NEBRASKA ACADEMY FOR
METHODOLOGY, ANALYTICS & PSYCHOMETRICS

Capturing Life in Motion: Leveraging Wearable Technology for Human Subjects Research

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December 8th, 2023

University of Nebraska Lincoln

Using wearable devices to capture heart rate variability

BLAB LAB
The UNL brain, learning & behavior lab

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Outline

- Why heart rate variability (HRV)?
- Different metrics for HRV
- Data collection and analysis
- Challenges and practicalities
- Some examples

Why heart rate variability?

- How do children develop self-regulation?
- How does self-regulation support learning?
- How do early caregiving experiences shape self-regulation development?

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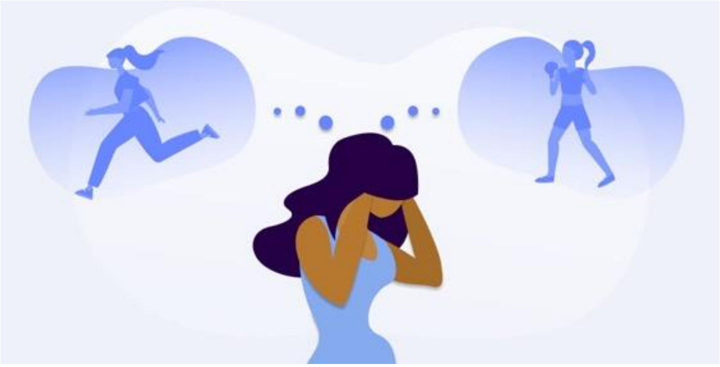
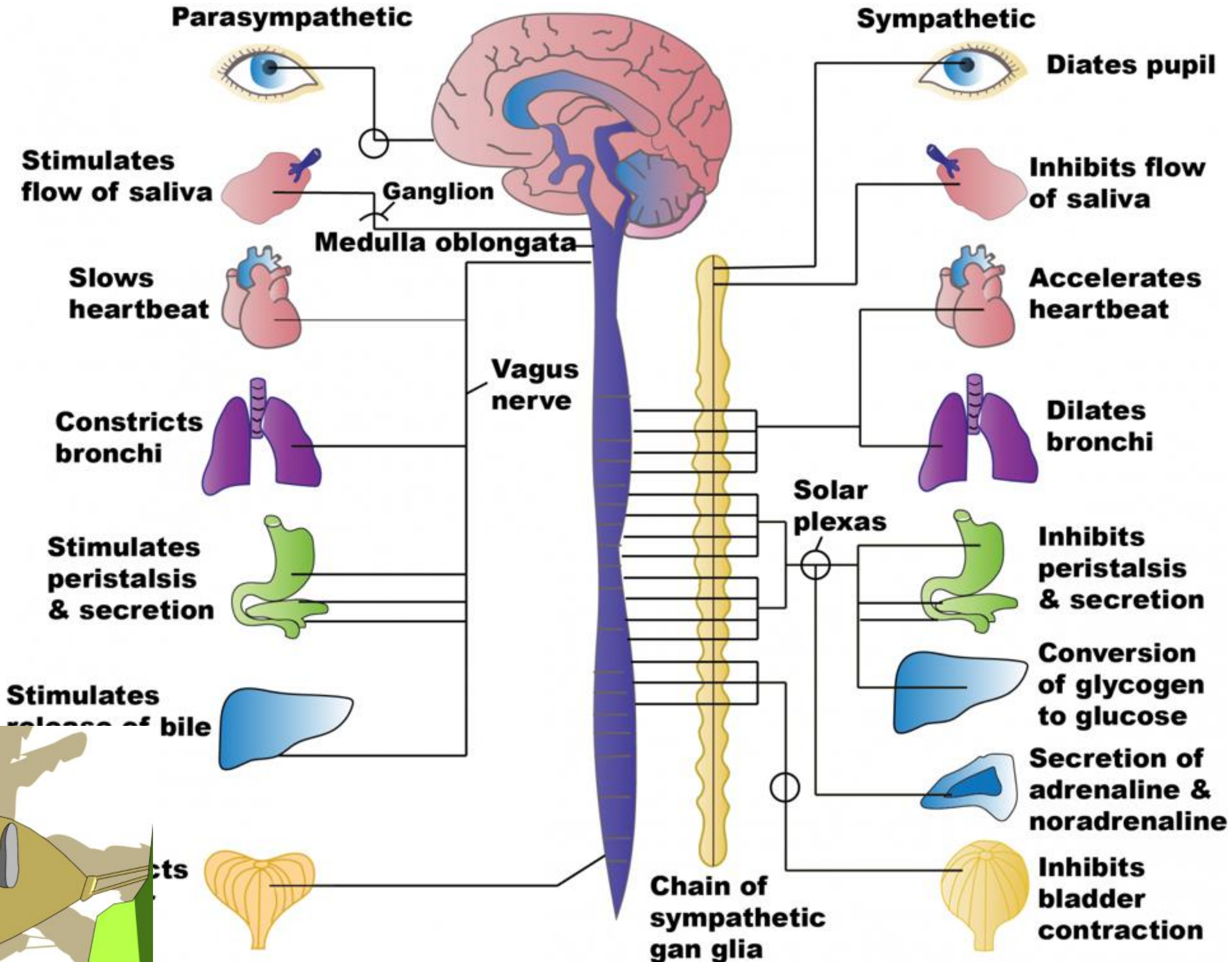
The autonomic nervous system





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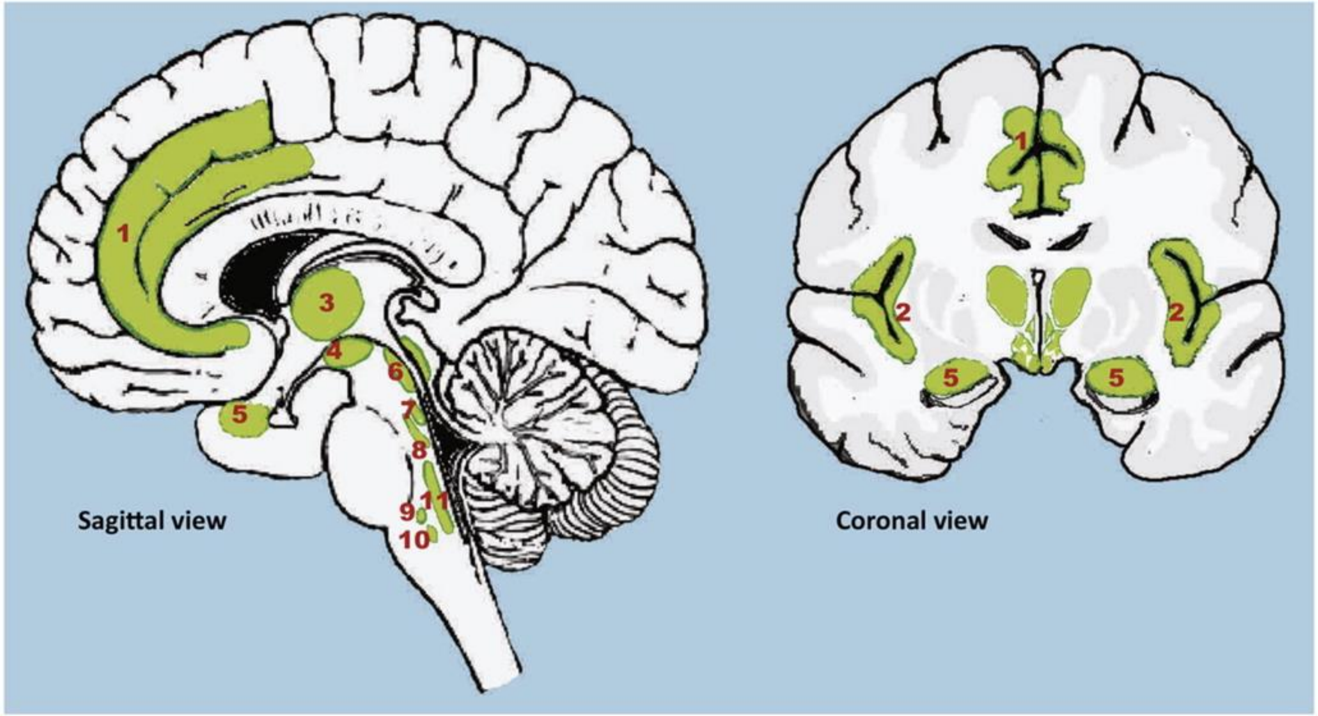
Neurovisceral integration theory (Thayer & Lane, 2000)

Components of the central autonomic network



1 anterior cingulate; 2 insula; 3 thalamus; 4 hypothalamus; 5 amygdala; 6 periaqueductal grey; 7 parabrachial nucleus; 8 locus coeruleus; 9 rostroventrolateral medulla; 10 caudoventrolateral medulla; 11 nucleus of the solitary tract

- **Central autonomic network** includes:
- Anterior cingulate cortex (ACC)
- Insula
- Ventro and orbito-prefrontal cortex
- Amygdala
- Hypothalamus
- Periaqueductal gray
- Several other brainstem structures

Taggart et al. (2016). Significance of neuro-cardiac control mechanisms governed by higher regions of the brain. Autonomic neuroscience: Basic and clinical, 199, 54-65.

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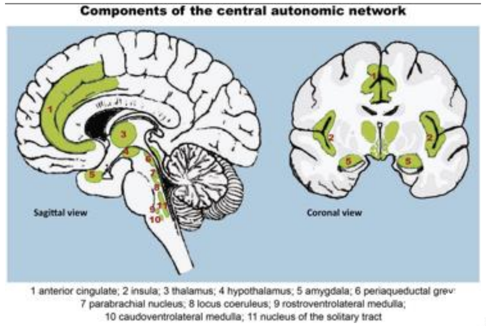
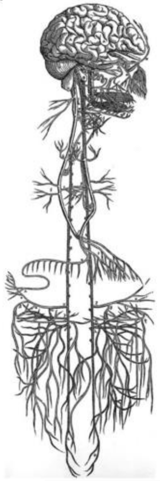
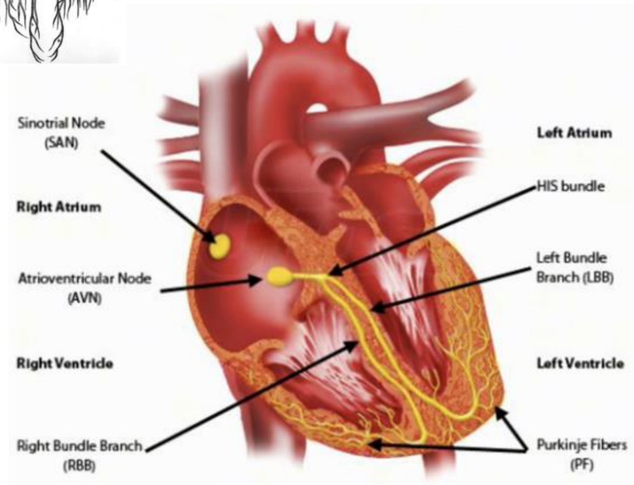


Central autonomic network



Sympathetic and parasympathetic neurons

Vagus nerve and stellate ganglia



Moment-by-moment adjustments in heart rate = parasympathetic, vagal influence on heart

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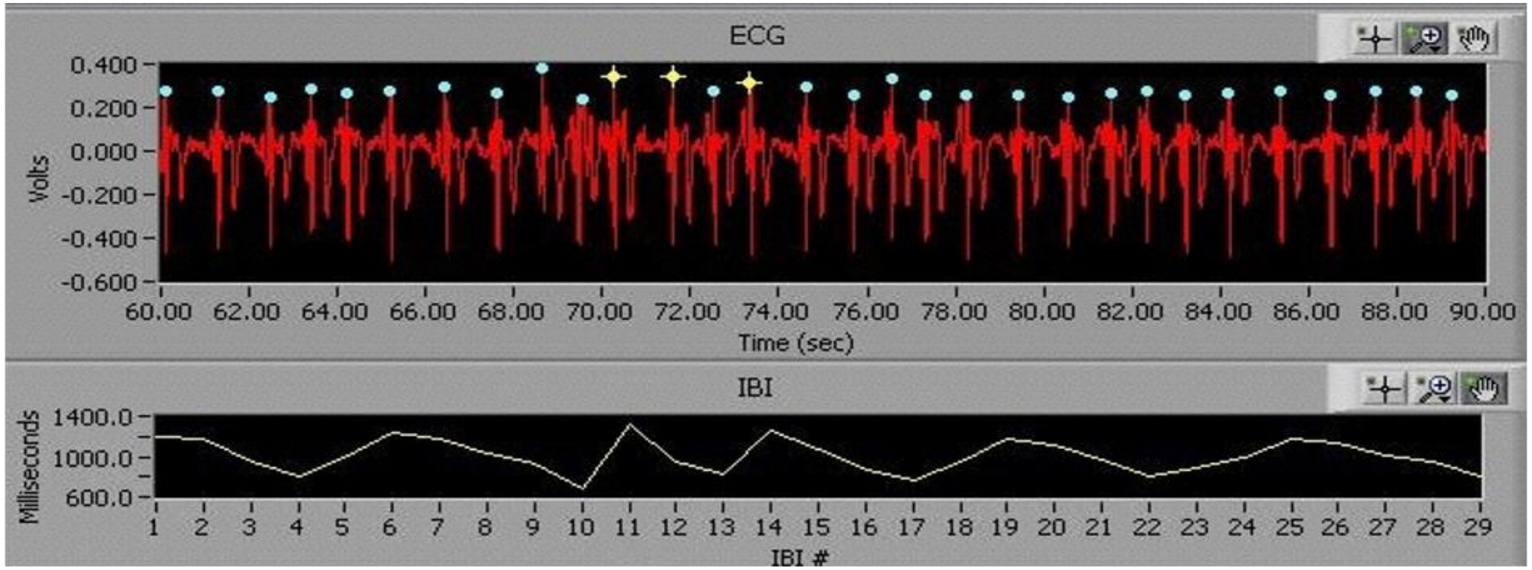
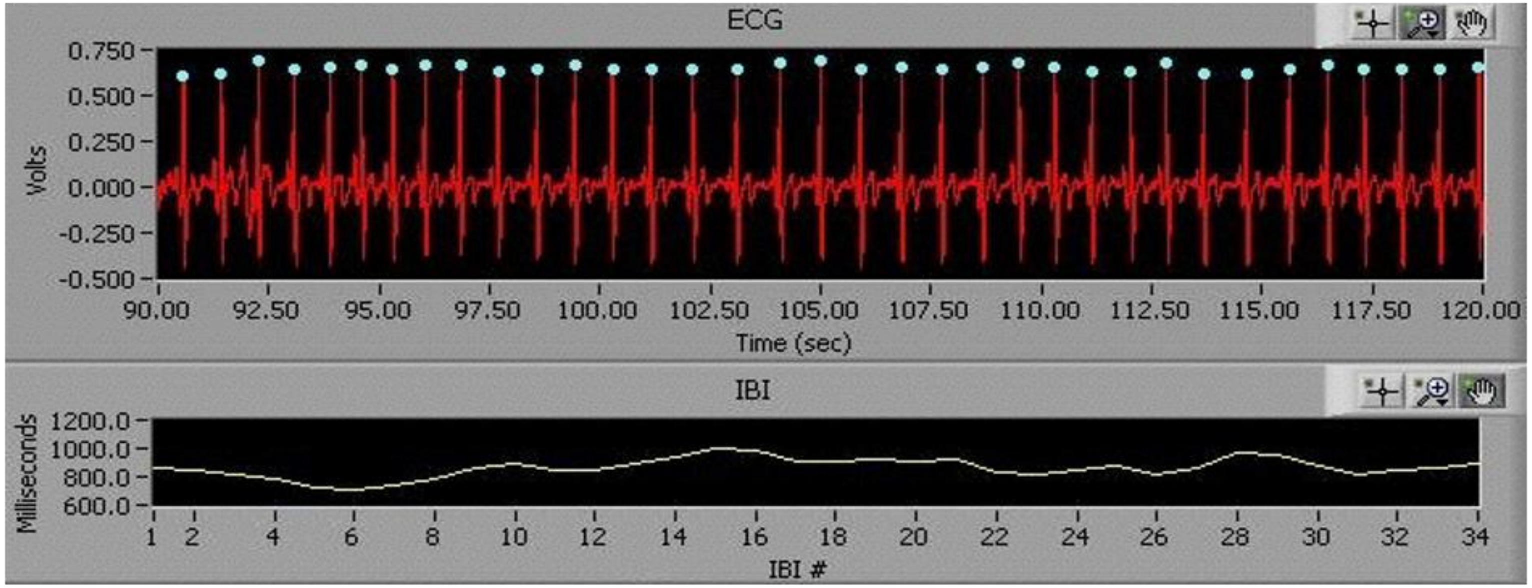
Smith, R., Thayer, J. F., Khalsa, S. S., & Lane, R. D. (2017). The hierarchical basis of neurovisceral integration. *Neuroscience & biobehavioral reviews*, *75*, 274-296.



High HRV: Lots of variability in time between R spikes



Low HRV: Limited variability in time between R spikes

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HRV and the brain

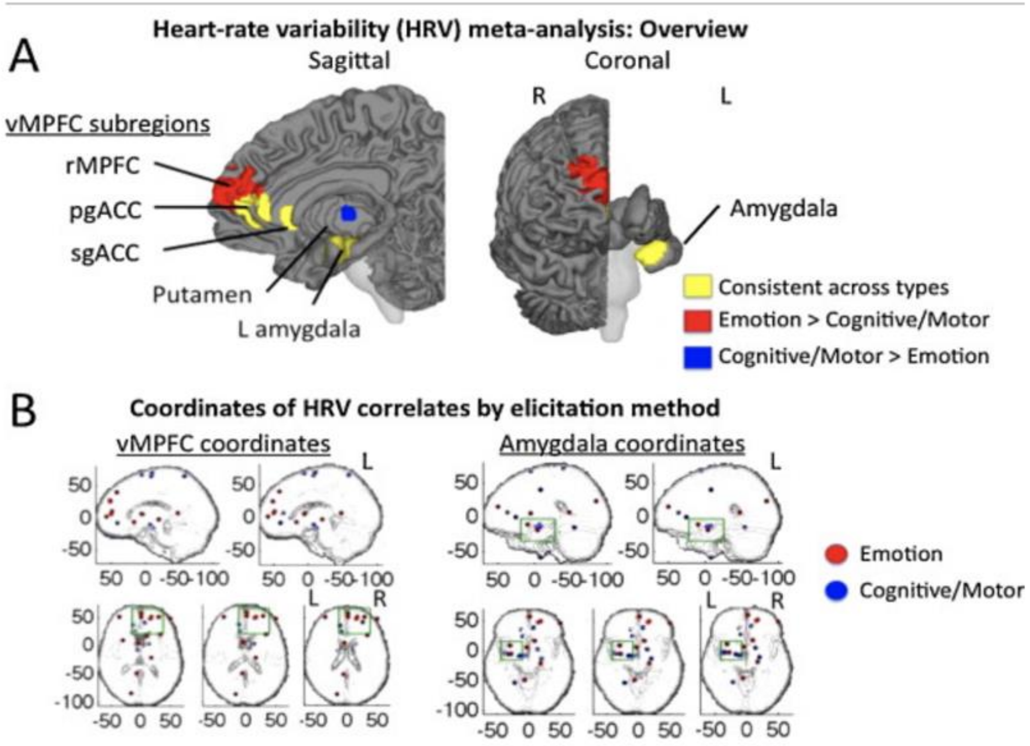

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Fig. 1. (a) map of the whole brain showing significant activations, (b) map of the coordinates of the contrasts at various levels of the neuroaxis.

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Thayer, J. F., Åhs, F., Fredrikson, M., Sollers III, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews*, *36*(2), 747-756.

Meta-analytic findings related to HRV

- Small positive link of HRV to **executive function** and **emotion regulation** (Graziano & Derefinki, 2013; Holzman & Bridgett, 2017; Magnon et al., 2022).
- HRV moderately linked with **compassion** (Di Bello et al., 2020).
- Lower HRV in **major depression** (Koch et al., 2019) and **anxiety** (Chalmers et al., 2014).
- Lower HRV in **PTSD** (Schneider & Schwerdtfeger, 2020)
- Higher **inflammatory markers** related to lower HRV (Williams et al., 2019).
- Small relation to **executive function, emotion regulation and attention control** may be subject to publication bias (Zahn et al., 2016).
- Lower HRV in anticipation of stress and cortisol stress response (Michels et al., 2013).

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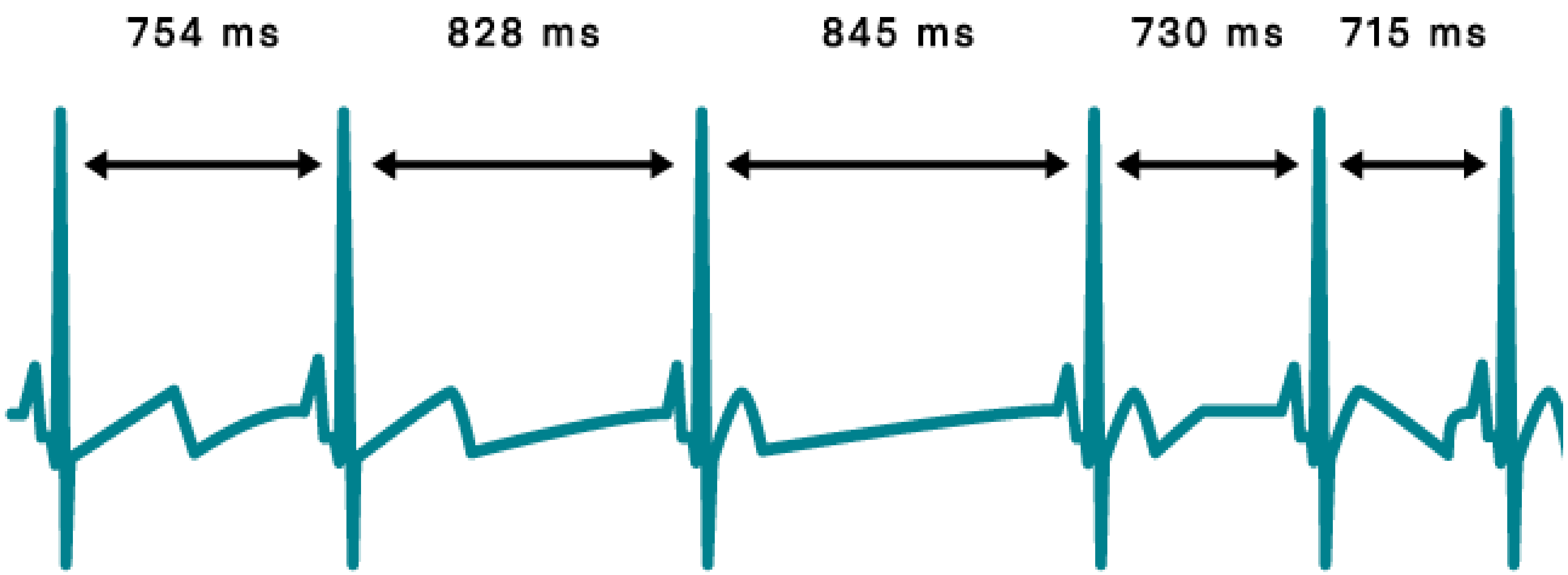
Time-based measures of HRV



- **RMSSD:** Root mean square of successive RR interval differences. Most related to parasympathetic influence.
- **SDNN:** Standard deviation of all clean, normal intervals
- **pNN50:** Proportion of intervals that differ by > 50ms

Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in public health*, *5*, 258. https://doi-org.libproxy.unl.edu/10.3389/fpubh.2017.00258

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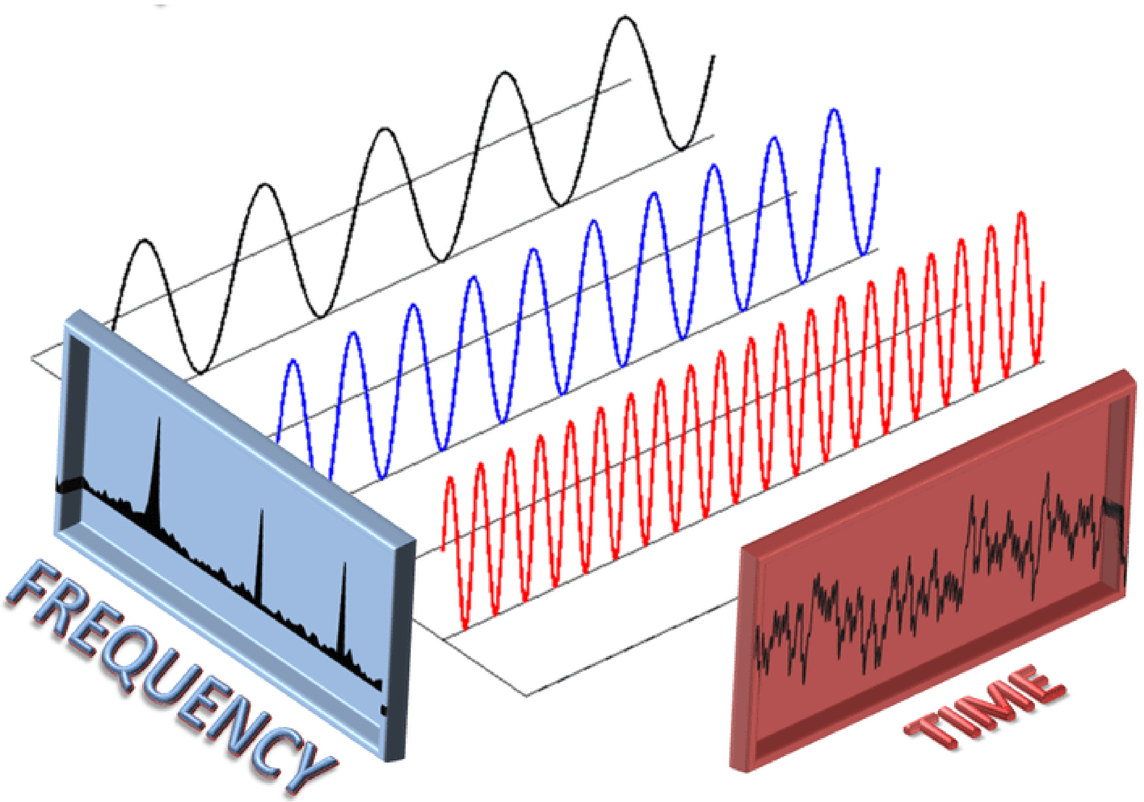
Frequency-based measures of HRV



- Power within the .15 - .40 Hz respiratory range (.24 to 1.04 for children)
- Ultra-low, very low & low frequency bands may reflect other processes, e.g., circadian rhythm, baroreflex
- LF/HF power ratio sometimes argued to reflect balance of parasympathetic and sympathetic influence, but controversial
- Hf-HRV doesn't always reflect vagal influence; also reflects changes in respiration rate that don't affect heart rate

Kalhara, Gayan & Jayasinghearachchi, Vishan & Dias, A. & Ratnayake, V. & Jayawardena, Chandimal & Kuruwitaarachchi, Nuwan. (2017). TreeSpirit: Illegal logging detection and alerting system using audio identification over an IoT network. 1-7. 10.1109/SKIMA.2017.8294127.

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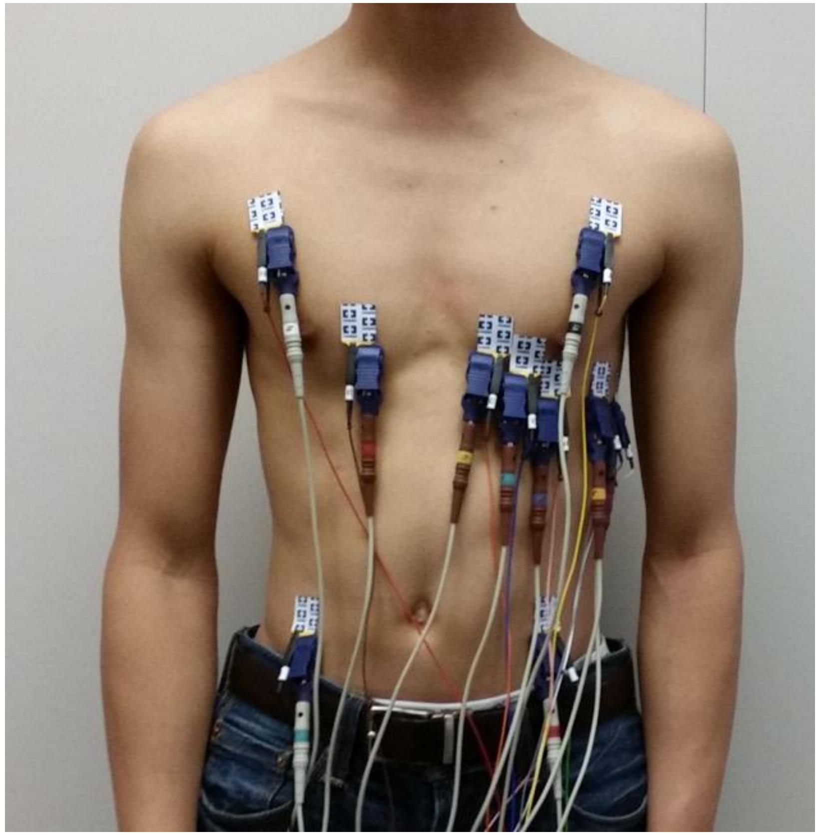
Collecting the data



ECG amplifier – Sampling rate ~1000Hz

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Collecting the data

Actiheart – Sampling varies up to 1024Hz
Wear for up to 2 weeks

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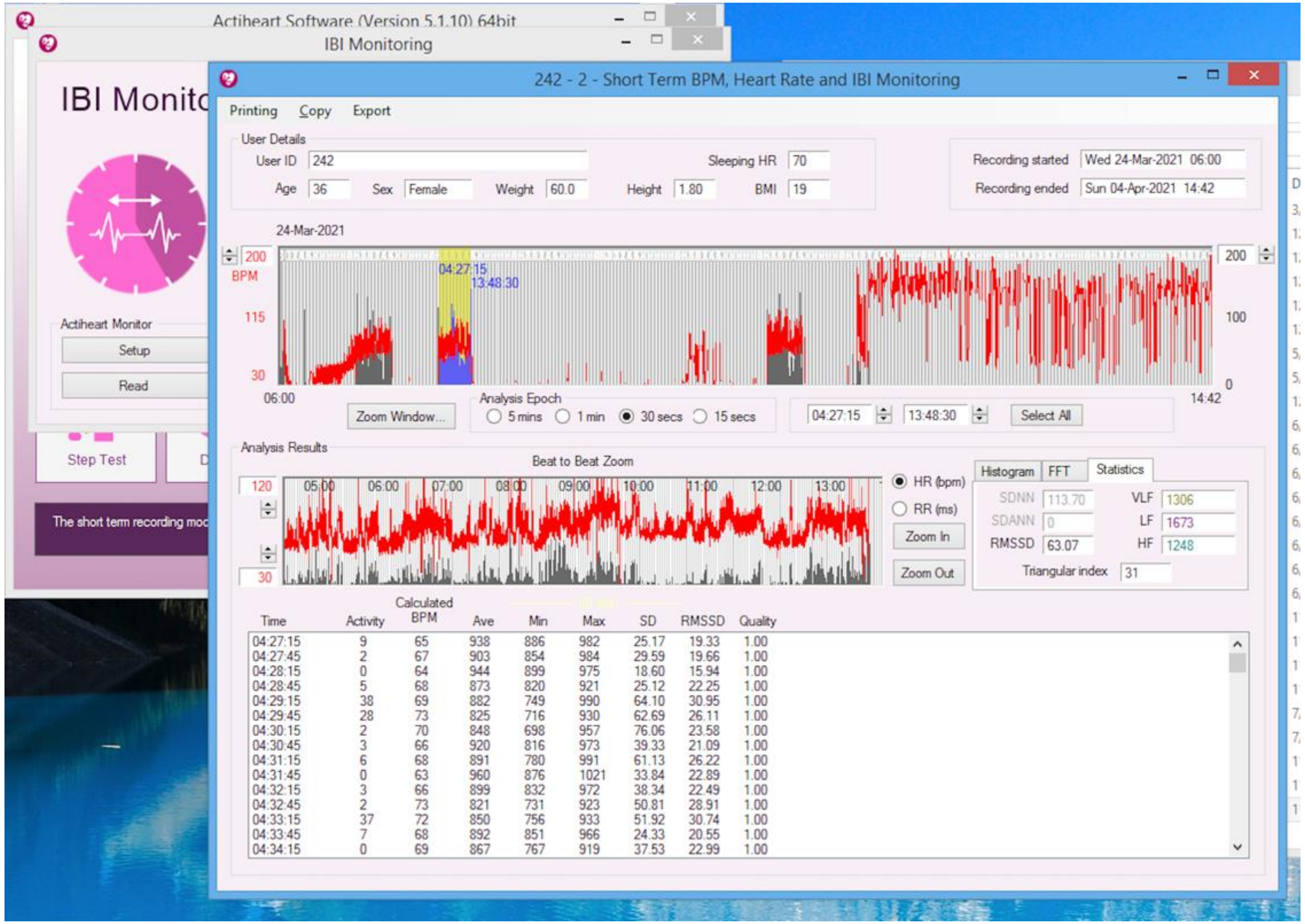
Processing and cleaning the data: Longer-term example of IBI analysis



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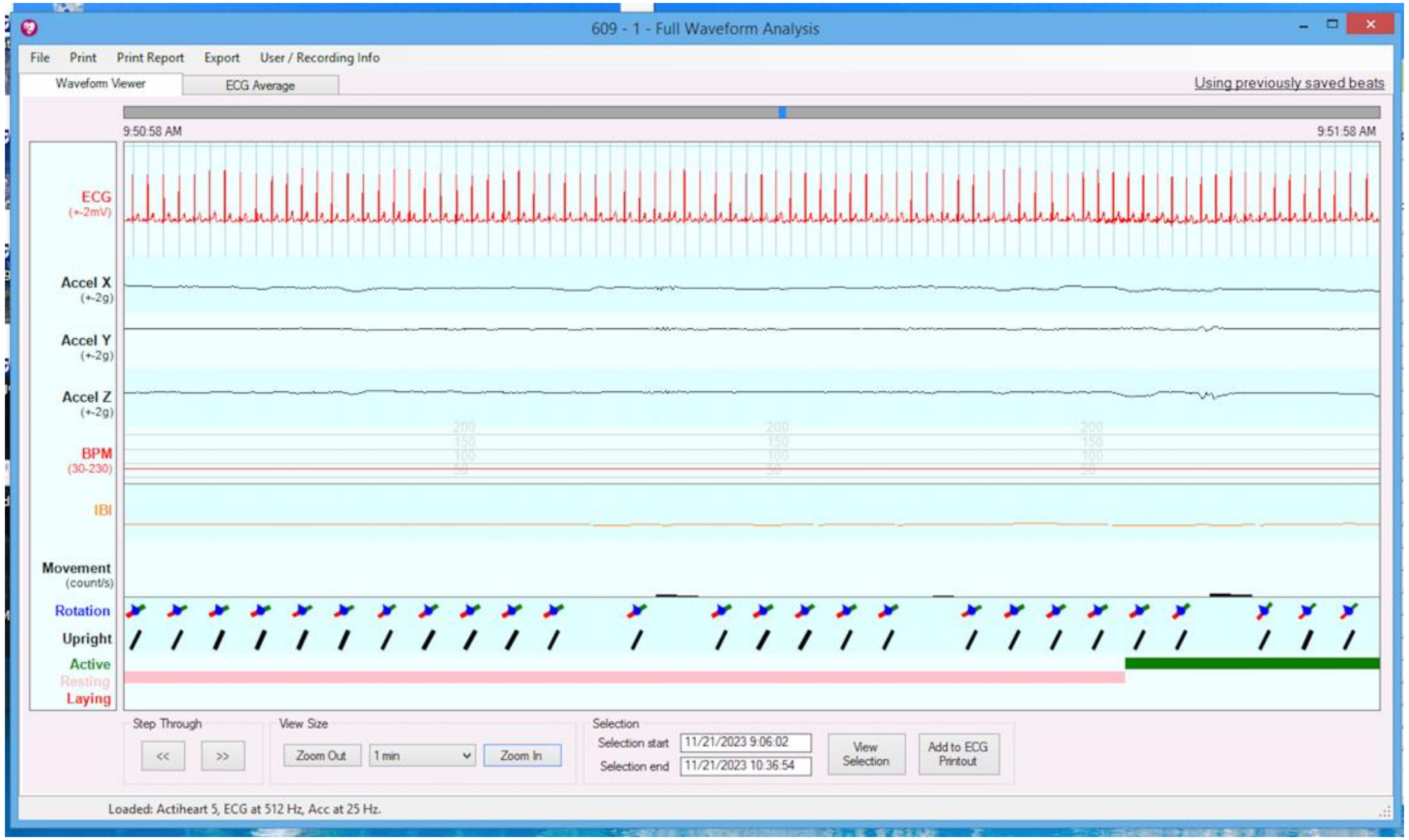
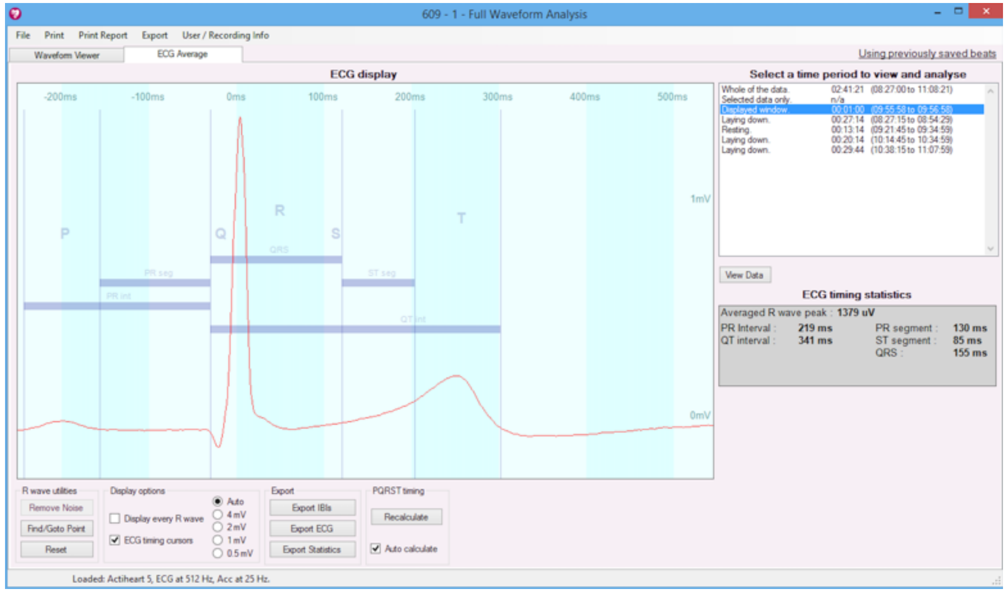
Shorter-term example with full waveform





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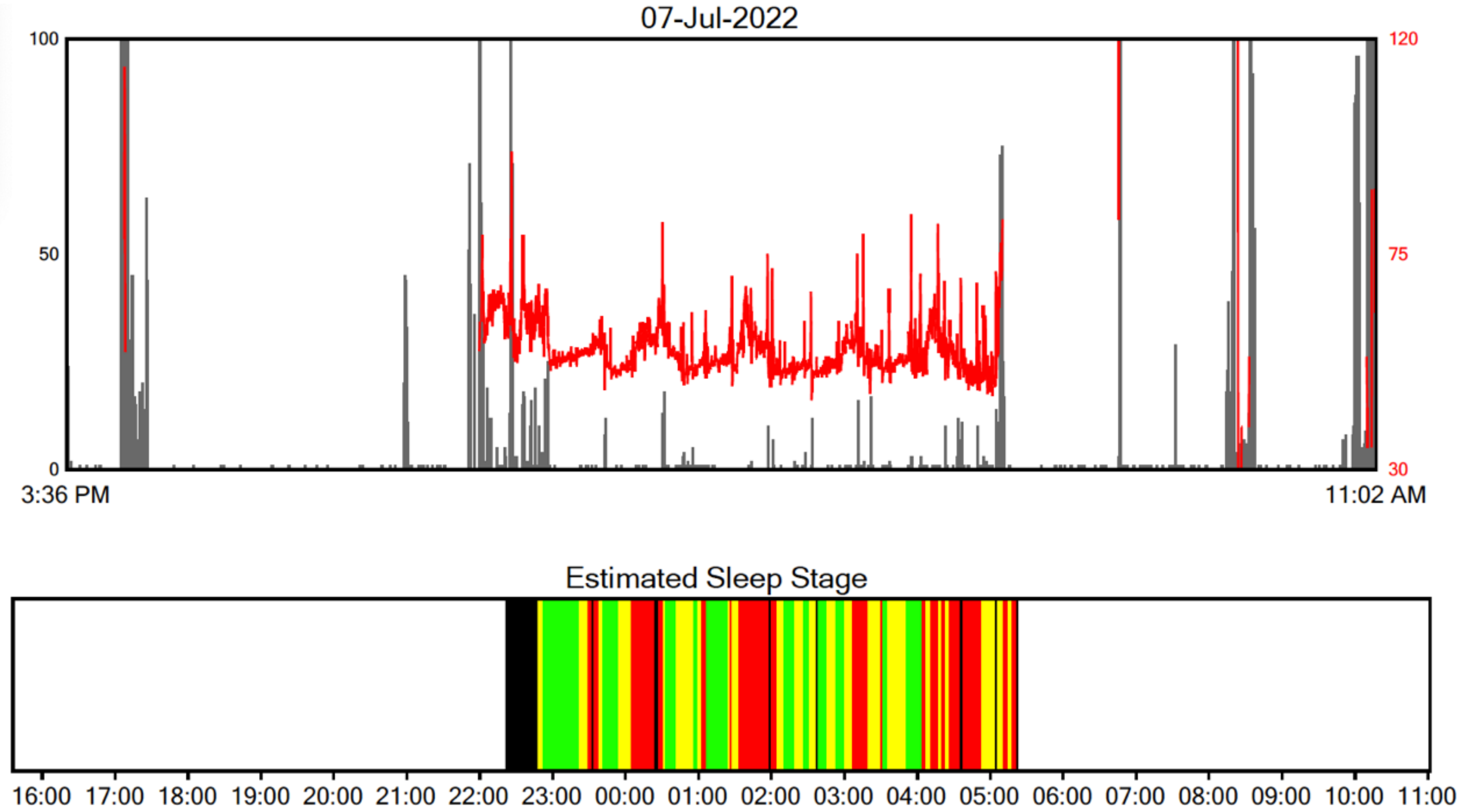
Side note: Can also do sleep staging with Actiheart



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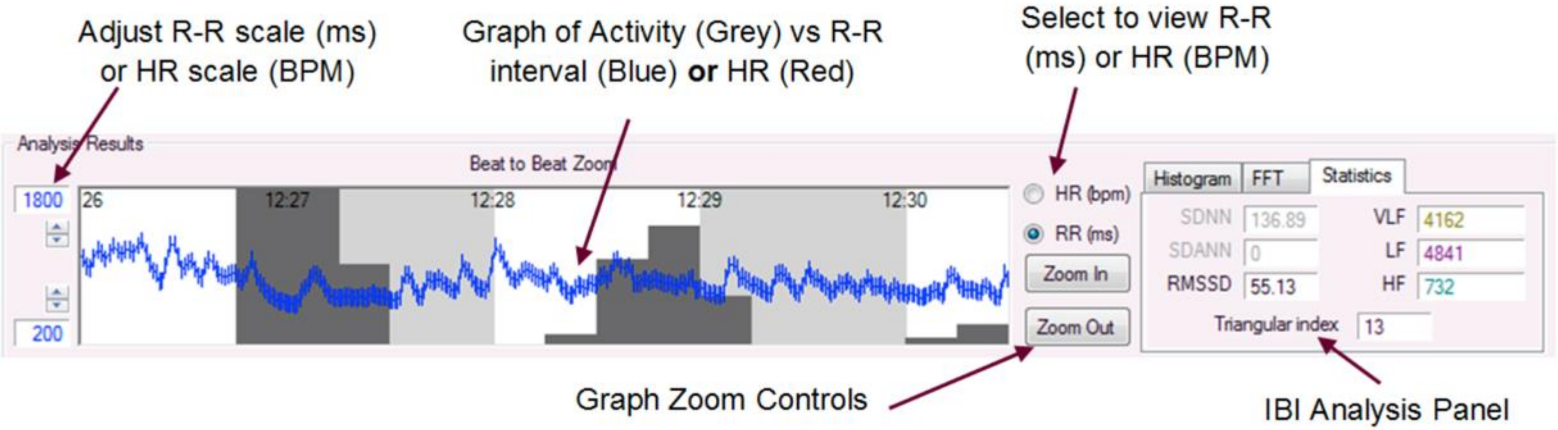
Outputs from *Actiheart* software: Results

Date	Time	Activity	BPM	Ave IBI (ms)	Min IBI (ms)	Max IBI (ms)	SD	RMSSD	Quality	
2022-11-03	09:33:30	0	83	723	588	915	76.68	50.47	1.00	
2022-11-03	09:34:00	11	77	854	287	2000	350.14	404.90	0.69	Invalid data
2022-11-03	09:34:30	3	92	720	281	2000	308.33	382.45	0.25	Invalid data
2022-11-03	09:35:00	6	86	704	663	751	21.50	16.18	1.00	
2022-11-03	09:35:30	11	88	684	656	740	19.39	12.90	1.00	
2022-11-03	09:36:00	22	85	714	672	801	30.12	20.94	1.00	
2022-11-03	09:36:30	10	83	731	673	782	29.13	17.43	1.00	
2022-11-03	09:37:00	9	90	681	607	1299	98.86	138.38	0.94	
2022-11-03	09:37:30	8	85	711	667	792	33.05	18.91	1.00	
2022-11-03	09:38:00	50	88	690	642	749	26.78	18.55	1.00	
2022-11-03	09:38:30	226	97	612	580	688	23.37	16.45	1.00	
2022-11-03	09:39:00	45	100	616	577	1188	85.89	123.28	0.94	
2022-11-03	09:39:30	13	96	629	589	704	25.41	14.46	1.00	
2022-11-03	09:40:00	37	93	647	590	765	42.18	16.14	1.00	
2022-11-03	09:40:30	35	87	692	622	765	32.12	21.60	1.00	
2022-11-03	09:41:00	55	90	832	443	2000	418.64	415.31	0.06	Invalid data
2022-11-03	09:41:30	131	97	631	569	1244	98.16	127.17	0.94	
2022-11-03	09:42:00	71	98	611	569	725	38.97	15.01	1.00	
2022-11-03	09:42:30	2	89	672	641	733	19.78	15.66	1.00	
2022-11-03	09:43:00	9	88	684	617	763	37.60	15.21	1.00	
2022-11-03	09:43:30	3	82	739	677	781	21.52	16.26	1.00	
2022-11-03	09:44:00	0	82	732	665	777	25.31	24.54	1.00	
2022-11-03	09:44:30	2	83	721	599	843	40.46	46.38	1.00	
2022-11-03	09:45:00	12	83	726	674	769	25.41	15.12	1.00	
2022-11-03	09:45:30	2	85	729	655	1447	118.15	158.31	0.94	
2022-11-03	09:46:00	3	85	723	655	1383	107.35	151.35	0.94	

Can do all data analysis with *Actiheart* software



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Outputs from *Actiheart* software: Inter-beat intervals

IBI_354_Sess1_Day1.txt

10:59:57.183	722.66
10:59:57.905	745.12
10:59:58.650	758.79
10:59:59.409	749.02
11:00:00.158	783.20
11:00:00.941	718.75
11:00:01.660	710.94
11:00:02.371	699.22
11:00:03.070	695.31
11:00:03.766	735.35
11:00:04.501	690.43
11:00:05.191	706.05
11:00:05.897	731.45
11:00:06.629	729.49
11:00:07.358	715.82
11:00:08.074	699.22
11:00:08.773	700.20
11:00:09.474	760.74
11:00:10.234	774.41
11:00:11.009	776.37
11:00:11.785	783.20
11:00:12.568	767.58
11:00:13.336	711.91
11:00:14.048	678.71
11:00:14.727	687.50
11:00:15.414	736.33
11:00:16.150	783.20
11:00:16.934	793.95
11:00:17.728	720.70
11:00:18.448	744.14

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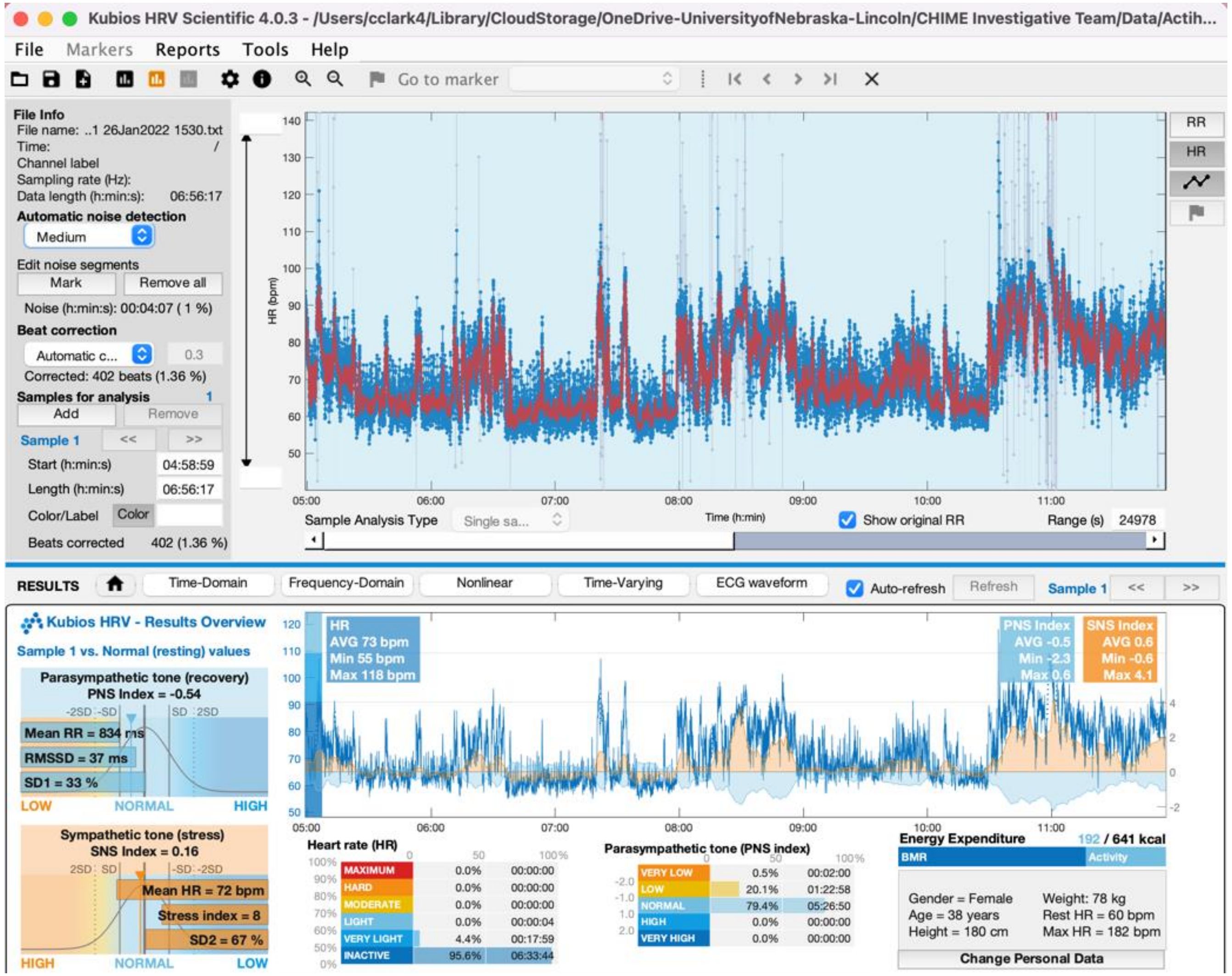
Data analysis in *Kubios*: The good…



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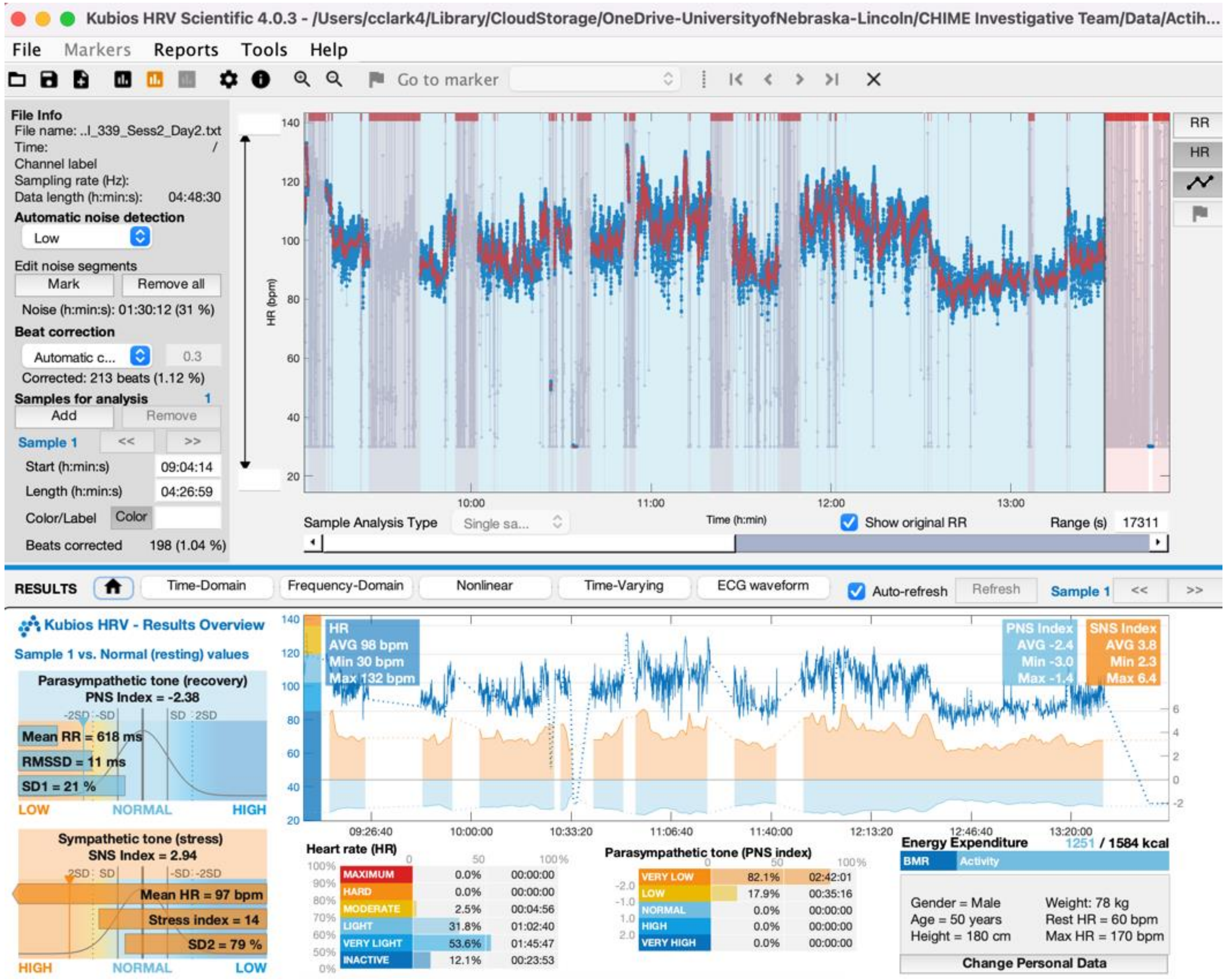
The not so good…



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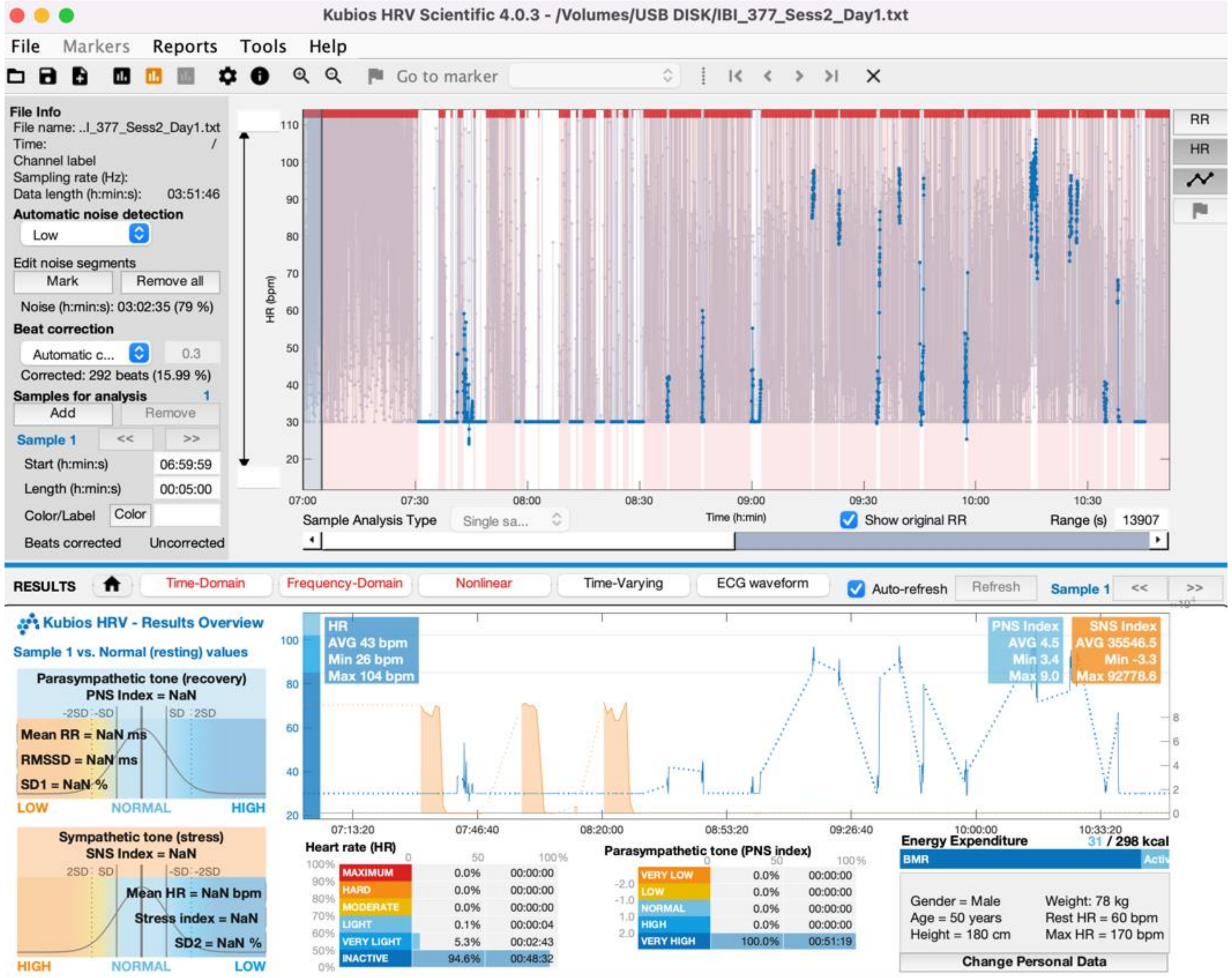
The stuff of nightmares



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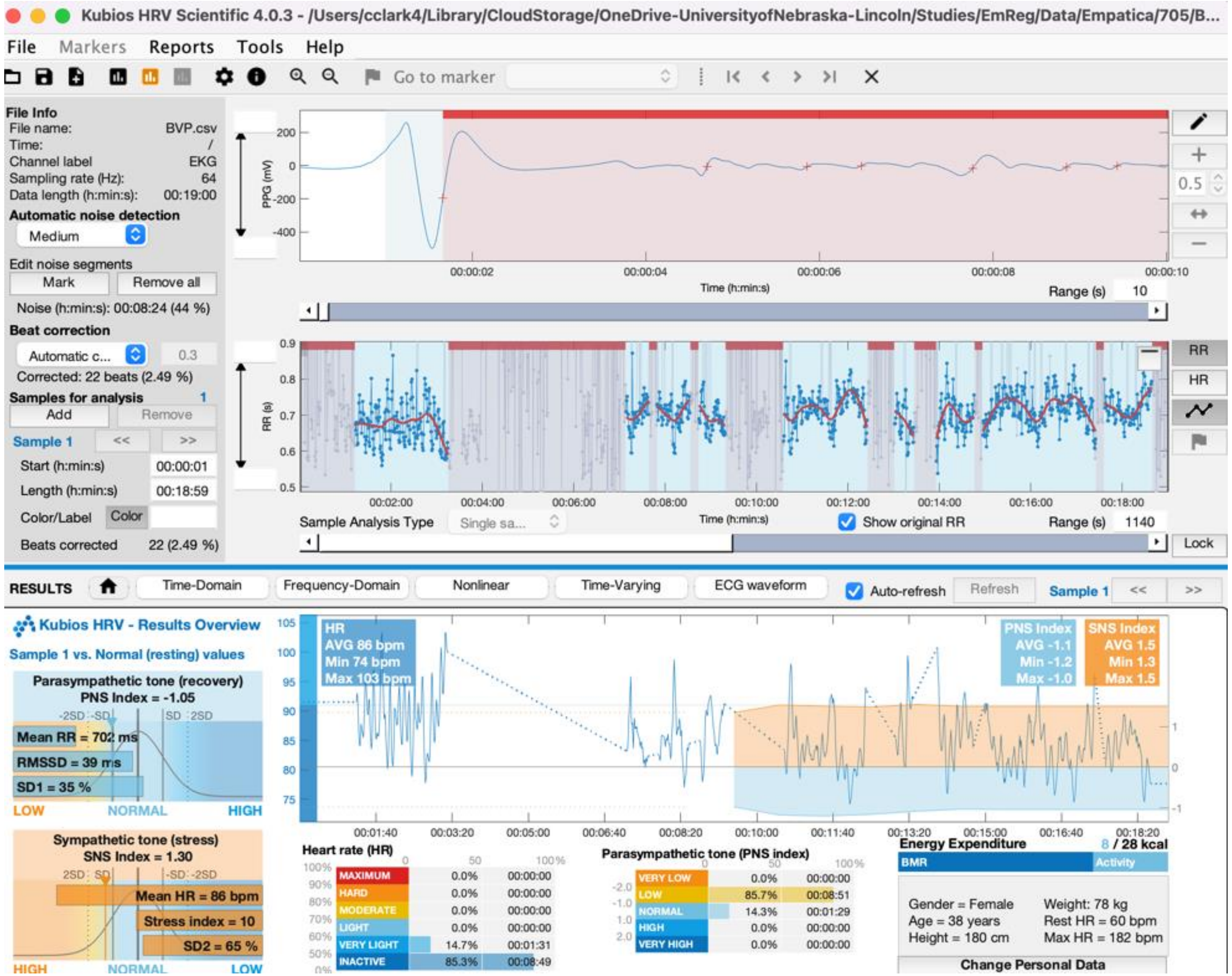
Comparison with *Empatica* wrist-worn device



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Outputs from *Kubios* software

WHOLE DA																				
						Overview								Time-Doma						
Time	Beats total	Beats correc	Beats correc	Effective dat	Effective dat	PNS index	SNS index	Stress index	EE activity	EE activity	Intensity	Load	VO2	Mean RR	SDNN	Mean HR	SD HR	Min HR	Max HR	RMSSD
(hh:mm:ss)	(count)	(count)	(%)	(sec)	(%)				(kcal/min)	(kcal)	(TRIMP/min	(TRIMP)	(l/min)	(ms)	(ms)	(1/min)	(1/min)	(1/min)	(1/min)	(ms)
00:02:30	100	6	6	78	25.8503	NaN	NaN	NaN	NaN	0	NaN	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
00:03:30	151	14	9.2715	122	40.8027	NaN	NaN	NaN	2.4828	2.4828	0.0767	0.0767	0.4384	NaN	NaN	NaN	NaN	NaN	NaN	NaN
00:04:30	198	16	8.0808	163	54.1806	-0.1582	0.1749	7.4342	NaN	2.4828	NaN	0.0767	NaN	820.6266	62.0042	73.1149	5.4233	54.7447	88.9416	53.449
00:05:30	267	19	7.1161	222	73.913	-0.1993	0.1178	7.2315	1.5	3.9828	0.0275	0.1041	0.2751	827.4006	61.4746	72.5163	5.4533	54.7447	89.6057	51.2429
00:06:30	287	15	5.2265	241	80.2676	-0.1621	0.1064	7.5769	2.7464	6.7292	0.0917	0.1958	0.4822	836.8232	58.3079	71.6997	5.0876	54.7447	89.6057	50.5595
00:07:30	349	18	5.1576	292	97.3244	-0.2396	0.1291	7.673	3.3617	10.0909	0.1303	0.3261	0.5845	835.7218	55.4503	71.7942	4.8525	54.7447	89.6057	47.9181
00:08:30	354	10	2.8249	293	97.6589	-0.4976	0.457	9.4678	2.6063	12.6972	0.0836	0.4098	0.4589	825.9951	45.4664	72.6397	4.1443	62.8667	89.6057	39.7512
00:09:30	359	8	2.2284	293	97.6589	-0.6107	0.4958	9.3312	1.8609	14.5581	0.0443	0.4541	0.3351	817.3508	44.4001	73.4079	4.1423	62.8667	89.6057	37.3996
00:10:30	365	5	1.3699	294	98	-0.6828	0.7539	10.7983	3.0089	17.567	0.1076	0.5616	0.5258	808.1024	39.1015	74.248	3.6303	62.8667	87.4126	35.3992
00:11:30	295	5	1.6949	238	79.2642	-0.7488	0.7713	10.7455	2.7106	20.2775	0.0896	0.6513	0.4763	805.0341	38.0961	74.531	3.5744	62.8667	87.4126	33.7329
00:12:30	230	0	0	184	61.204	-0.7646	0.8711	11.1552	4.0795	24.3571	0.1819	0.8332	0.7037	797.8	37.7349	75.2068	3.5988	67.659	87.4126	34.1026
00:13:30	216	0	0	175	58.194	-0.4949	0.6709	10.4674	NaN	24.3571	NaN	0.8332	NaN	807.0926	41.1453	74.3409	3.8633	64.4607	87.4126	41.1796
00:14:30	157	1	0.6369	129	42.953	NaN	NaN	NaN	NaN	24.3571	NaN	0.8332	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
00:15:30	82	1	1.2195	68	22.7425	NaN	NaN	NaN	2.4965	26.8536	0.0774	0.9106	0.4407	NaN	NaN	NaN	NaN	NaN	NaN	NaN
00:16:30	136	2	1.4706	113	37.7926	NaN	NaN	NaN	NaN	26.8536	NaN	0.9106	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
00:17:30	210	5	2.381	173	57.5251	0.0903	0.0632	7.2199	NaN	26.8536	NaN	0.9106	NaN	819.5398	55.3516	73.2118	4.8865	62.5	97.4026	59.7506
00:18:30	225	5	2.2222	180	60	-0.0688	0.252	7.8114	2.3376	29.1912	0.0687	0.9793	0.4143	805.5349	54.3717	74.4847	4.9634	62.5	97.4026	56.759
00:19:30	258	7	2.7132	208	69.4631	0.1847	0.0896	6.7421	3.3435	32.5347	0.1291	1.1084	0.5814	802.5045	61.2226	74.7659	5.4976	62.5	97.4026	66.1971
00:20:30	326	9	2.7607	264	87.9599	0.2121	-0.0091	6.0881	3.4234	35.9581	0.1345	1.2429	0.5947	806.4331	66.6333	74.4017	6.1637	57.5595	97.4026	67.5335
00:21:30	268	8	2.9851	217	72.2408	0.1478	0.0203	6.2848	2.643	38.6011	0.0857	1.3286	0.465	807.6121	65.1866	74.2931	6.0626	57.5595	93.4871	65.1486
00:22:30	194	5	2.5773	157	52.1739	0.305	-0.0613	5.8024	1.3171	39.9182	0.0194	1.348	0.2447	809.294	71.4848	74.1387	6.633	57.5595	93.4871	70.8522

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Challenges and issues: Measurement

- **Motion artifact:** Can have a major impact on findings. Data requires extensive cleaning and checking.
- **Length of data collection:** Different recording lengths can impact HRV.
- **Respiration:** Lower respiration rates increase hf-HRV. Less pronounced impact on RMSSD.
- **Other unmeasured factors:** Health and fitness, sex, age
- **Tonic vs. Phasic measures:** What is the 'baseline' in real-world contexts?

Challenges and issues: Practicalities

- Child willingness to wear device
- Ensuring that the devices are worn correctly
- Quality measurement, e.g., electrode expiration, electrode types
- Updates to software and hardware during data collection
- Data cleaning and processing time

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Example: The CHIME intervention study

- 162 Nebraska early childhood educators (106 Treatment, 47 Waitlisted)
- 143 consented to HRV – 12 dropped out/didn't complete study
- Collected from 111 teachers
- 99 with usable data pre-intervention, 87 post-intervention

CHIME

CULTIVATING HEALTHY INTENTIONAL MINDFUL EDUCATORS

CHIME Intervention

- Begins with a 2-hour introduction to mindfulness as an ECE professional, followed by 7 sessions that are 1.5 hours long

- **Session structure:**
- Reflecting in journals and listening to understand dyadic activity
- Group discussion of topic for the week (mindfulness in breathing, mindfulness in listening)
- Mindfulness activity and guided meditation
- Learn put into practice activities (mindfulness activities to do with children)
- Setting intentions

https://child.unl.edu/chime

Hatton-Bowers H, Clark C, Parra G, Calvi J, Bird MY, Avari P, Foged J, Smith J. Promising Findings that the Cultivating Healthy Intentional Mindful Educators' Program (CHIME) Strengthens Early Childhood Teachers' Emotional Resources: An Iterative Study. Early Child Educ J. 2022 Aug 8:1-14.

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Sample characteristics

M (range) Age	38.3 (20 - 70)
% Female	100
% White	87.1
% Hispanic/Latinx	7.1
M (range) Years childcare experience	10.7 (1 – 21)
% Bachelor's/Associate's degree	60.40
% Graduate degree	10.3
Median monthly household income bracket	$2,500 - $3,332
% Preschool teacher	59

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Measures of emotion regulation collected pre- and post-intervention

- **Difficulties in Emotion Regulation Scale** (DERS; Gratz & Roemer, 2004): Nonacceptance, goal-directed behavior, impulse control, emotional awareness, strategies, emotional clarity
- **Emotion Regulation Questionnaire** (Gross & John, 2013): Emotional Reappraisal, Suppression
- Created a composite variable from DERS and ERQ Reappraisal (r = -.55) for each timepoint

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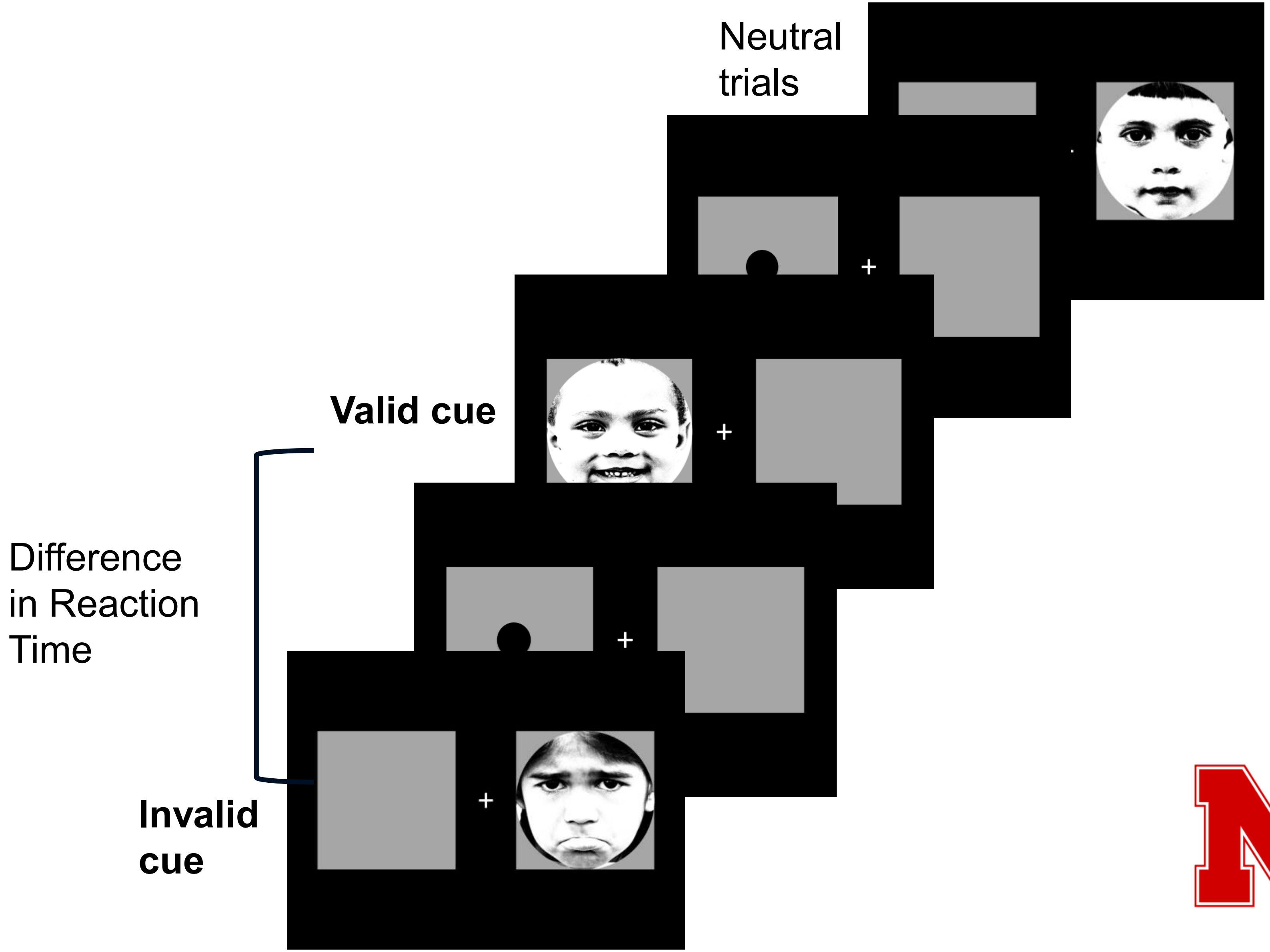
Emotion regulation task: Spatial affective cue



Based on Fox, Riccardo, & Dutton (2002)

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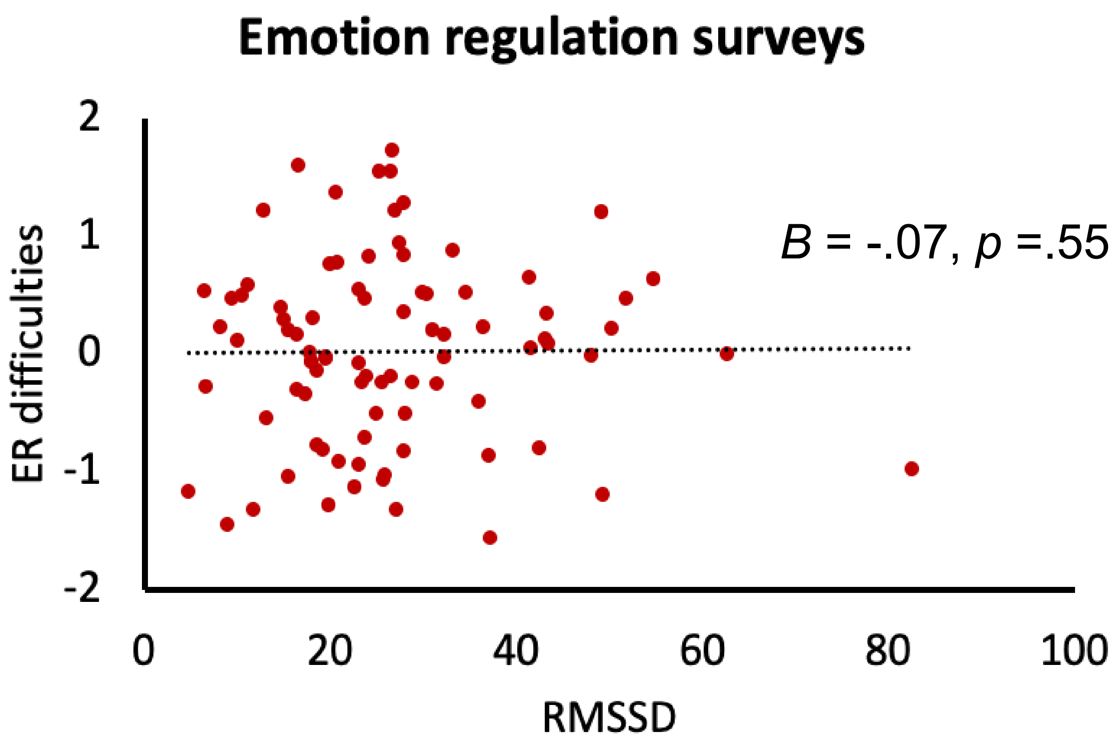
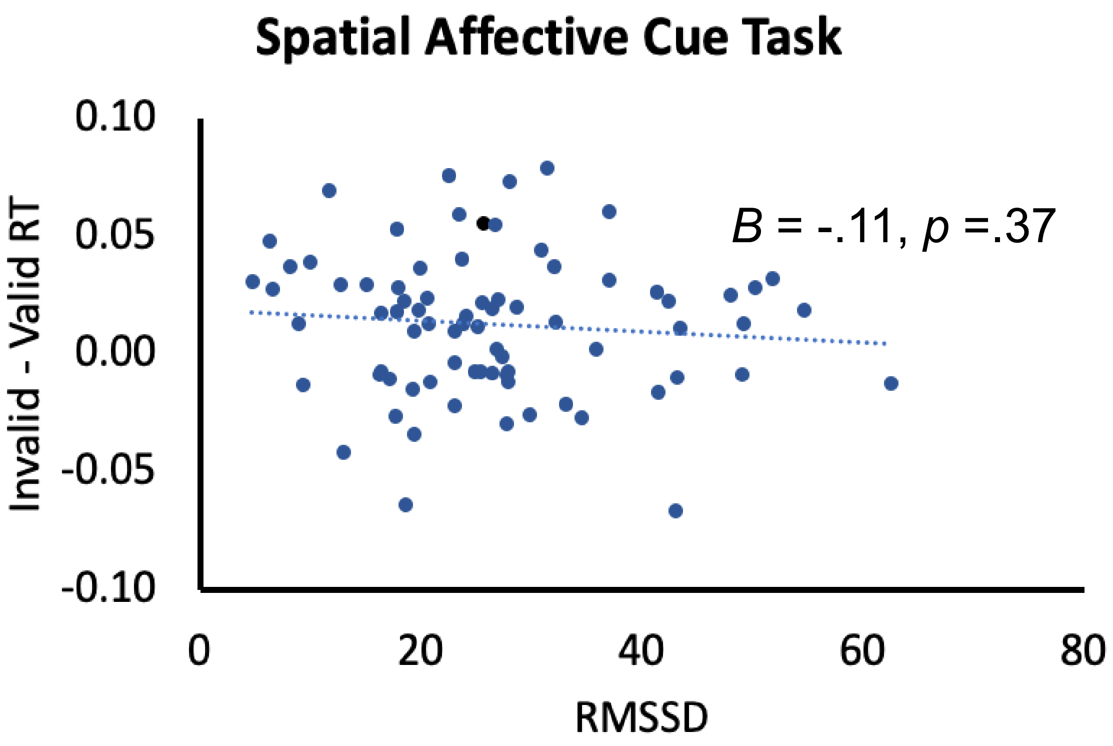
Correlations between measures at different time points

	RMSSD Pre	RMSSD Post	Hf-HRV Pre	Hf-HRV Post	HR Pre
RMSSD Post	.74**				
Hf-HRV Pre	.85**	.68**			
HF-HRV Post	.66**	.92**	.76**		
HR Pre	-.52**	-.24*	-.38**	-.13	
HR Post	-.42**	-.49**	-.30*	-.37**	.78**

N MAP ACADEMY

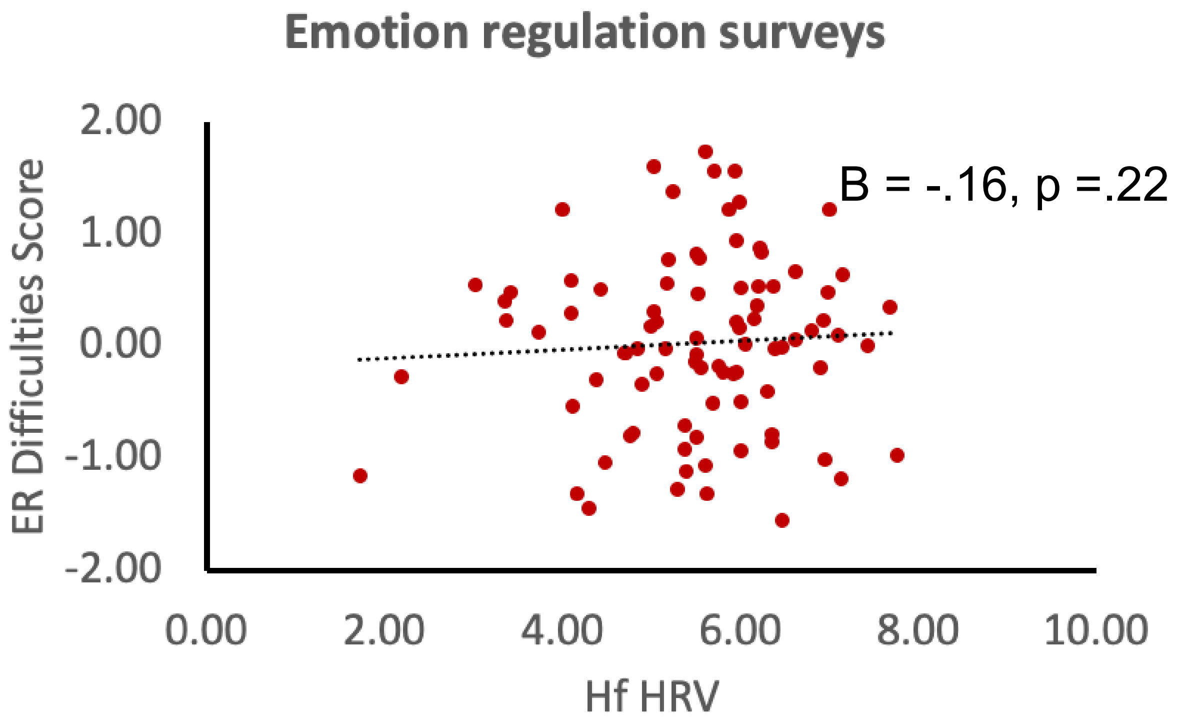
Pre-intervention associations: RMSSD

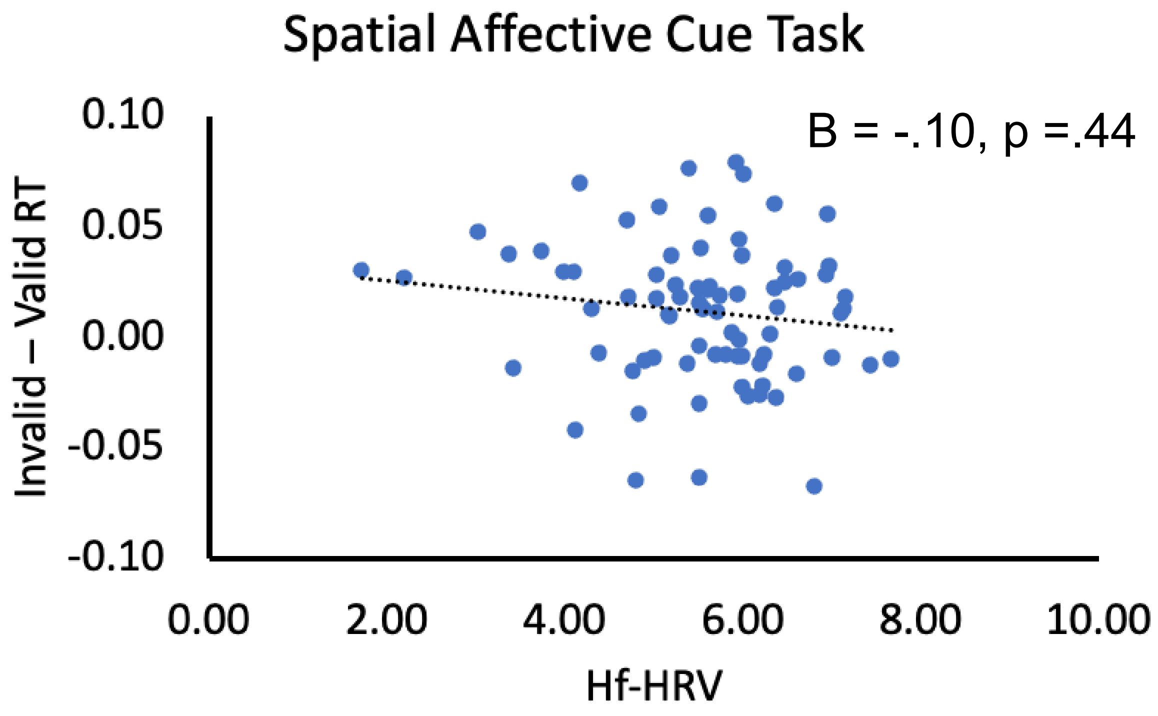




MAP ACADEMY

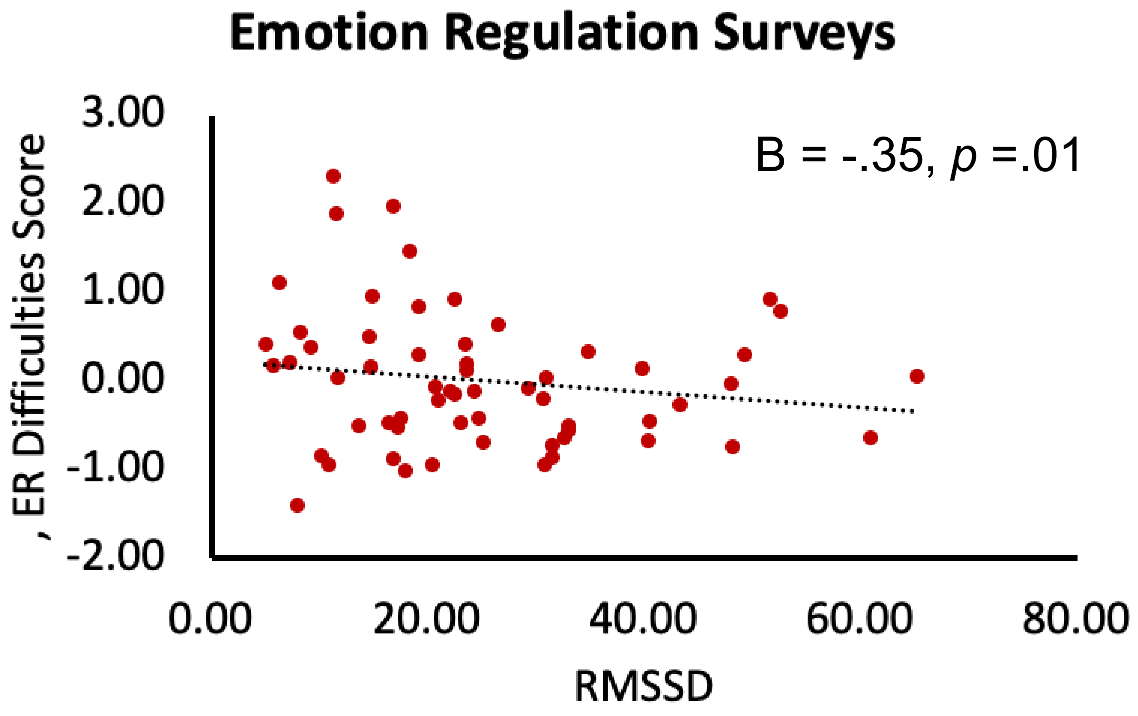
Pre-intervention associations: hf-HRV

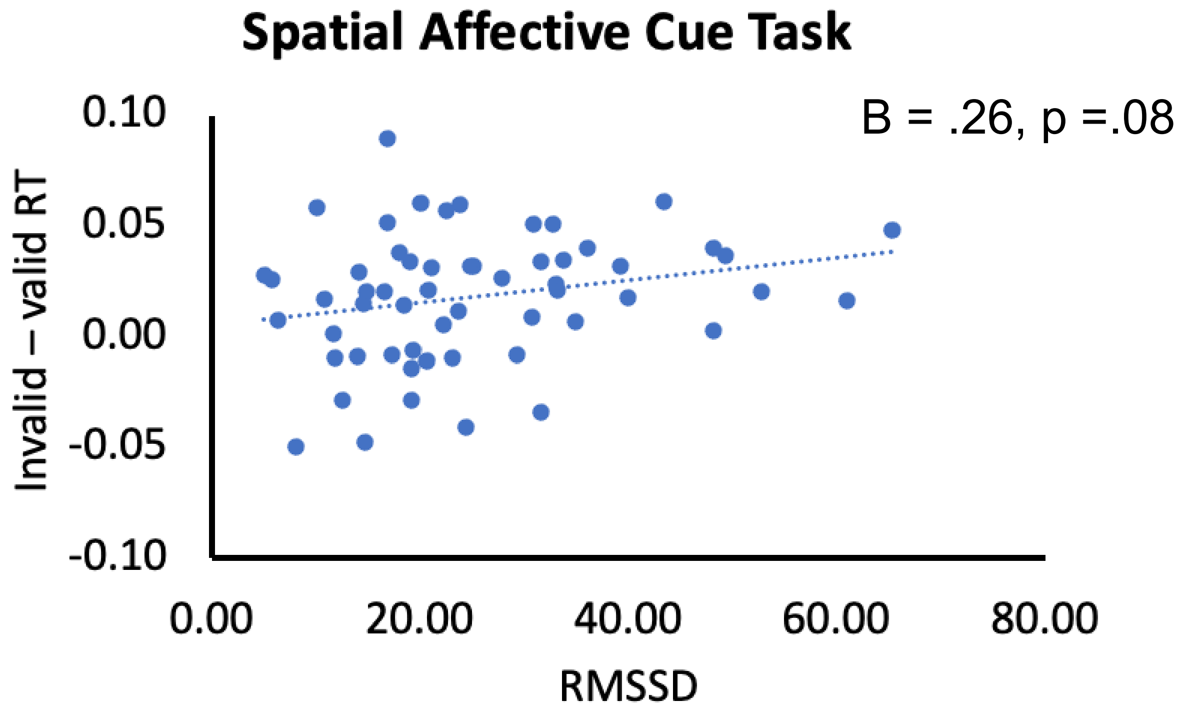




MAP ACADEMY

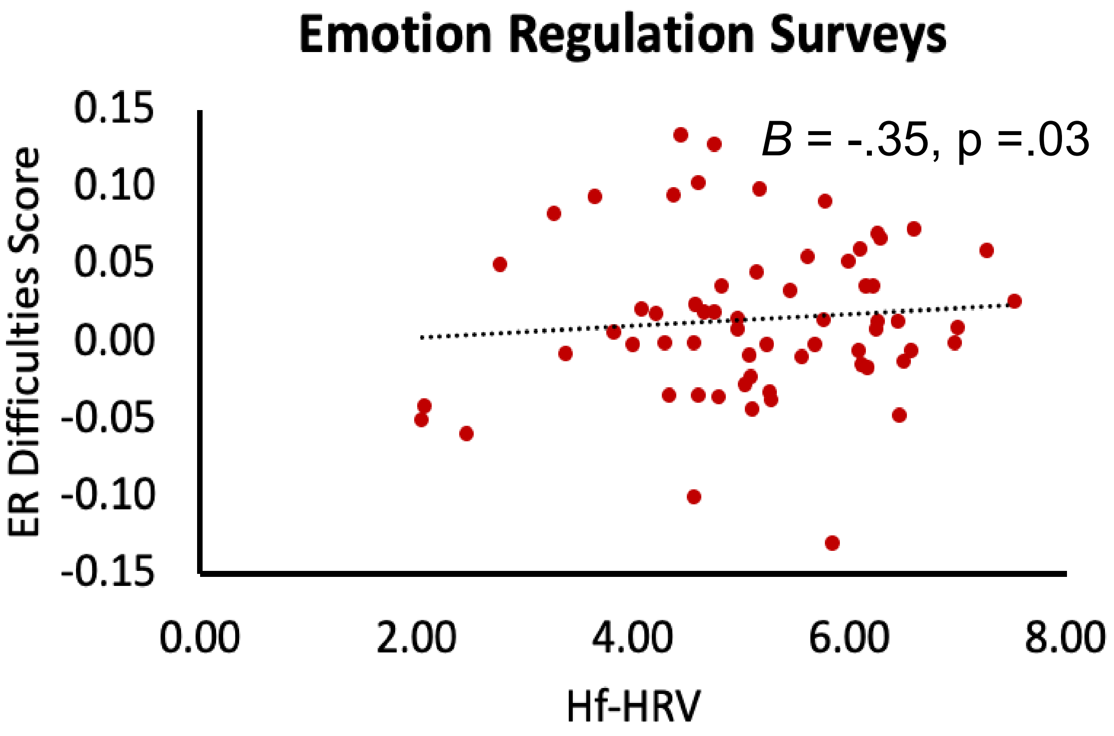
Post-Intervention associations: RMSSD

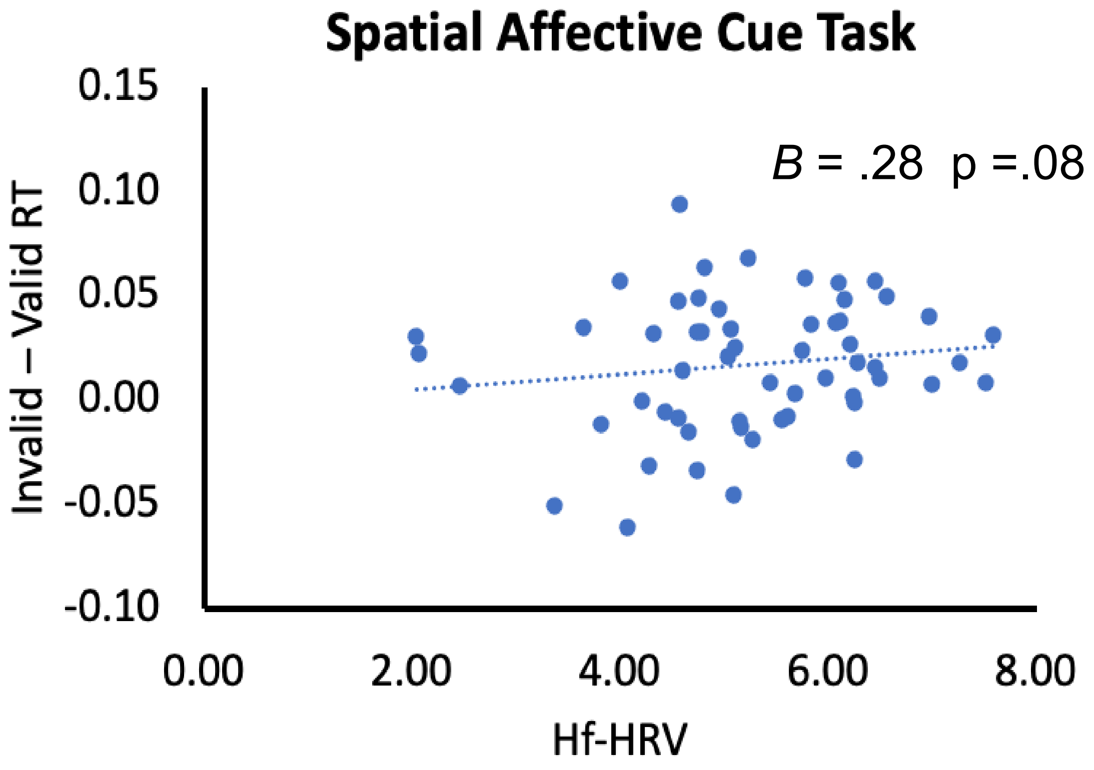




MAP ACADEMY

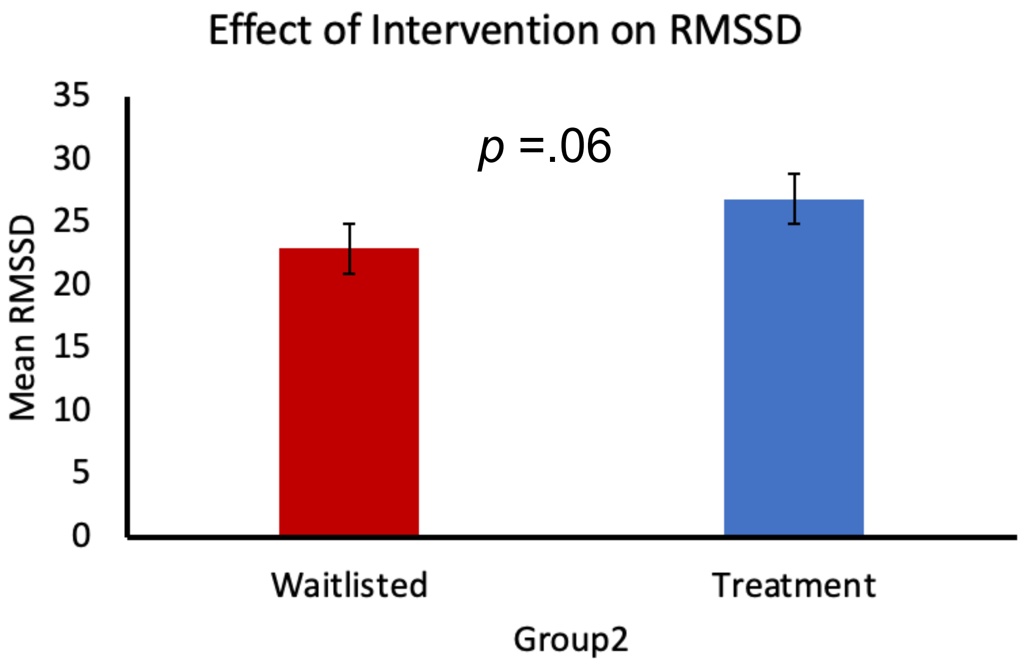
Post-intervention associations: hf-HRV



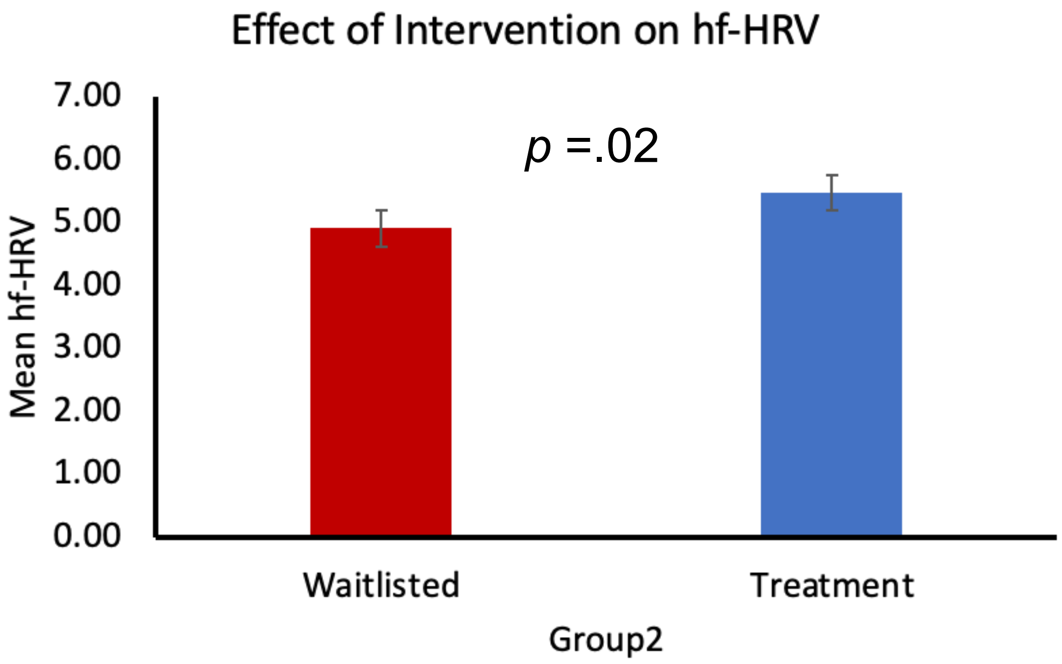


MAP ACADEMY

CHIME intervention effects on HRV



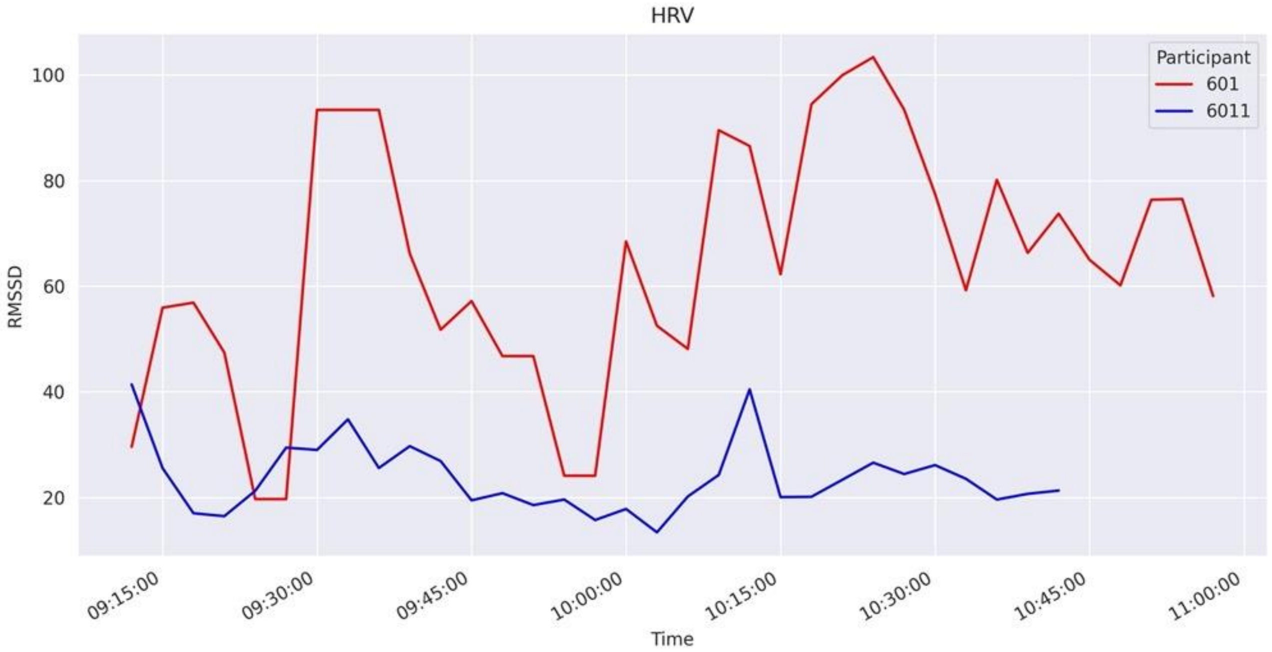
Controlling for RMSSD at time 1

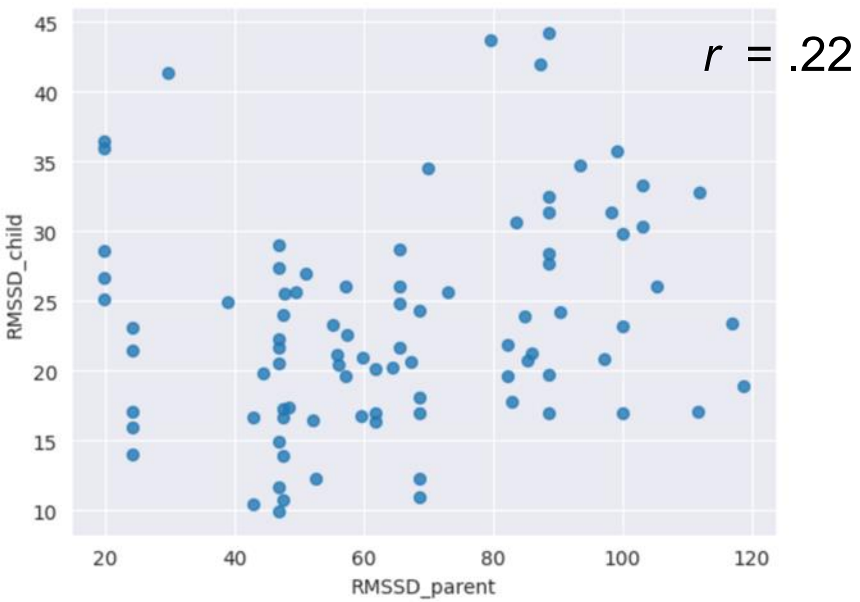


Controlling for hf-HRV at time 1

MAP ACADEMY

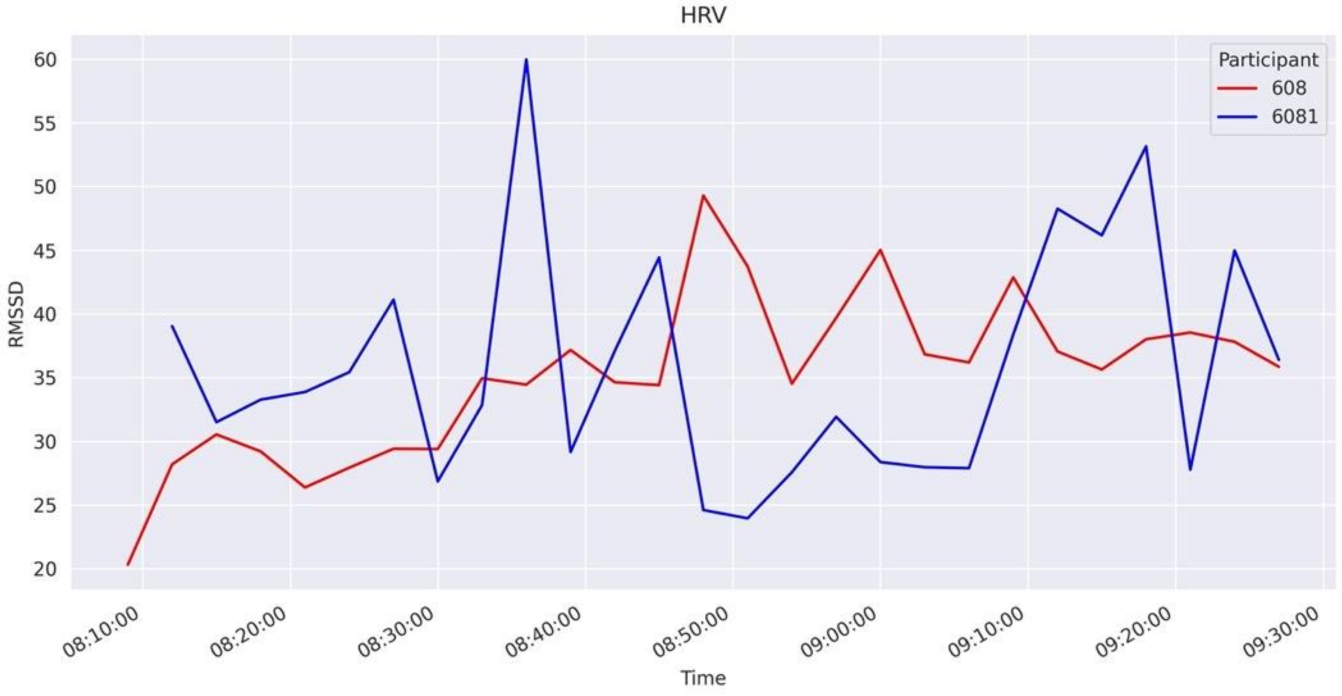
Current directions: Parent-child synchrony

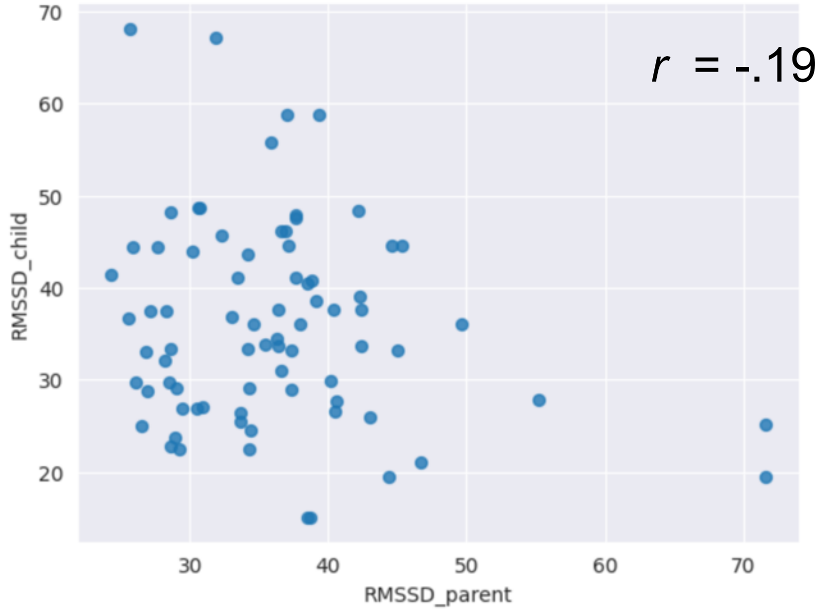




MAP ACADEMY

Parent-child synchrony





MAP ACADEMY

Especially helpful readings

- Appelhans, B.M., & Leuken, L. (2006). Heart rate variability as an index of regulated emotional responding. Review of General Psychology, 10 (3), 229-240.
- Laborde, S., Mosley, E., & Mertgen, A. (2018). Vagal tank theory: The three Rs of cardiac vagal control functioning – resting, reactivity, and recovery. Frontiers in Neuroscience, 12.
- Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research–recommendations for experiment planning, data analysis, and data reporting. *Frontiers in psychology*, *8,* 213.
- Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in public health*, *5*, 258.
- Thayer, J., & Lane, R. (2000). A model of neurovisceral dysregulation in emotion regulation and dysregulation. J of Affective Disorders, 61, 201 – 216.

From Dusk Till Dawn: The Role of Wearables in Understanding Sleep Patterns

Full Disclosure- the title of this presentation was generated by ChatGPT. I am an academic, not a creative writer. The rest of this presentation however, is all me.

MAP ACADEMY

Sleep- Why Should we Care?

- In children
  - Social/emotional, behavioral, cognitive, physical health, academic achievement (Chen et al., 2008; Geiger et al., 2010; Gregory & Sadeh, 2012, Touchette et al., 2009)

- In adults
  - Increased risk for health problems & lower quality of life (Strine & Chapman, 2005)
    - Arthritis, asthma, cancer, depression, diabetes, emphysema, epilepsy, hypertension, heart disease, migraines, stroke, ulcers, BMI (Gregory, 2008; Kohatsu et al., 2006)

How Sleep is Traditionally Measured in Naturalistic Settings

- Self-report
- Overall average
- Sleep diaries

- How much sleep do you get at night?

National Sleep Foundation Recommendations

Hirshkowitz et al., 2015

- Infants: 14-17 hours
- Toddlers: 11-14 hours
- Preschoolers: 10-13 hours
- School-age children: 9-11 hours
- Teenagers: 8-10 hours
- Young adults/adults: 7-9 hours
- Older adults: 7-8 hours

Fun fact: Determined by committee- no empirical basis

What’s Wrong with Self- Report???

Adults conditioned to report 7-8 hours sleep/night

Parents notorious for over-estimating their child’s sleep- anywhere between half and hour and 2 hours (Dayyat et al., 2011; Molfese et al., 2015; Nelson et al., 2014)

Preview

Toddler Study:

- P reported sleep duration: 10.5 hours/night
- A recorded sleep duration: 8.30 hours/night
  - *Difference of 2+ hours*

Sleep in Ag Study:

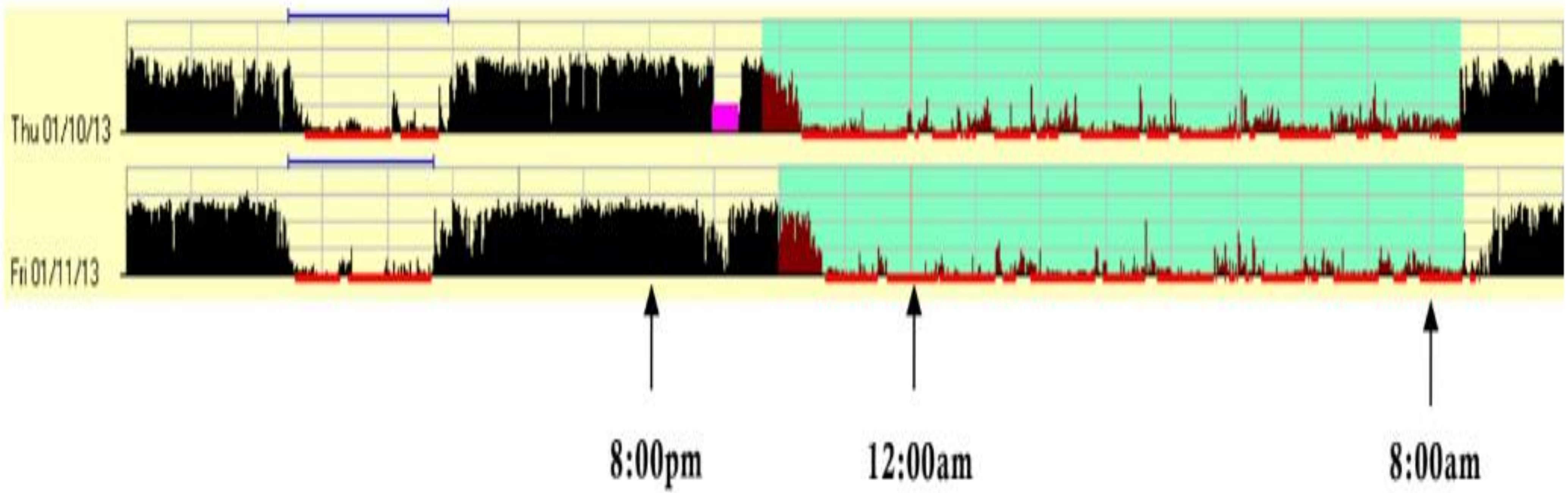
- Self reported: 7.92 hours/night
- A recorded: 6.8 to 7.3 hours/night
  - *Difference of 37 to 67 minutes/night*

The Solution

- Actigraphy: accelerometer
  - Small, wristwatch like device that measures motion and activity levels
  - Records a level of acceleration every minute
  - Periods of high motion = awake
  - Periods of low motion = sleep

- Actigraphy validated against gold-standard polysomnography
  (Acebo et al., 2005; Sadaka et al., 2014, Sadeh & Acebo, 2002; Sadeh et al., 1991)

Actigraphy Data



Advantages of Actigraphy

More accurate/objective measure of sleep

- Total Sleep Time
- Sleep Latency
- Sleep Efficiency
- Wake After Sleep Onset

Ability to measure several nights in a row

- Night to Night Variability

Can collect data for up to 3 weeks

Newer models can capture:

- Ambient Light
- Skin Temperature
- HRV
- Oxygen Saturation
- Blood Pressure

Software automatically scores sleep/wake/non-wear times

Two Studies

Toddler Sleep Study (PIs: Bates, Molfese, Molfese, Rudasill)

- 5-year longitudinal multi-site NICHD study
- Sleep, temperament, self regulation in toddlers
- Sleep measured for 2 weeks at 30, 36, and 42 months old

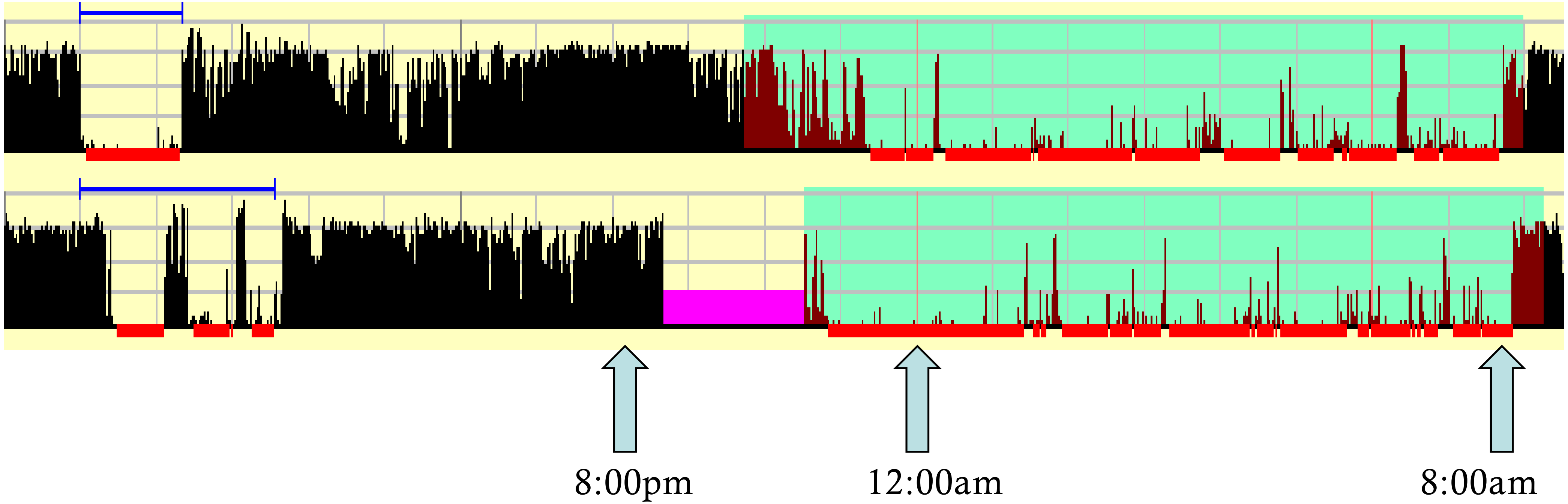
Funding: National Institute for Child Health and Human Development, grant number HD073202

Sleep in Ag Study (PIs: Prokasky, Harris)

- Pilot study of sleep in farmers/ranchers in 5 states in Midwest
- Differences between peak "busy" seasons and non-peak "slow" seasons
- Sleep measured for 1 week during busy season, and 1 week during slow season

Funding: Central States Center for Agricultural Safety and Health NIOSH (U54 OH010162)

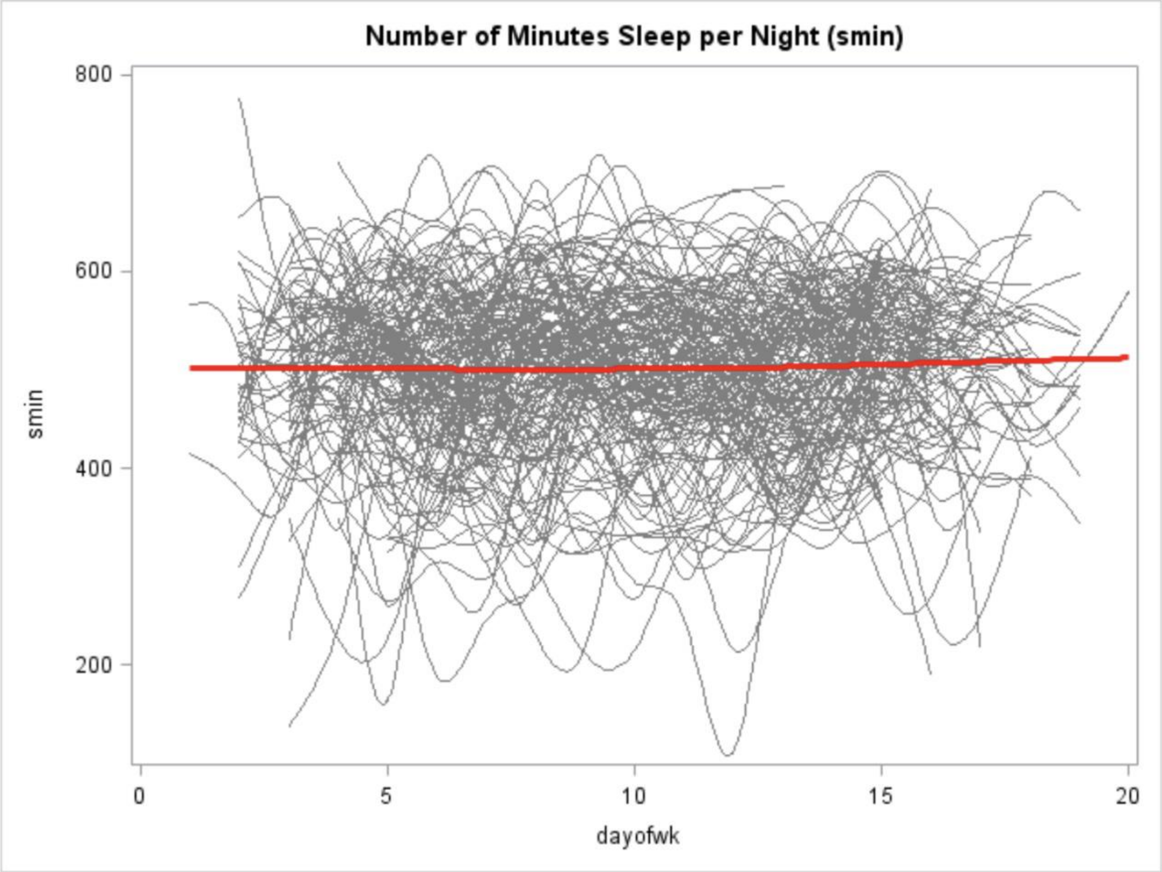
Toddler Study: Actigraphy + Sleep Diary Data

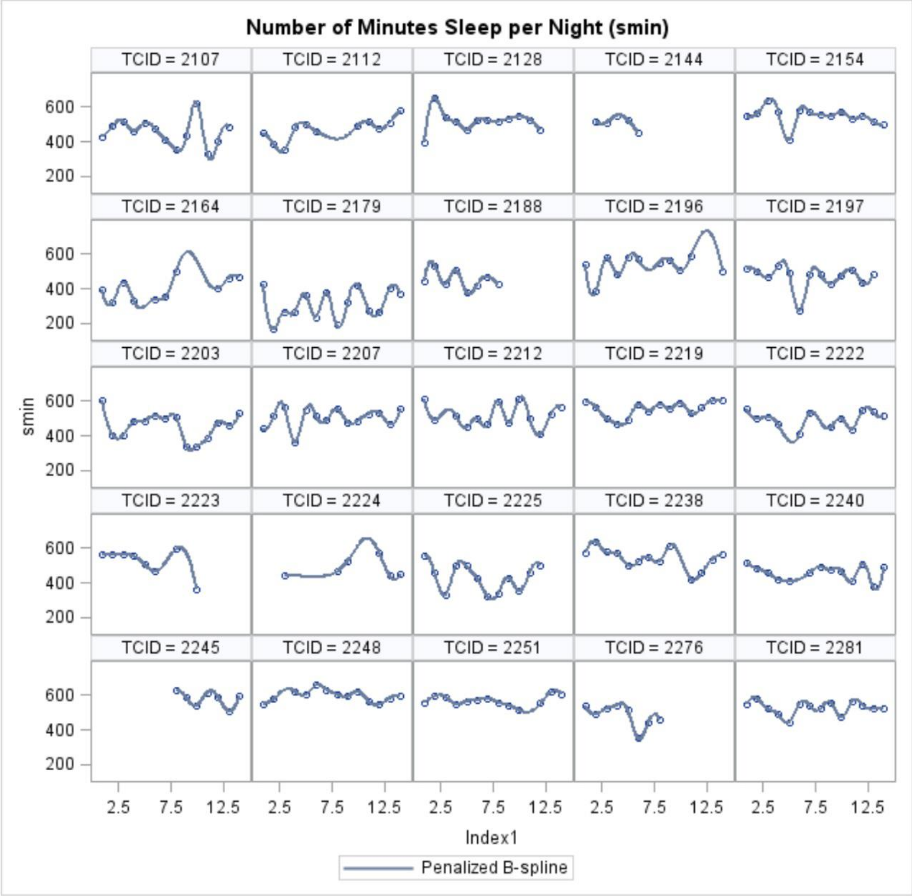


Red Underline: Actigraph recorded sleep
Teal highlight: Parent reported time in bed
Blue overline: Parent reported nap time
pink highlight: Actigraph not worn

Toddler Study: Night to Night Variability

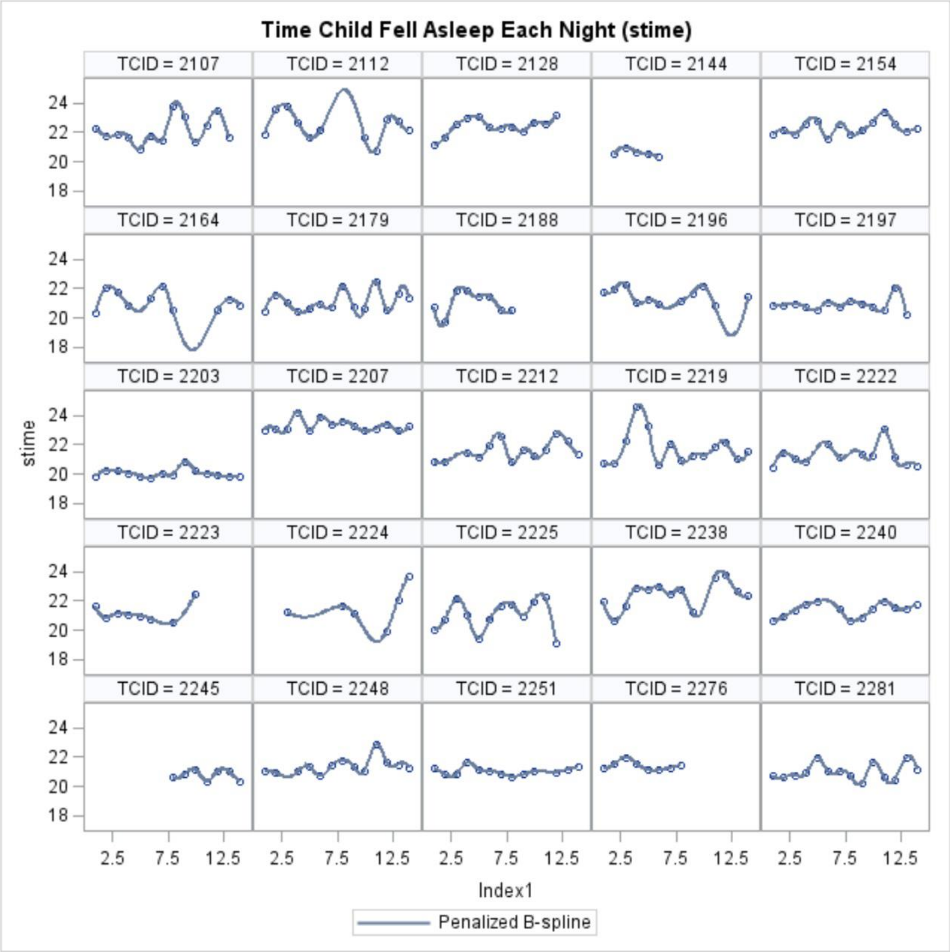
Prokasky, Fritz, Molfese, 2019

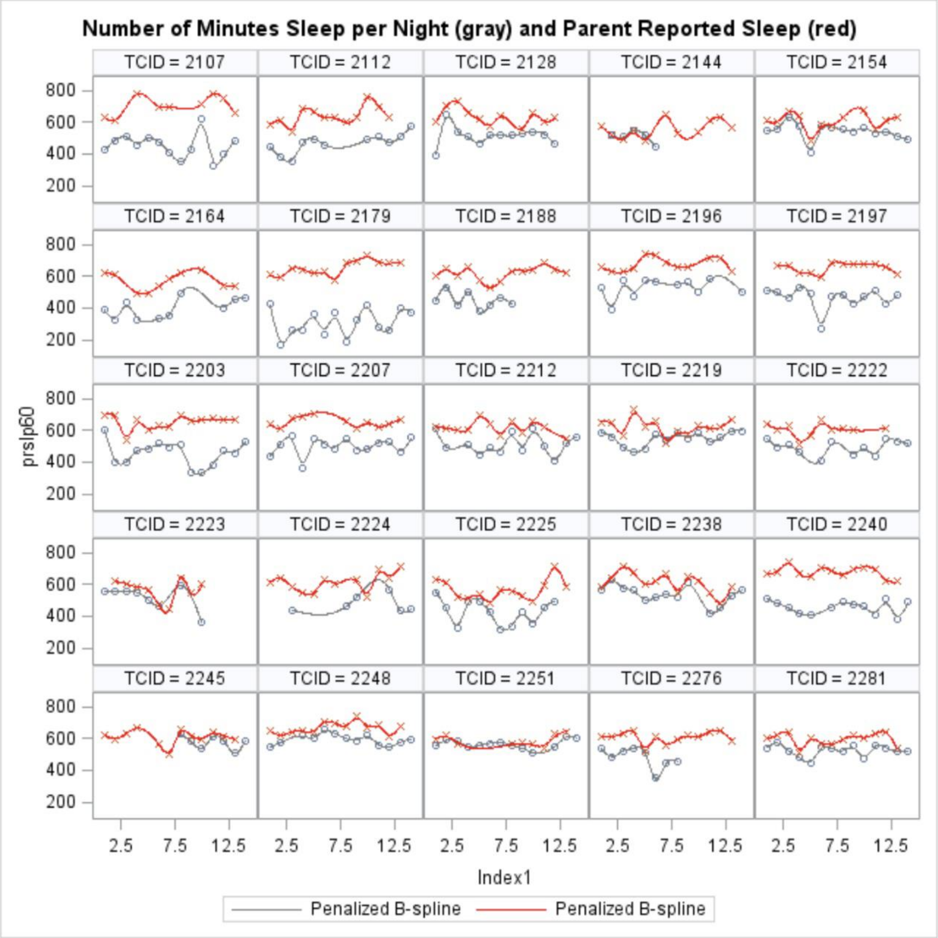




Toddler Study: Night to Night Variability

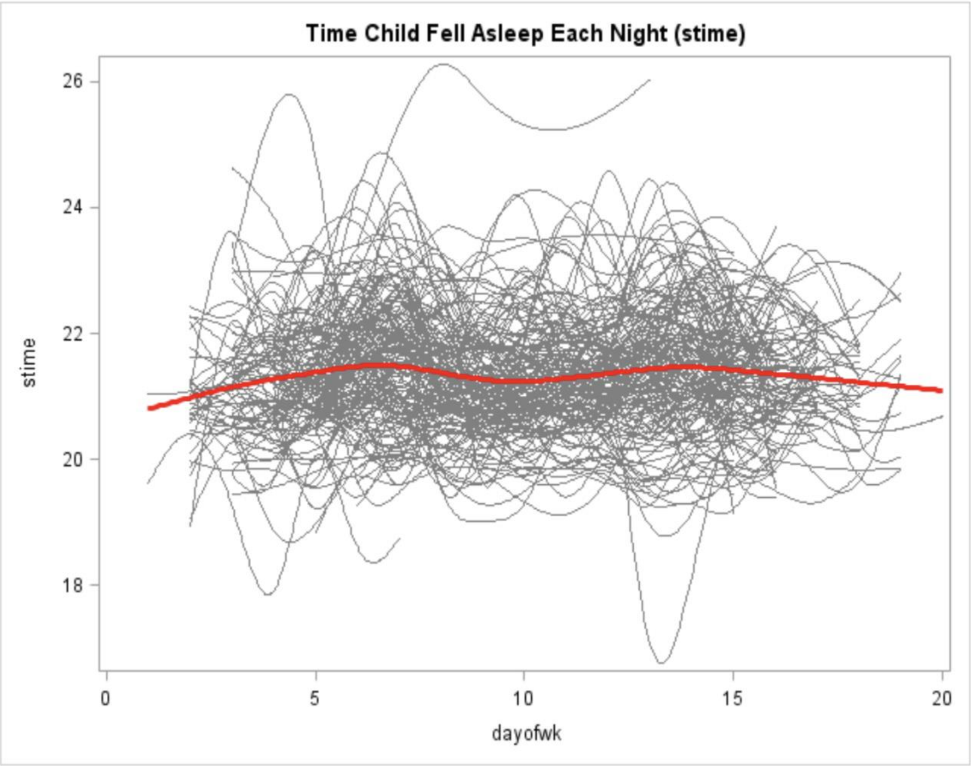
Prokasky, Fritz, Molfese, 2019

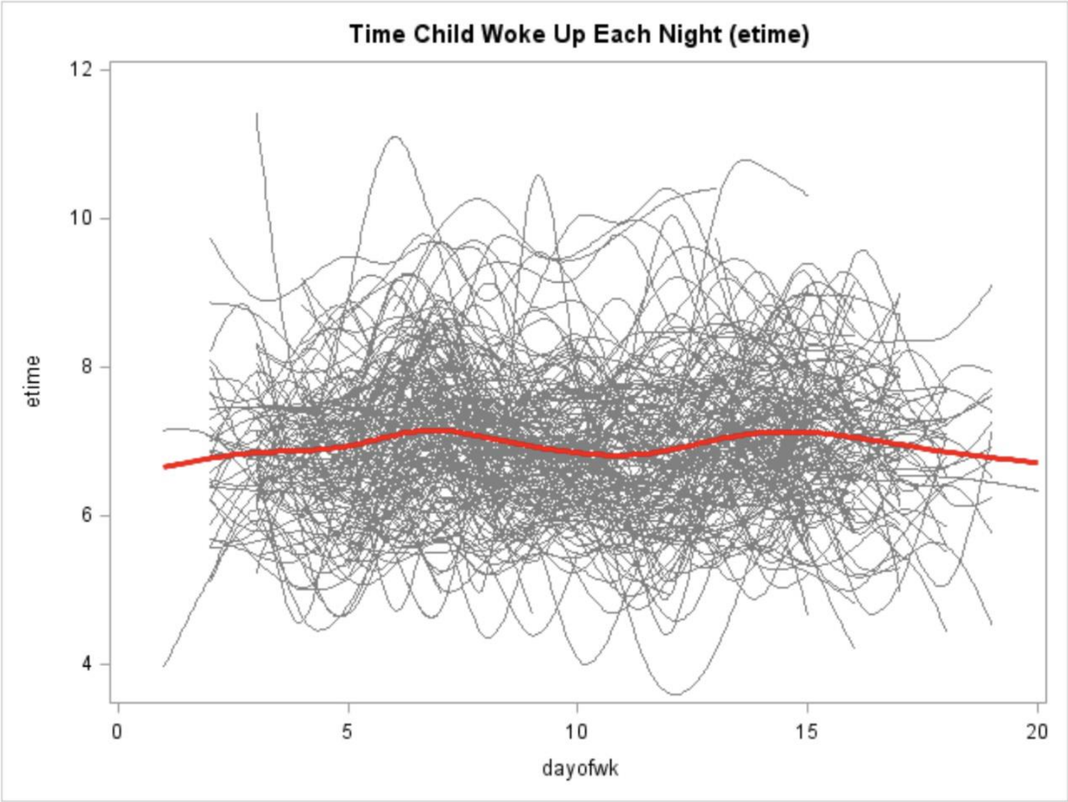




Toddler Study: Night to Night Variability

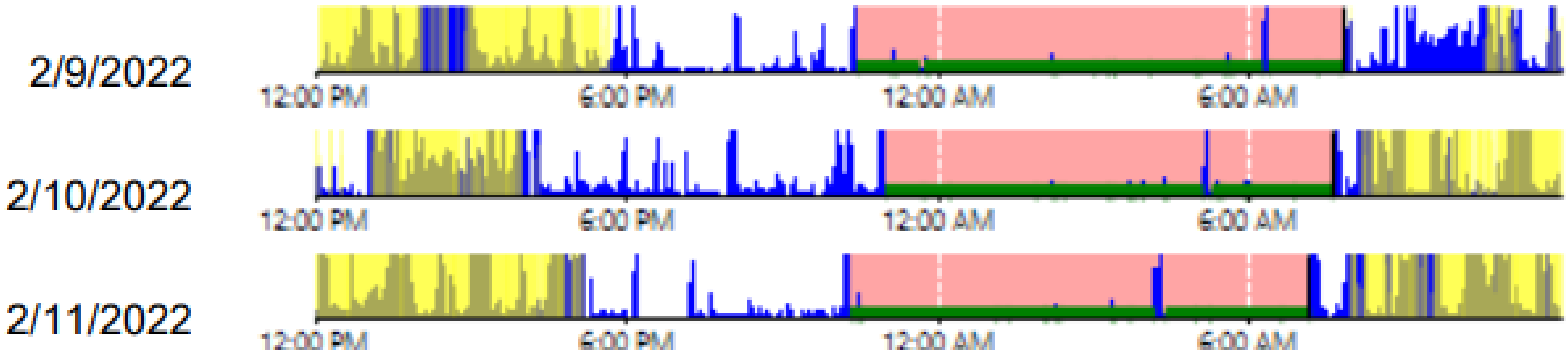
Prokasky, Fritz, Molfese, 2019





Sleep in Ag Study

Prokasky & Harris, 2022



Sleep in Ag Study

Prokasky & Harris, 2022

	Peak (Busy) Season	Non-Peak (Slow) Season
Sleep Quantity		
Bedtime	11:00 pm	10:54 pm
Wake Time	6:48 am	6:56 am
Total Time in Bed*	7.6 hours	8.0 hours
Total Sleep Time*	6.8 hours	7.3 hours
Sleep Quality		
Sleep Efficiency	90.0%	91.1%
Wake after Sleep Onset	45.3 minutes	42.2 minutes
Number of Night Wakings	16.6	16.4
Average Length of Night Waking	2.7 minutes	2.6 minutes

Practical Considerations

Recruitment
- Participant burden

Expense
- Depending on manufacturer, model
- Device failure

Compliance
- Some toddlers (and farmers) just don't like wearing stuff on their wrists

NEBRASKA ACADEMY FOR
METHODOLOGY, ANALYTICS & PSYCHOMETRICS

Thank you!

Questions?