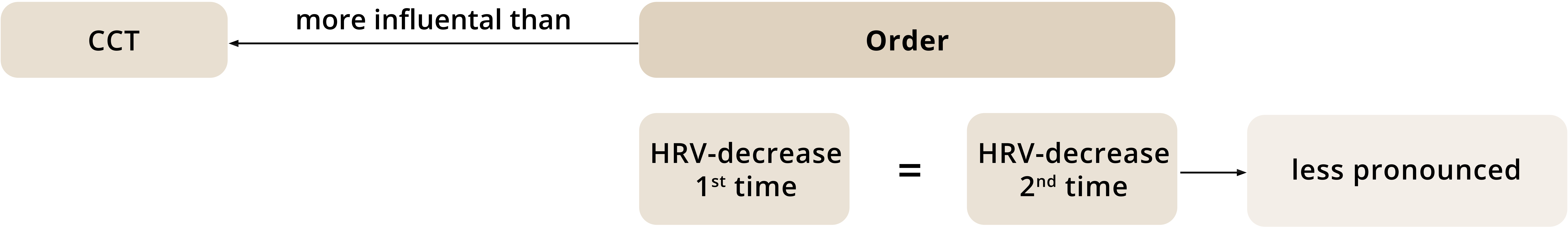
Order

HRV-decrease 1st time = HRV-decrease 2nd time → less pronounced

Barthel, M.-C., Fricke, K., Muehlhan, M., Vogel, S., & Alexander, N. (2025). Habituation of the biological response to repeated psychosocial stress: A systematic review and meta-analysis. Neuroscience & Biobehavioral Reviews, 169, 105996. https://doi.org/10.1016/j.neubiorev.2024.105996
Boesch, M., Sefidan, S., Ehlert, U., Annen, H., Wyss, T., Steptoe, A., & La Marca, R. (2014). Mood and autonomic responses to repeated exposure to the Trier Social Stress Test for Groups (TSST-G). Psychoneuroendocrinology, 43, 41–51. https://doi.org/10.1016/j.psyneuen.2014.02.003
Jönsson, P., Wallergård, M., Österberg, K., Hansen, Å. M., Johansson, G., & Karlson, B. (2010). Cardiovascular and cortisol reactivity and habituation to a virtual reality version of the Trier Social Stress Test: A pilot study. Psychoneuroendocrinology, 35(9), 1397–1403. https://doi.org/10.1016/j.psyneuen.2010.04.003

Result Interpretation

Influence of Order



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Result Interpretation

Influence of CCT

CCT

Warm (2700 K)

Cold (6000 K)

Luo, X., Ru, T., Chen, Q., Li, Y., Chen, Y., & Zhou, G. (2022). Influence of daytime blue-enriched bright light on heart rate variability in healthy subjects. Chronobiology International, 39(6), 826–835. https://doi.org/10.1080/07420528.2022.2040526
Blume, C., Garbazza, C., & Spitschan, M. (2019). Effects of light on human circadian rhythms, sleep and mood. Somnologie, 23(3), 147–156. https://doi.org/10.1007/s11818-019-00215-x
Westerink, J., Krans, M., & Ouwerkerk, M. (Eds.). (2011). Sensing Emotions (Vol. 12). Springer Netherlands. https://doi.org/10.1007/978-90-481-3258-4
Petrowski, K., Buehrer, S., Niedling, M., & Schmalbach, B. (2021). The effects of light exposure on the cortisol stress response in human males. Stress, 24(1), 29–35. https://doi.org/10.1080/10253890.2020.1741543
Schäfer, A., & Kratky, K. W. (2006). The Effect of Colored Illumination on Heart rate variability. Complementary Medicine Research, 13(3), 167–173. https://doi.org/10.1159/000092644

Result Interpretation

Influence of CCT

CCT

Warm (2700 K)

Cold (6000 K)

higher absolute HRV

- interaction effects between illuminance and CCT
- positive contextual association with warm CCT
- reduced arousal/altertness compared to blue CCT

Luo, X., Ru, T., Chen, Q., Li, Y., Chen, Y., & Zhou, G. (2022). Influence of daytime blue-enriched bright light on heart rate variability in healthy subjects. Chronobiology International, 39(6), 826–835. https://doi.org/10.1080/07420528.2022.2040526
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Result Interpretation

Influence of CCT

CCT

Warm (2700 K)	Cold (6000 K)
higher absolute HRV	stronger relative HRV-change (19 %)

- interaction effects between illuminance and CCT
- positive contextual association with warm CCT
- reduced arousal/altertness compared to blue CCT

- recovery-change enhanced/accelerated in blue CCT

Luo, X., Ru, T., Chen, Q., Li, Y., Chen, Y., & Zhou, G. (2022). Influence of daytime blue-enriched bright light on heart rate variability in healthy subjects. Chronobiology International, 39(6), 826–835. https://doi.org/10.1080/07420528.2022.2040526
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What is still unanswered

Considerations for this study:
- neither meaningful for health of participants nor generalizable to wider usergroup (more data required)
- very high residual errors of models indicate uncertainty

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Open questions :

- can CCT act as countermeasure to stress (reliably proven and of significant size > 5%)?
- can acute counteraction prevent longerm health effects?

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Shortcomings of cross-sectional research:
- limited data on biomarker reaction during stress
- uncomplete situational data
- uncomplete picture of past health/biomarker-baseline
- group dynamic/difference of preferences

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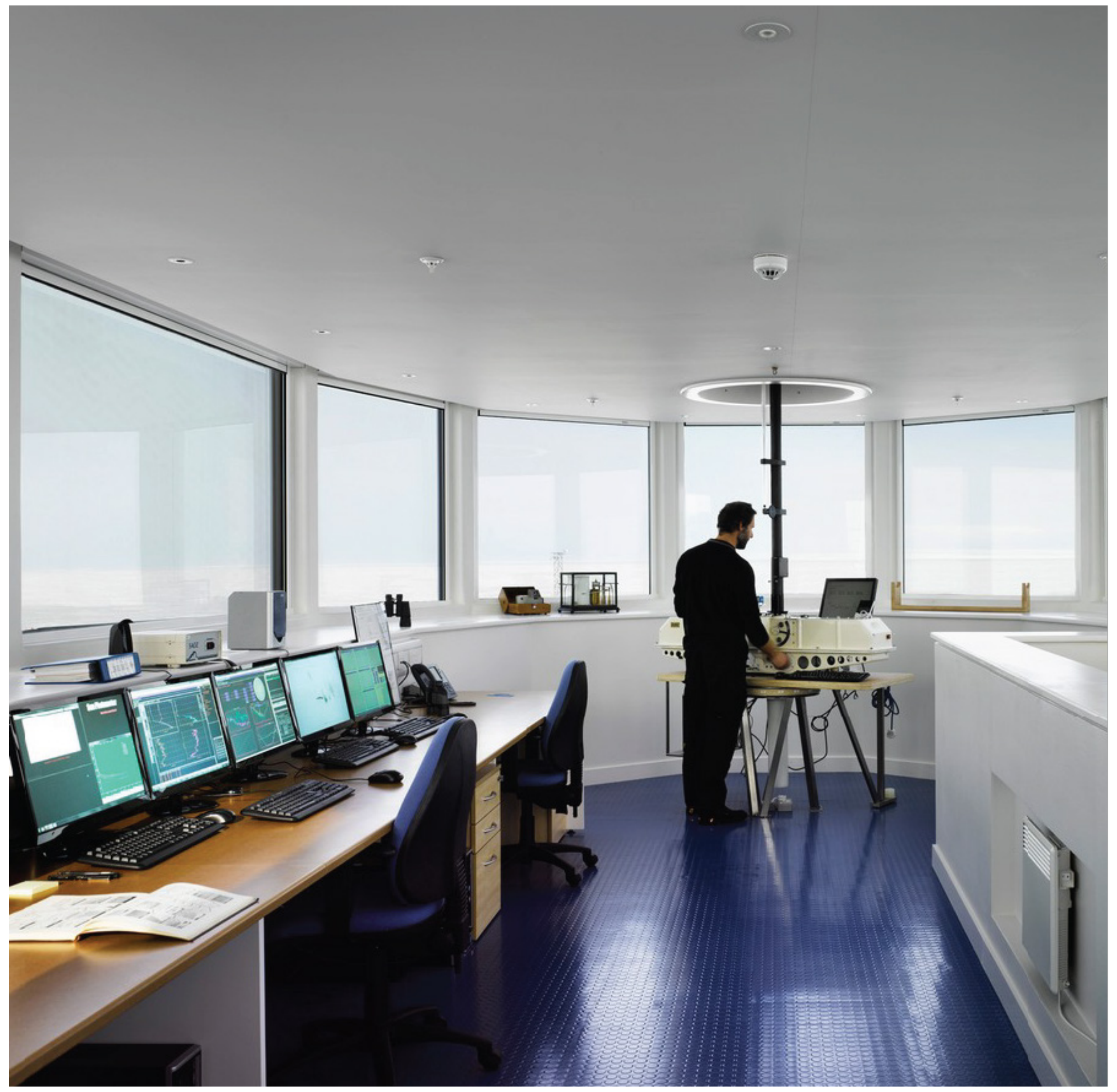
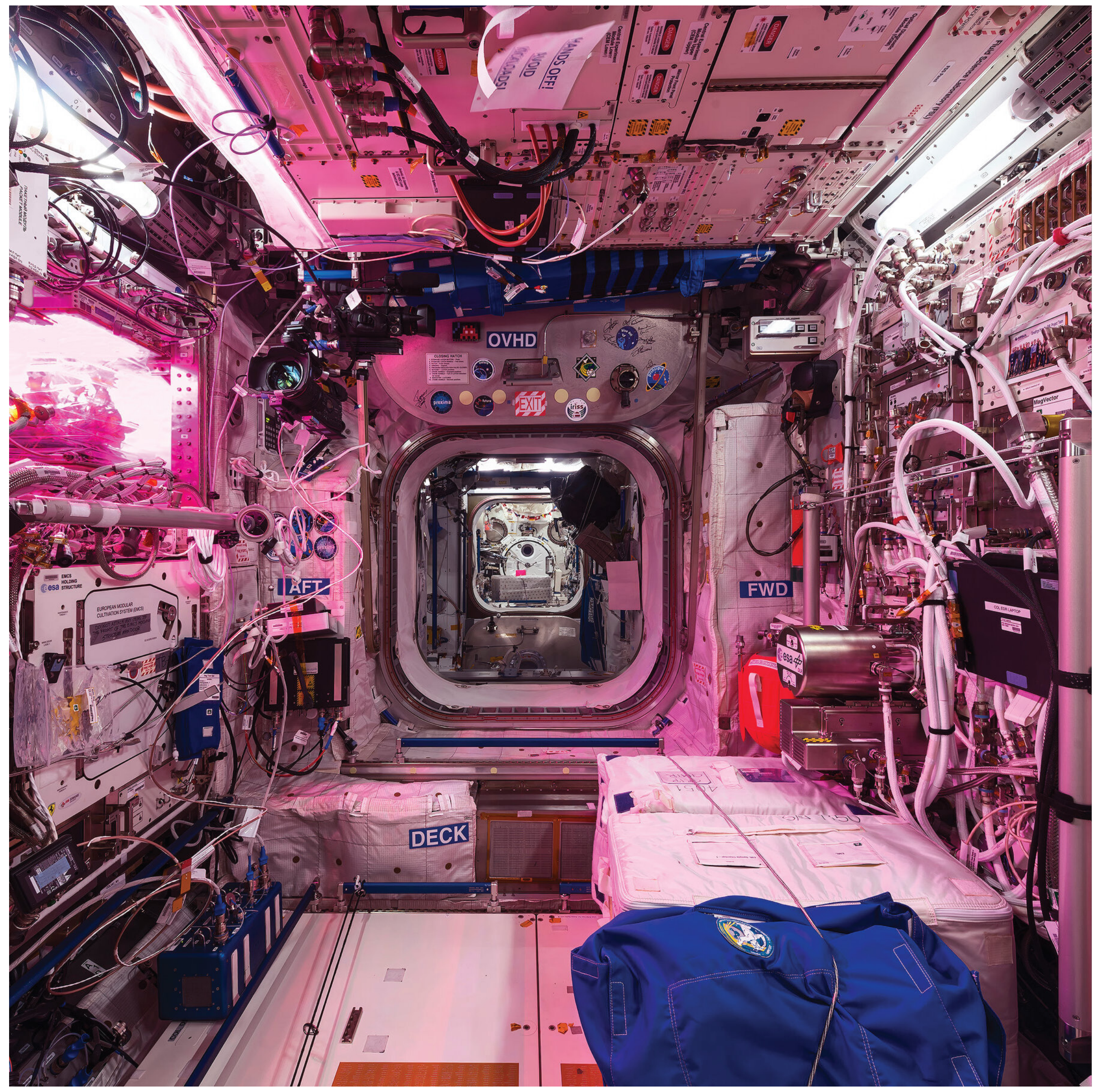
Future Application





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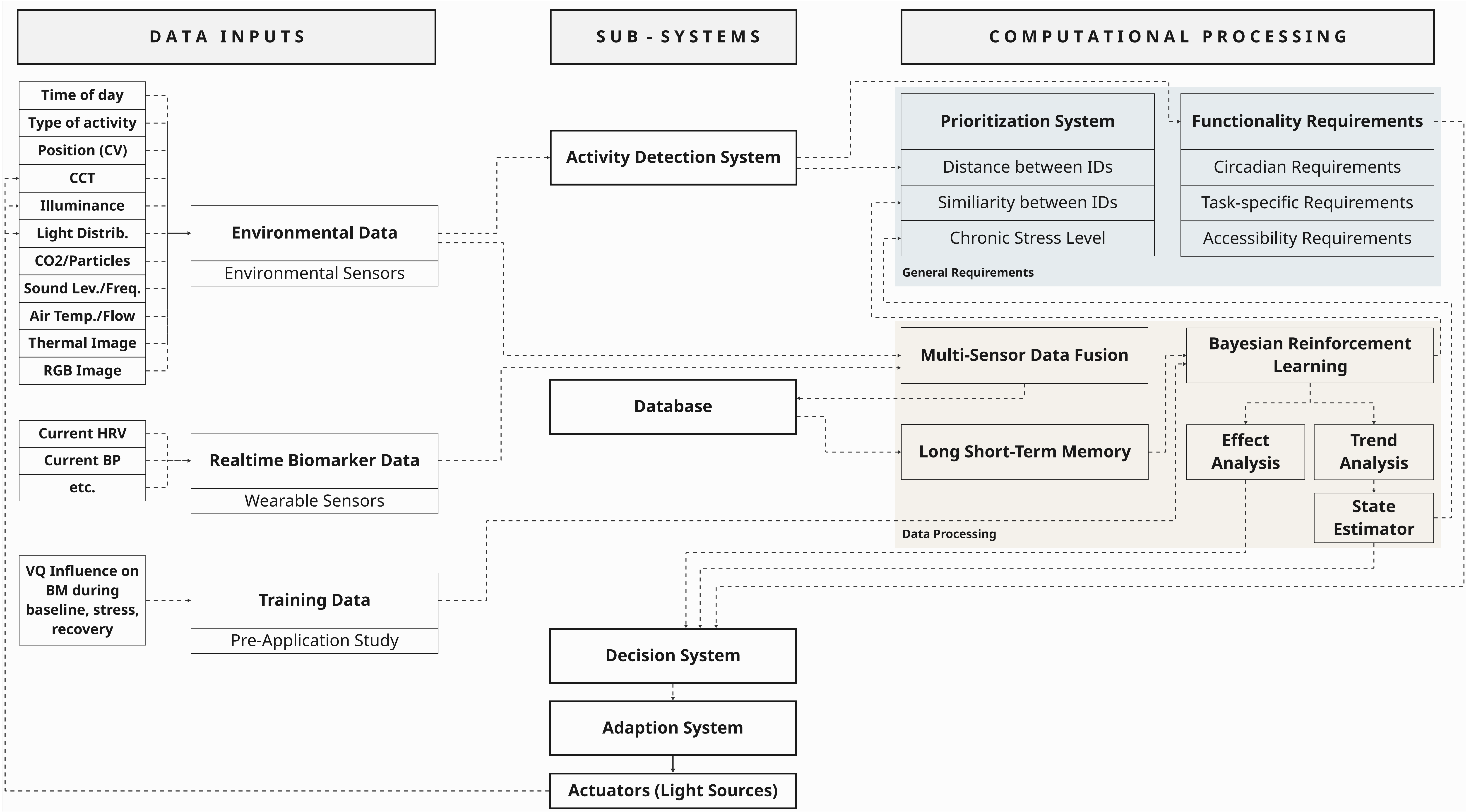
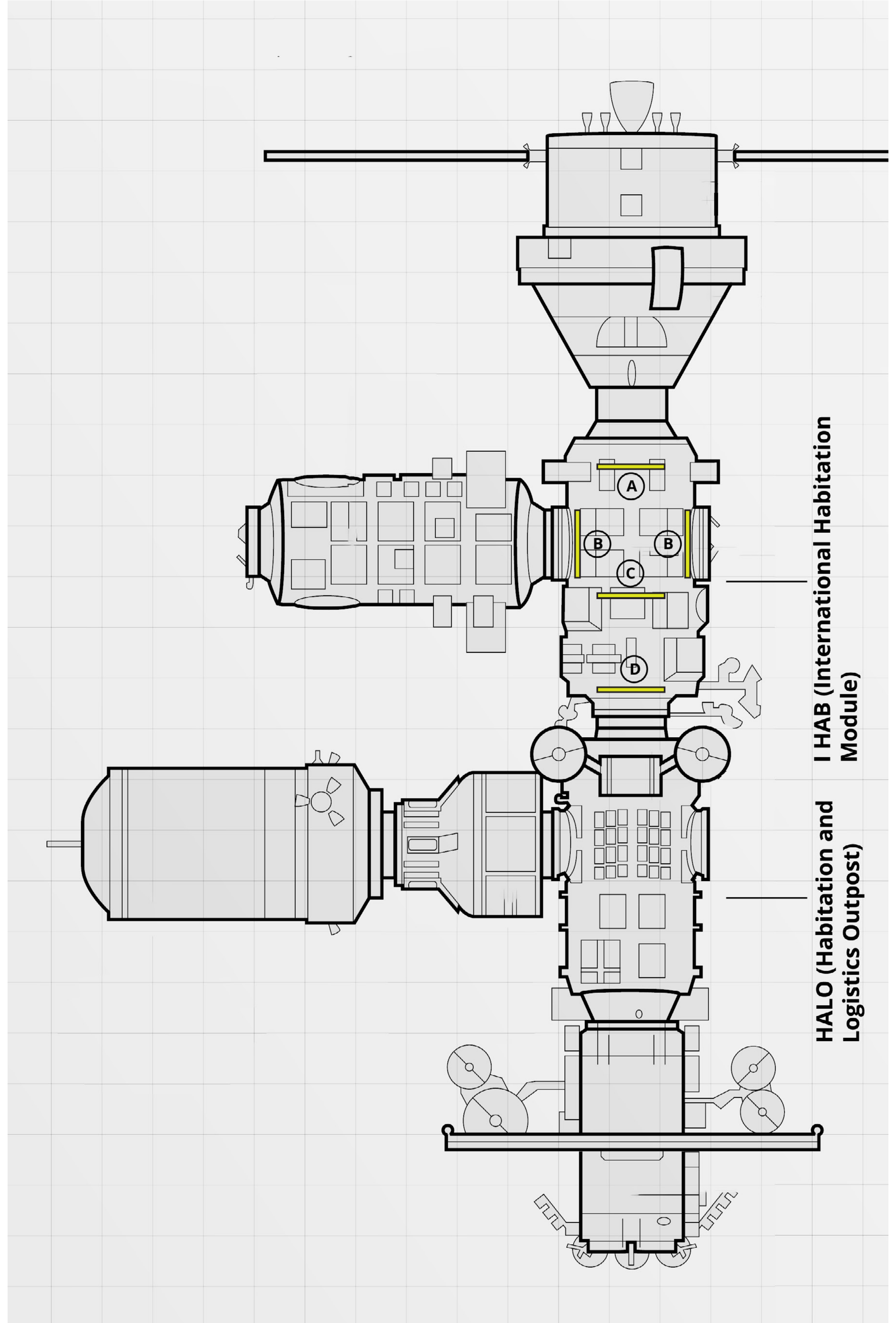




Future Application

group dynamic/difference of preferences

uncomplete situational data

uncomplete picture of past health/biomarker-baseline

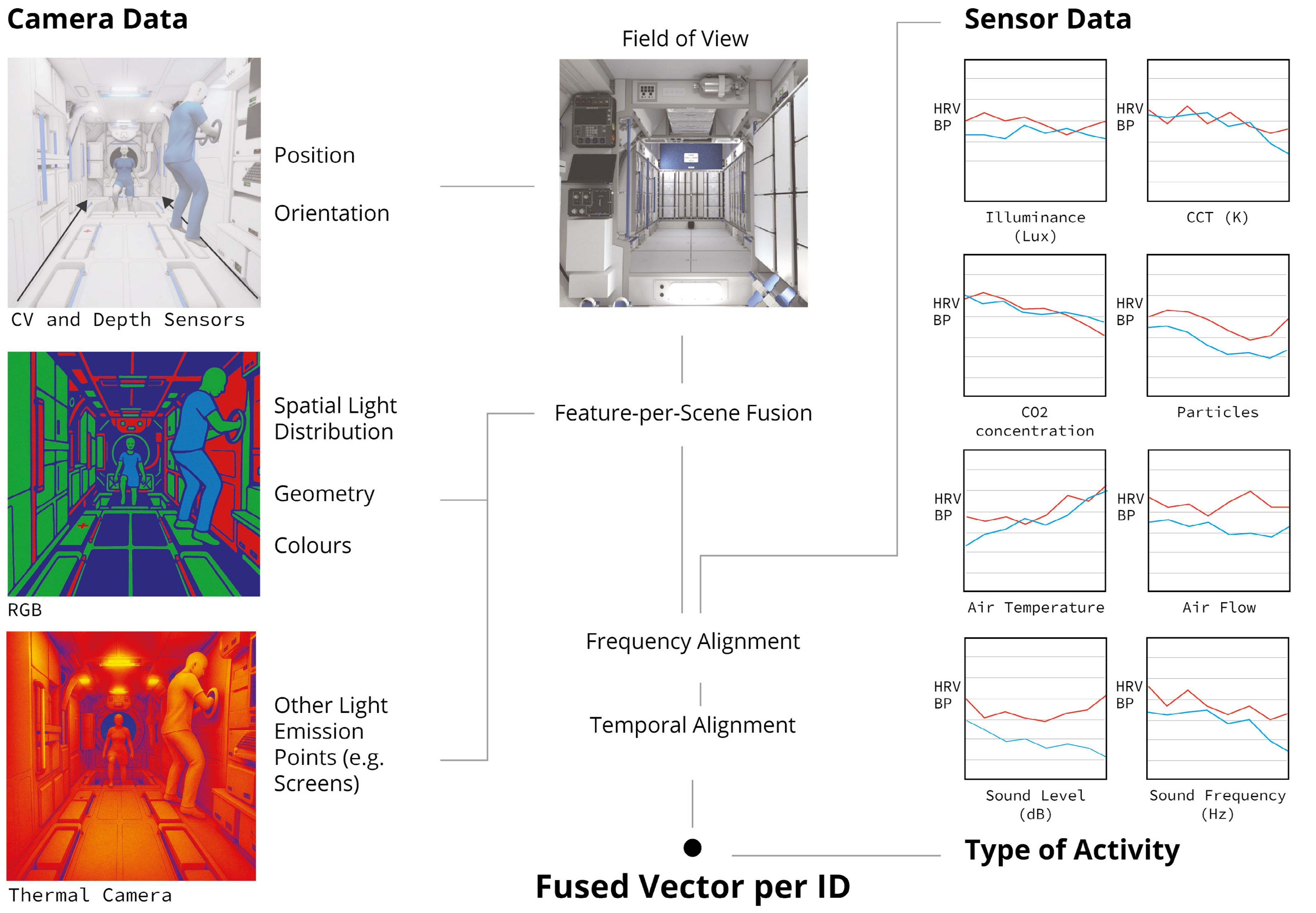
limited data on biomarker reaction during stress

Future Application

uncomplete situational data

limited data on biomarker reaction during stress

Future Application: Data Architecture



Multi-Sensor Data Fusion

addresses →

uncomplete situational data

limited data on biomarker reaction during stress

Future Application

group dynamic/difference of preferences

uncomplete situational data

uncomplete picture of past health/biomarker-baseline

limited data on biomarker reaction during stress

Future Application

group dynamic/difference of preferences

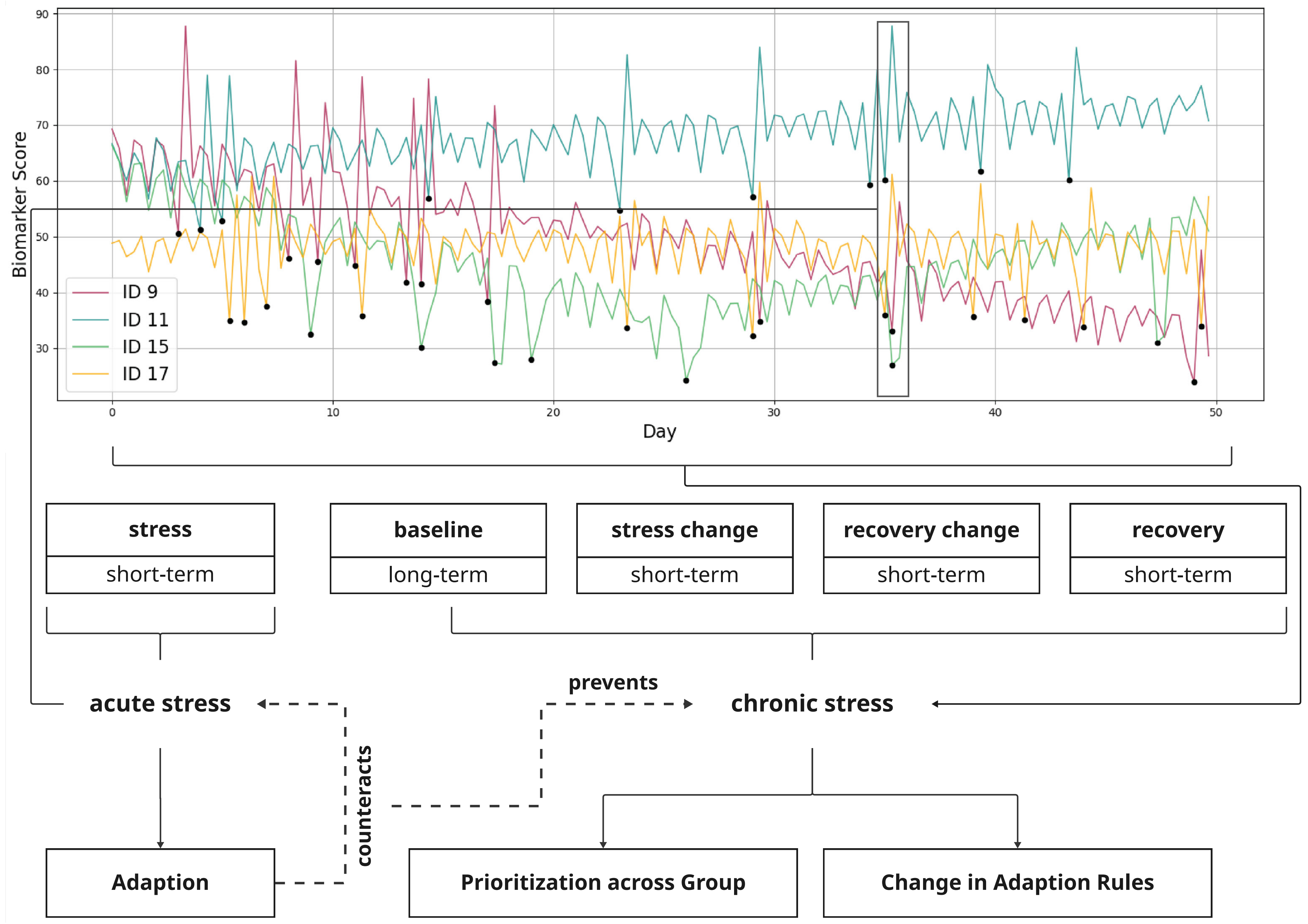
uncomplete picture of past health/biomarker-baseline

Future Application: Biomarker-based Machine Learning

group dynamic/difference of preferences

uncomplete picture of past health/biomarker-baseline

addresses

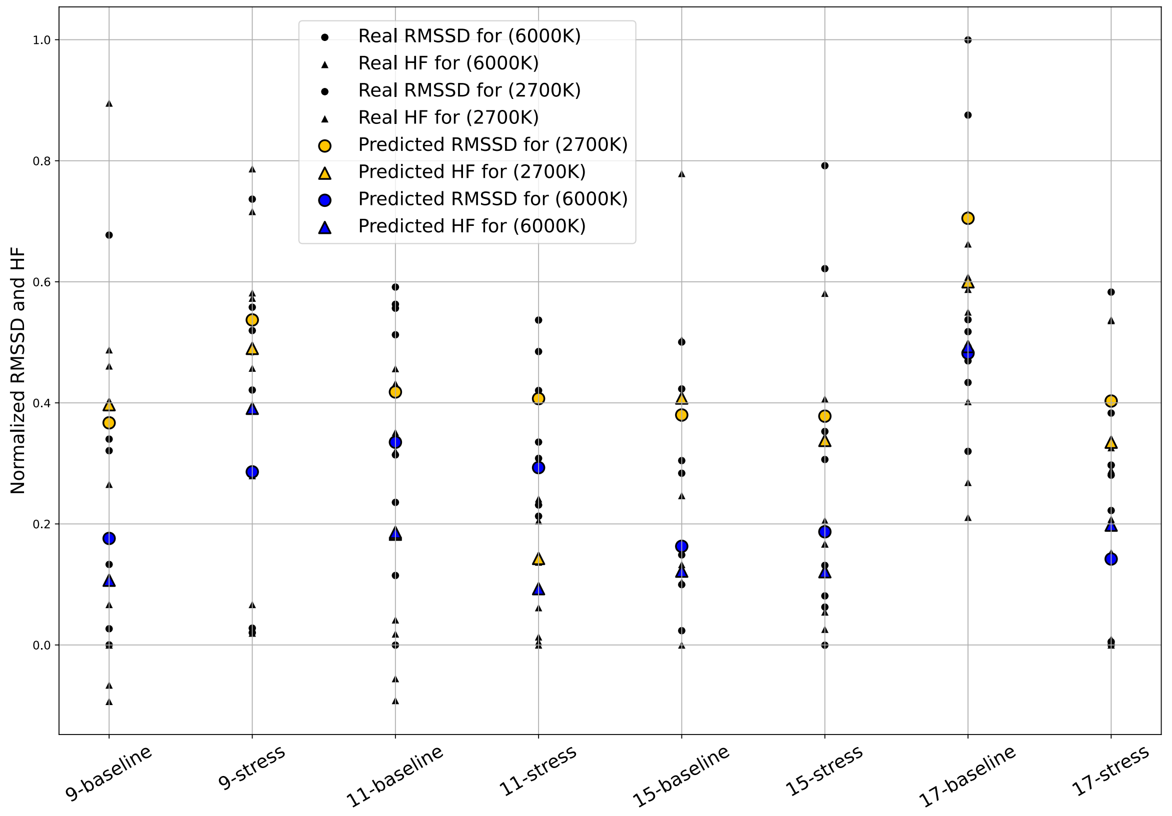


Biomarker Trend Analysis and State Estimator

Future Application: Training Process

Study Data → **Training Dataset** → **Q Vectors** / **Reward Function** → **Adaptive System**

28,57	5,99	175,47	741,3752	0,19	4,23
		218,816			
50,71	26,33	546,90	2312,92	0,19	4,23
		685,4696			
62,50	40,30	823,65	1418,912	0,37	1,72
		421,1096			
41,62	19,31	474,33	1287,568	0,27	2,71
		115,04			
55,35	33,33	639,73	1913,832	0,25	2,99
		552,636			
43,80	27,83	372,40	849,776	0,30	2,28
		278,1456			
62,86	28,53	755,85	682,9344	0,53	0,90
		491,5888			
46,73	19,15	356,84	858,088	0,29	2,40
		471,9688			
83,27	14,98	504,52	993,176	0,34	1,97
		389,5768			
40,42	10,53	347,56	487,2088	0,42	1,40
		132,5656			
21,95	2,67	188,16	593,0696	0,24	3,15
		218,8192			
31,09	8,06	287,03	1682,504	0,15	5,86
		177,7216			
75,35	36,63	3047,99	4290,16	0,42	1,41
		2921,744			
51,30	15,77	1407,38	2933,512	0,32	2,08
		1756,896			
102,15	67,86	5837,01	1943,088	0,75	0,33
		3991,464			
68,66	35,19	2347,30	3066,832	0,43	1,31
		2507,192			
66,31	26,14	1920,26	5362,888	0,26	2,79
		1944,008			
96,64	49,70	4425,02	4299,216	0,51	0,97



Locally-normalized Comparison of Multi-Output Random Forest Regression and Study Data

Q Vectors: map input states to Q-values (value of action-state pair)

Reward Function: definition of how/for what rewards are assigned

Adaptive System: using Bayesian RL

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Challenges in their Investigation

in cross-sectional research:

individual biomarker-baselines

influence of confounding variables

reliable transient stressor simulation

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two experiments per person, multi-criteria decision analysis

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in cross-sectional research:

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influence of confounding variables

iterative group analysis, Bayesian linear effects models

reliable transient stressor simulation

Challenges in their Investigation

in cross-sectional research:

individual biomarker-baselines

two experiments per person, multi-criteria decision analysis

influence of confounding variables

iterative group analysis, Bayesian linear effects models

reliable transient stressor simulation

psychological stress test, order effect analysis

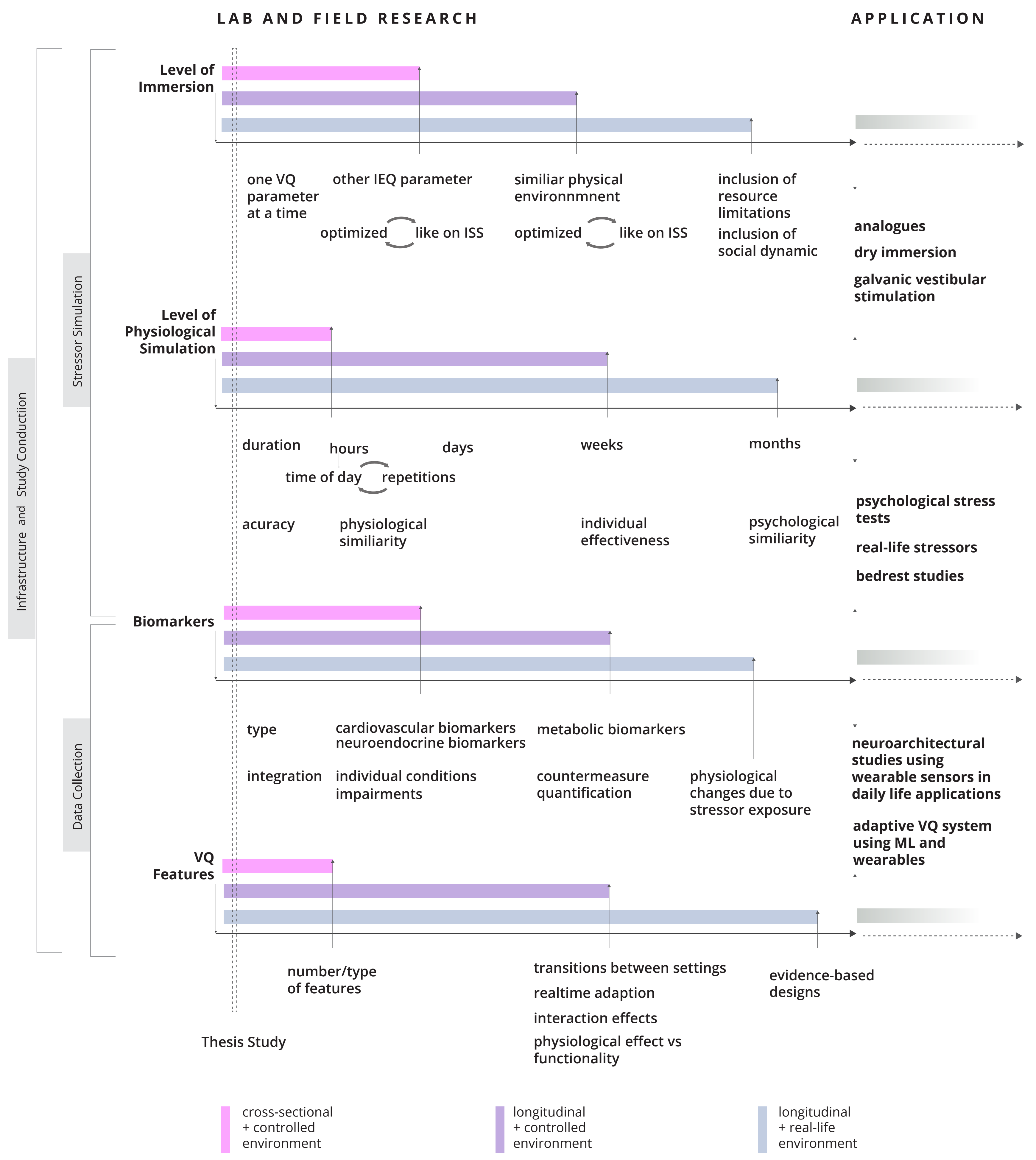
Outlook

Cross-sectional studies

- probability of effects resulting from confounding variables can be used for individual analysis
- more experiments needed conflicting with use of same stressor simulation
- integration of different vision impairments

Longitudinal studies

- can solve most identified challenges in cross-sectional research
- confined environment (like research/space station) provides ideal conditions for field research



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Master‘s Thesis Defense

Antonia Sattler

Thank you!

Supervisors

Dr. Michela Turrin
Dr. Henriette Bier

30th of June 2025

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