



[Brain/Body Entrainment Attention & Timing]

[@ McMaster University]

Smartwatches in Research

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12 November 2025

Overview

- Motivation
- Mechanisms
- Methods
- Metrics
- Research designs
- BEATmonitor
- Demonstration

Motivation

Why measure heart behaviour in psychology?

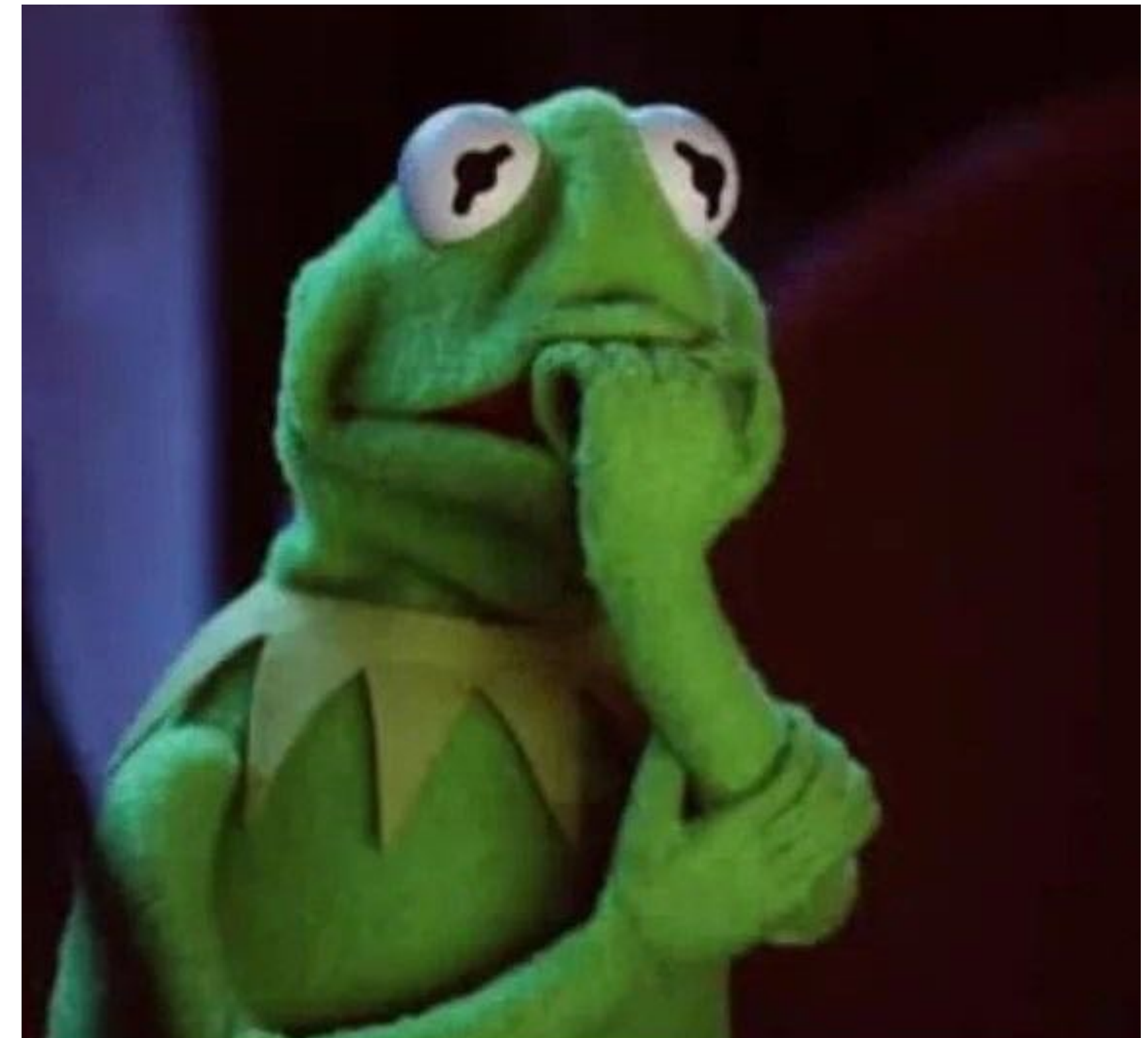


Physical characteristics

- Heart rate norms differ by age, gender, health, fitness (Souza et al., 2021)

Motivation

Why measure heart behaviour in psychology?



Psychological characteristics

- Emotions, Immersion, Attention, Effort (Hammond et al., 2023; Kreibig, 2010; Madsen & Parra, 2022)

Table 2
Overview of modal* ANS responses found for reviewed emotions.

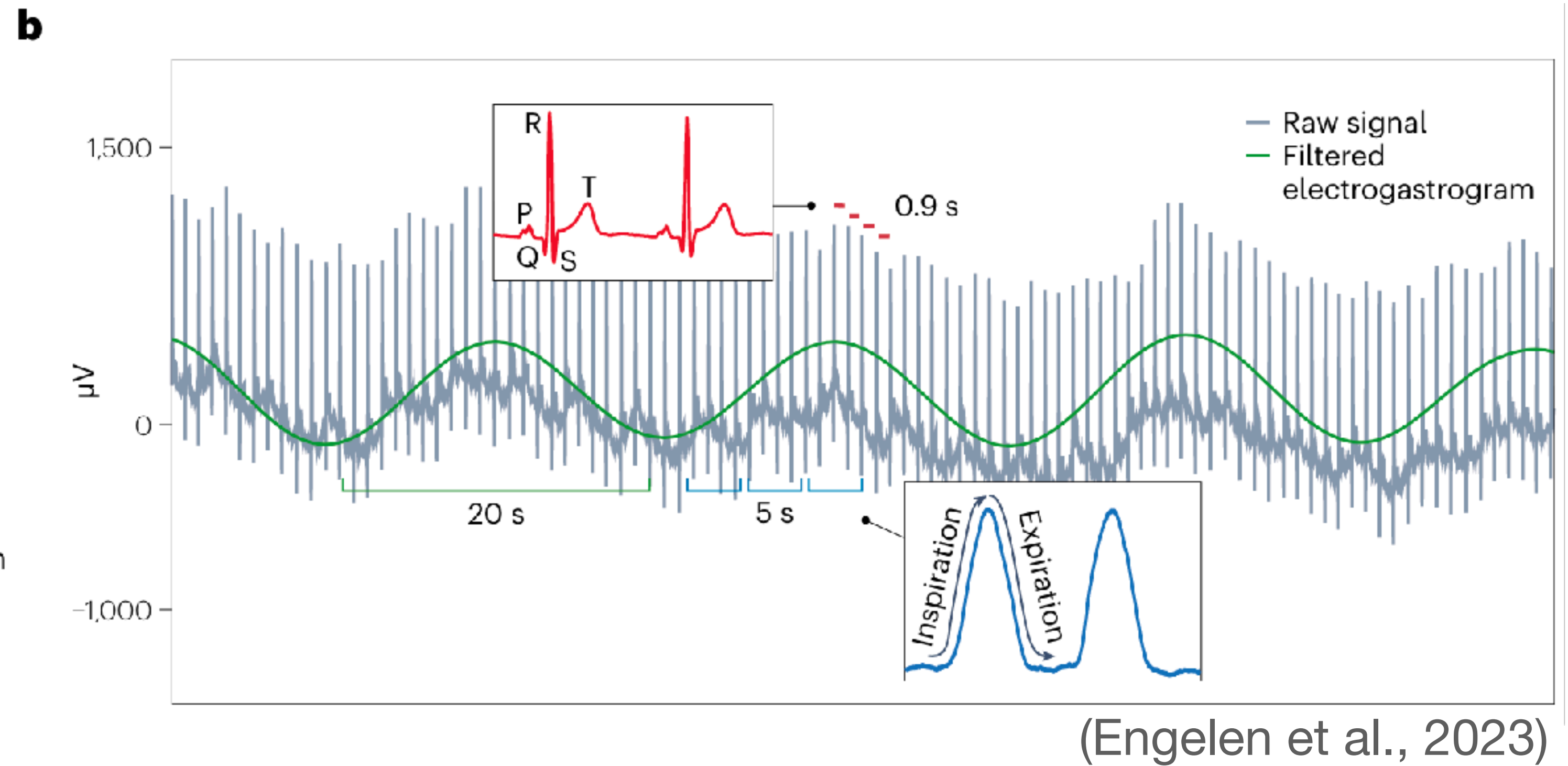
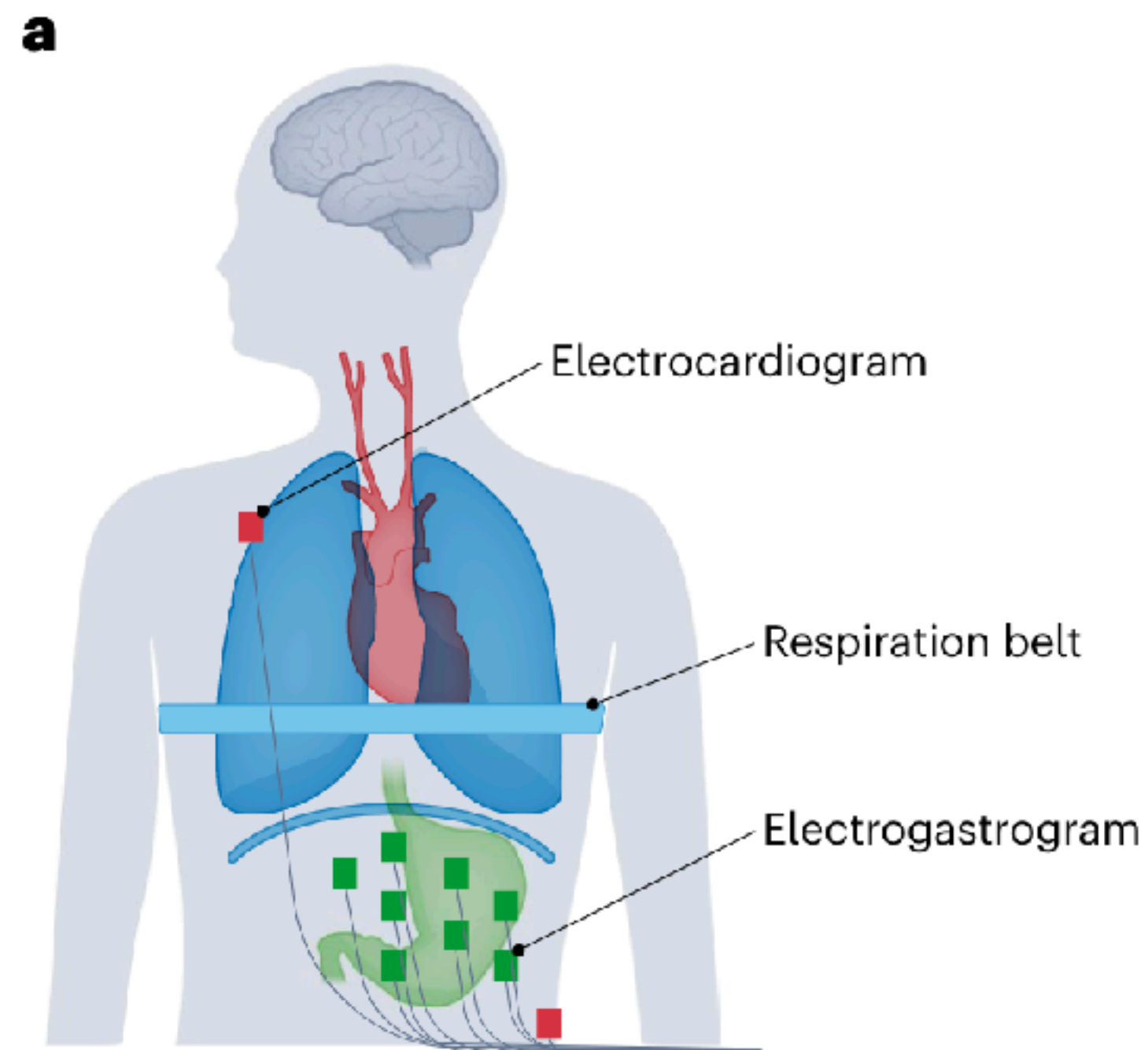
	Anger	Anxiety	Disgust Contamination	Disgust Mutilation	Embarrassment	Fear	Fear Imminent threat	Sadness Crying	Sadness Noncrying	Sadness Anticipatory	Sadness Acute	Affection	Amusement	Contentment	Happiness	Joy	Antic. Pleasure Visual	Antic. Pleasure Imagery	Pride	Relief	Surprise	Suspense
Cardiovascular																						
HR	↑	↑	↑--	↓	↑	↑	↓	↑	↓	↑	↓	↓	↑↑	↓	↑	↑	↓	↑	↑↑	↑--	↑	(↓)
HRV	↓	↓	↑	--	(↓)	↓	(--)	--	↓	(↓)	↑--		↑	↑↑	↓	(↑)	(↑)		(--)			
LF		(↑)				(--)									--							
LF/HF		(↑)		(↓)									(--)									
PWA						(↑)																
TWA	↓			(↑)		(↓)								(↑)								
LVET	↓		(↓)	(↓)		↓				↑↑				(↑)	(--)	(↓)						
HI	↑					(↑)																
PEP	↓		(↓)	(↓)	(↓)	↓				↑↑	↑		(↑)		(↑)	↑↑			(--)			
SV	↑↑	(--)	↓	(--)		↓				↓--					(--)	(↓)						
CO	↑↑	(↑)	(↓)	(↓)	(--)	↑				↑--			(↓)		(--)	--			(--)			
SBP	↑	↑	↑	↑	(↑)	↑				↑	(↓)		↑--	(↓)	↑	↑						
DBP	↑	↑	↑	↑	(↑)	↑				↑	↓--		↑--	(↓)	↑	--						
MAP			↑	↑		↑					↓--		↑--	(↓)	↑							
TPR	↑		↑	(--)	(↑)	↓				↑			(↑)		(↑)	(--)			(--)			
FPA	↓	↓	↓	↓		↓	(↓)	↓	↓	(↑)	↓		(↓)	(--)	↑↑					(↑)		
FPTT	↓	(↓)	↑↑	↑↑		↓	(--)			(↓)	↑				↑							
EPTT		(↓)	↑↑	↑↑		↓	(↓)				↑				↑							
FT	↓	(↓)	↑↑	↑↑		↓		↓	↓	↑↑	↓		(--)		↑		(↑)				↑↑	
HT	↑↑	(↑)	(↓)	(↓)			(↑)															
Electrodermal																						
SCR	↑	↑	↑	↑		↑	↑				↓		↑	(--)			↑			↓		
nSRR	↑	↑	↑	↑		↑		↑	↓	↑	↑--		↑		↑	↑	↑	↑		(↓)		(↑)
SCL	↑	↑	↑	↑	(↑)	↑	↓	↑	↓	↑	↓	(↑)	↑	↓	↑--	--	↑		↑	↓	(↑)	(↑)
Respiratory																						
RR	↑	↑	↑	↑		↑		↑	↑	↑↑	↑↑		↑	↑↑	↑	(↑)	(↓)	↑		(↓)	↓--	(↑)
Ti	(↓)	↓	↓	--		↓--					(↓)		(↓)	(↑)	↓		(↑)	(↓)		(↑)		
Te	(↓)	↓	↑	--		↓					(↓)			(↑)	↓		(↑)	(↓)		(↑)		(↓)
Pi	(↑)					(↑)									(↓)						(↑)	
Pe											(↓)											(↓)
Ti/Ttot			(↓)	--		(↑)						(↑)	(↓)									(↑)
Vt	↑↑	↓	↓	(↓)		↑↑		↓	↑	↑↑	↓		↑↑	↑↑	↑↑		(↓)	(↓)		(↑)	↑--	
Vi/Ti			(↓)	--											(↑)							(↓)
V(rhyth)			(↑)	--						(↑)		(↑)	(↑)		(--)							(↓)
V(vol)	(↑)	(↑)	(↑)	--		↑						(↓)	(↑)		(↓)					(↓)		
sighing		↑↑																		↑↑		
Ros	(↑)	(↑)	(↑)	--									(↑)	(--)	(↑)		(--)					
pCO ₂		↓				↓					↑			↑				(↓)				
ANS activation components																						
α-adrenergic	↑	(↑)	↑	(--)	(↑)	↑		(↑)	(↑)	(↑)			↑--	(↓)	(↑)	--						
β-adrenergic	↑	(↑)	(↑)	(↑)	(↑)	↑				↑↑	↓		(↓)	(↓)	↓	↑↑			--			
cholinergic	↑	↑	↑	↑	(↑)	↑		↑	↓	↑	↓	(↑)	↑	↓	↑--	↑--	(↑)	(↑)	(↑)	↓	(↑)	(↑)
vagal	↓	↓	↑	--	(↓)	↓		--	↓	(↓)	↑--		↑	↑↑	↓	(↑)	(↑)		(--)			
respiratory	↑	↑	↑	--		↑		↑	↑	(↑)	↑	(↑)	↑	↓	↑	(↑)	↓	↑		↓	↓	(↑)
	↑pause	↓depth	↑exp			↑insp		↓depth	↑depth		↓depth	↓↑var	↑var				(↓) depth	↓depth		↑depth	↑pause	↓exp

(Kreibig, 2010)

Table 2
Overview of modal* ANS responses found for reviewed emotions.

	Anger	Anxiety	Disgust Contamination	Disgust Mutilation	Embarrassment	Fear	Fear Imminent threat	Sadness Crying	Sadness Numb/ying	Sadness Anticipatory	Sadness Acute	Affection	Amusement	Contentment	Happiness	Joy	Antic. Pleasure Visual	Antic. Pleasure Imagery	Pride	Relief	Surprise	Suspense
Cardiovascular																						
HR	↑	↑	↑--	↓	↑	↑	↓	↑	↓	↑	↓	↓	↑↑	↓	↑	↑	↓	↑	↑↑	↑--	↑	(↓)
HRV	↓	↓	↑	--	(↓)	↓	(-)	--	↓	(↓)	↑-		↑	↑↑	↓	(↑)	(↑)		(-)			
Cardiovascular HR HRV																						
		Anger			Anxiety		Disgust Contamination		Disgust Mutilation		Embarrassment		Fear		Fear Imminent threat		Sadness Crying					
		↑			↑		↑--		↓		↑		↑		↓		↑		↑		↓	↑
		↓			↓		↑		--		(↓)		↓		(-)		↓		(-)		--	
V(vol) sighing Ros pCO₂ ANS activation components α-adrenergic β-adrenergic cholinergic vagal respiratory																						
V(vol)	(↑)	(↑)	(↑)	--	↑							(↓)	(↑)		(↓)					(↓)		
sighing		↑↑																		↑↑		
Ros	(↑)	(↑)	(↑)	--								(↑)	(-)	(↑)		(-)						
pCO ₂		↓			↓				↑			↑					(↓)					
ANS activation components																						
α-adrenergic	↑	(↑)	↑	(-)	(↑)	↑		(↑)	(↑)	(↑)		↑--	(↓)	(↑)	--							
β-adrenergic	↑	(↑)	(↑)	(↑)	(↑)	↑				↑↑	↓	(↓)	(↓)	↓	↑↑	--						
cholinergic	↑	↑	↑	↑	(↑)	↑		↑	↓	↑	↓	(↑)	↑	↓	↑--	↑--	(↑)	(↑)	(↑)	↓	(↑)	(↑)
vagal	↓	↓	↑	--	(↓)	↓		--	↓	(↓)	↑-	↑	↑↑	↓	(↑)	(↑)		(-)				
respiratory	↑	↑	↑	--	↑	↑		↑	↑	(↑)	↑	(↑)	↑	↓	↑	(↑)	↓	↑		↓	↓	(↑)
	↑pause	↓depth	↑exp		↑insp			↓depth	↑depth		↓depth	↓↑var	↑var				(↓) depth	↓depth		↑depth	↑pause	↓exp

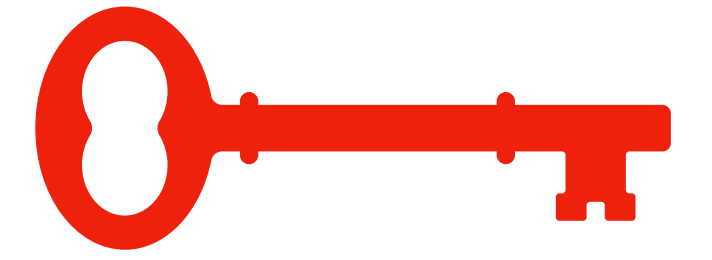
(Kreibig, 2010)



Why measure heart behaviour in psychology?

Intrinsic rhythm

- Always present
- Short cycle, responsive



Motivation

Takeaways

The heart:

- Readily responds to physical and psychological stimuli in the environment
- Implicit response
- Continuous measure

Mechanism



Homeostasis

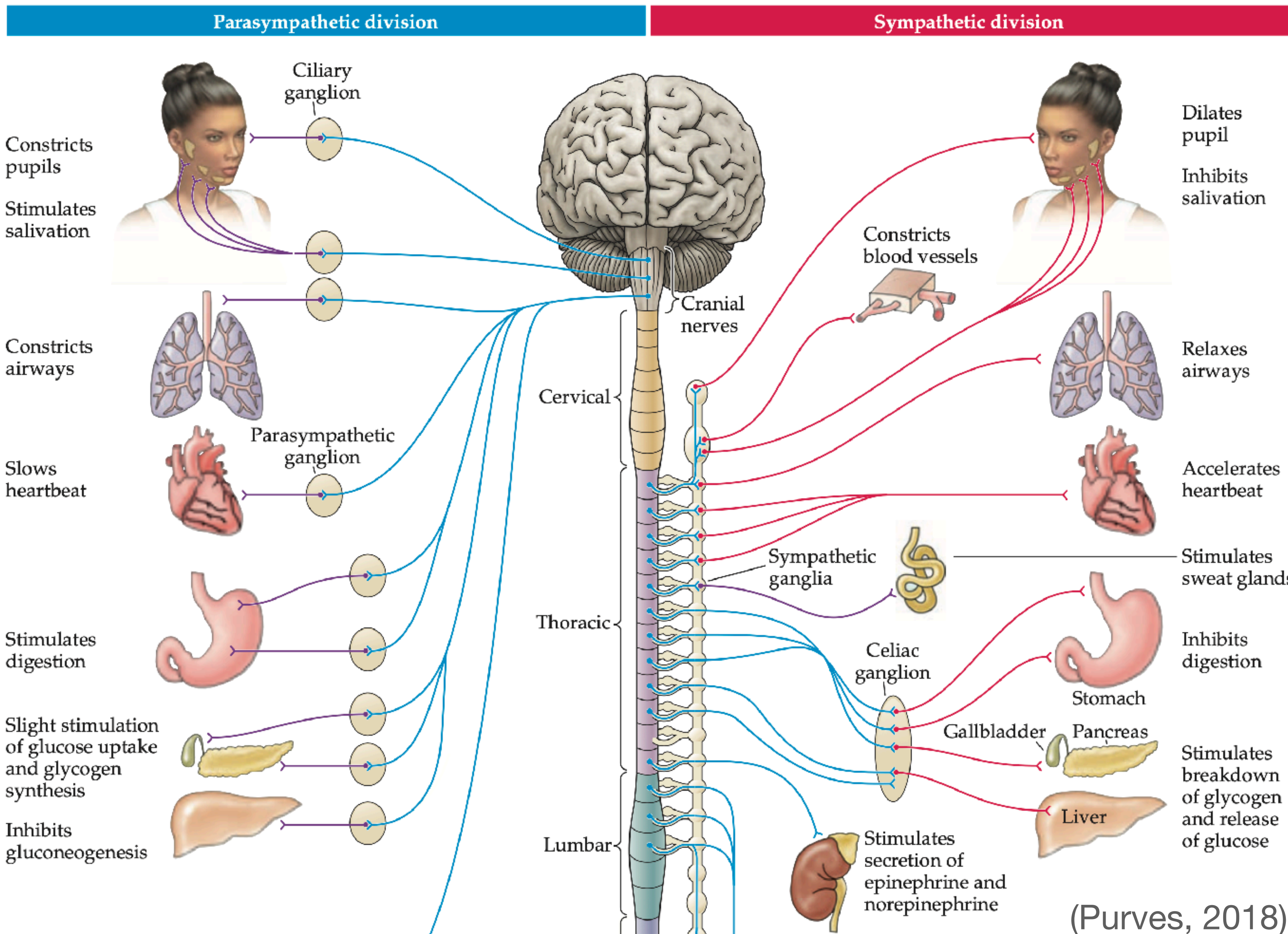
- Organisms must respond to the environment to maintain internal 'stability'

Mechanism



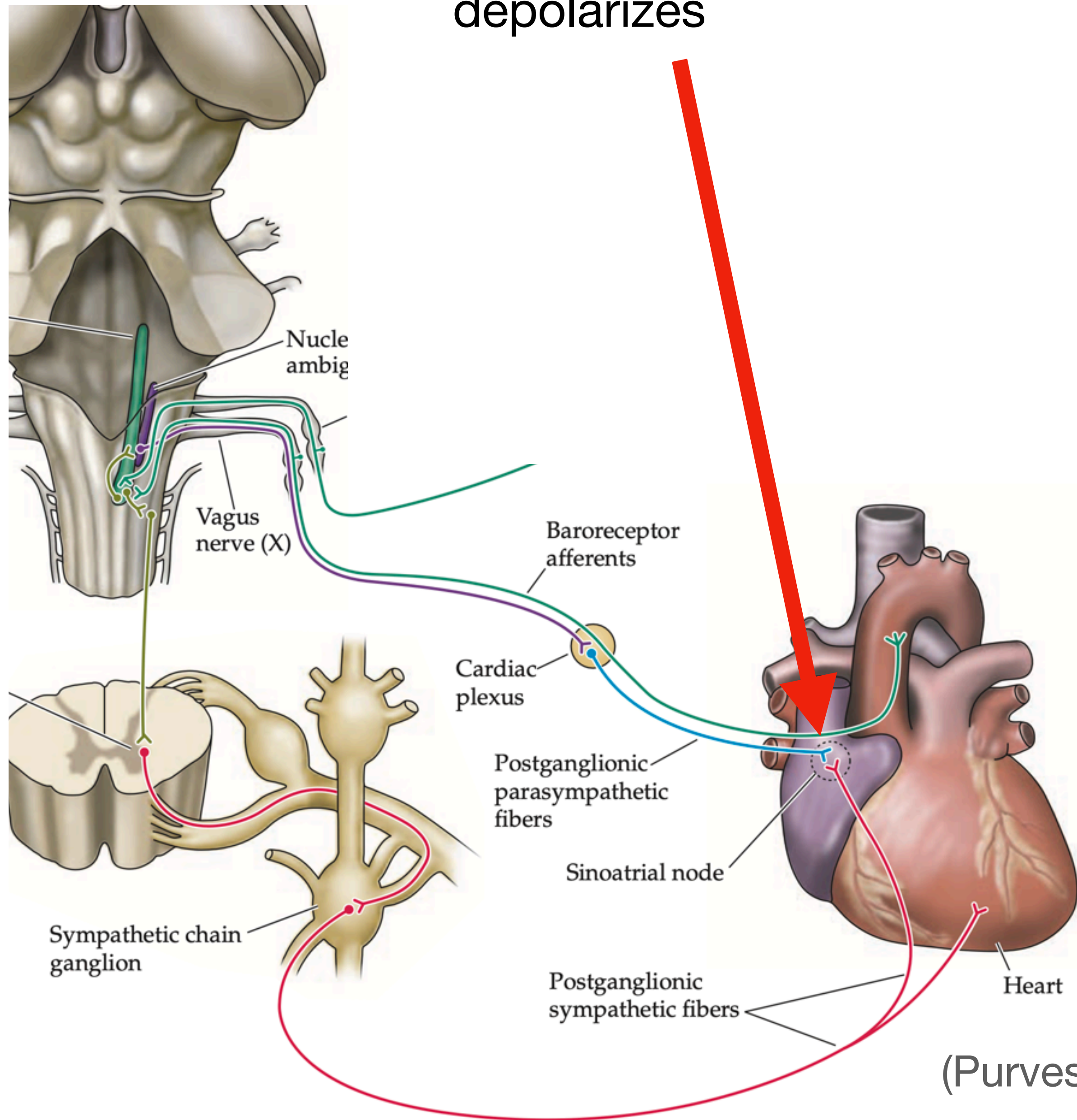
Allostasis

- "Remaining stable by being variable"
- Anticipate environmental effects and preemptively respond



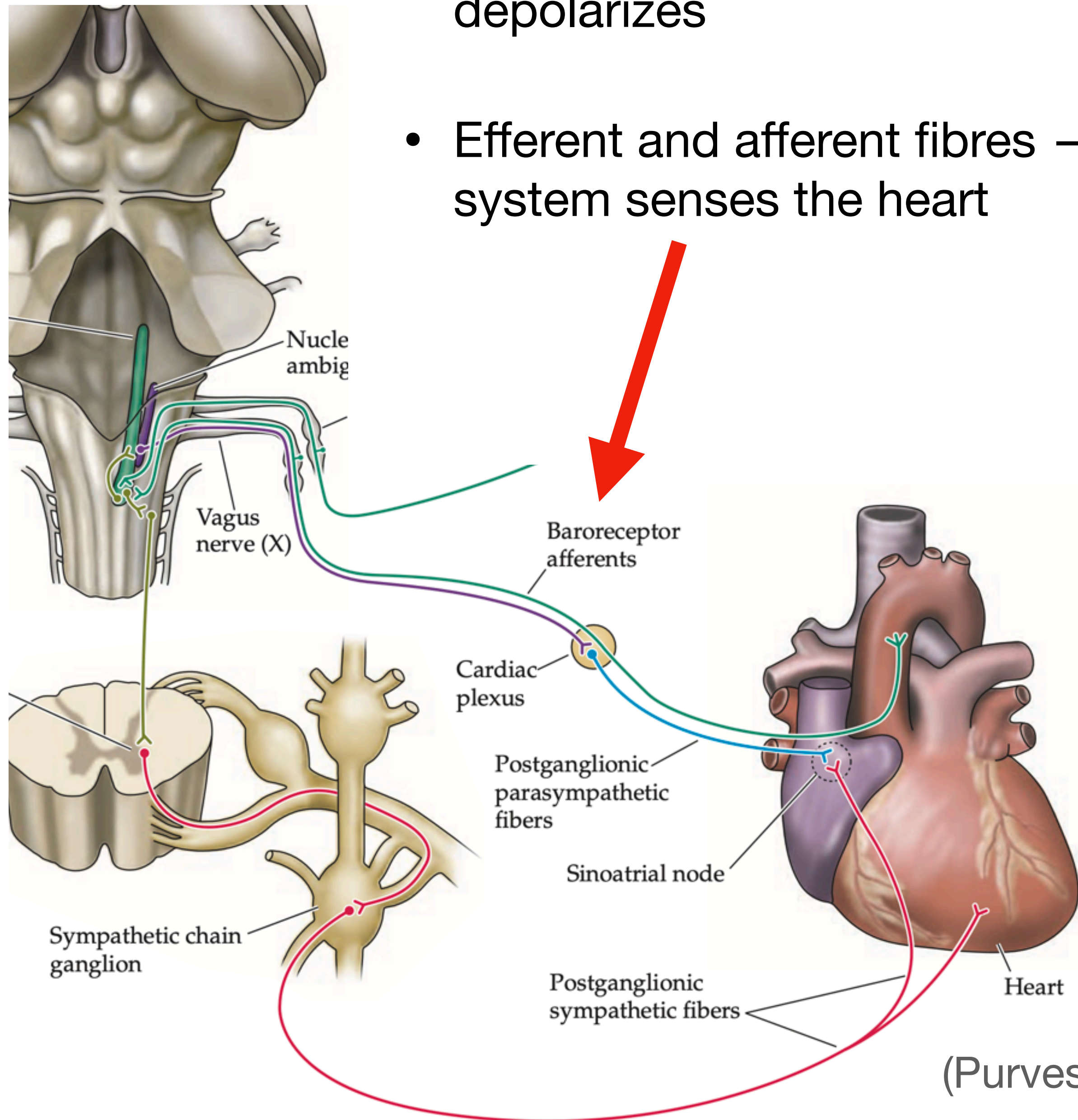
(Purves, 2018)

- Sinoatrial node — spontaneously depolarizes

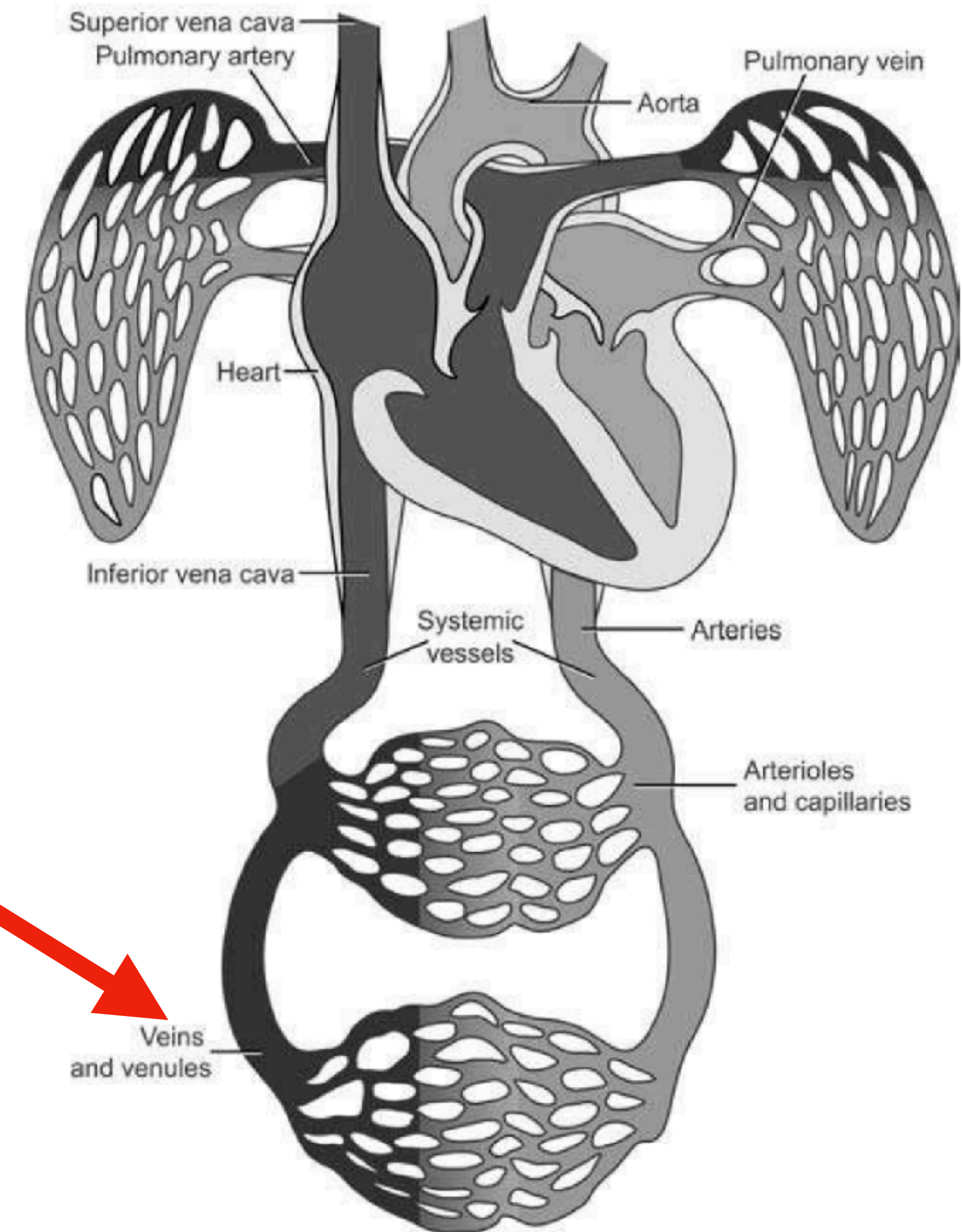
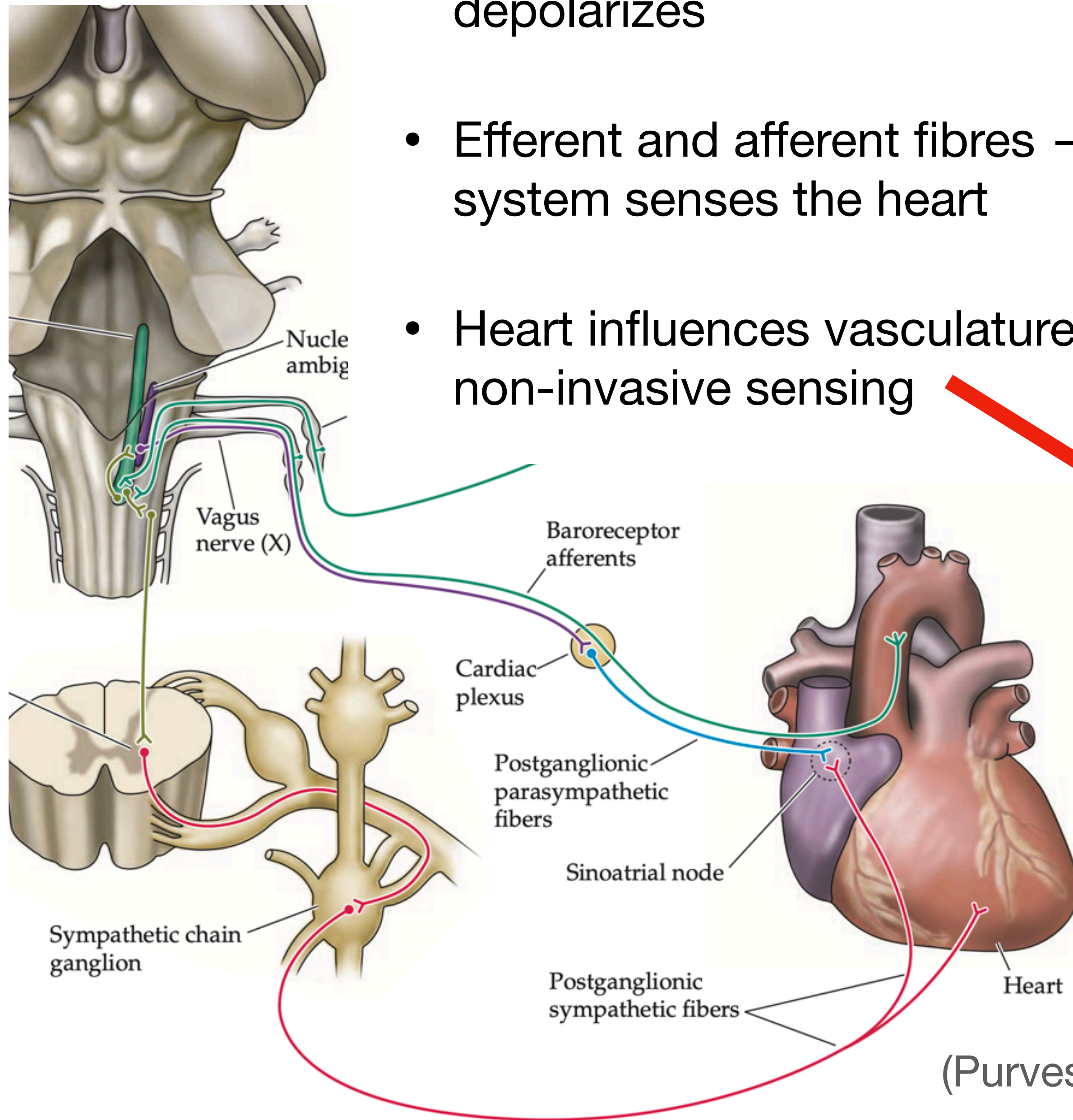


(Purves, 2018)

- Sinoatrial node — spontaneously depolarizes
- Efferent and afferent fibres — nervous system senses the heart

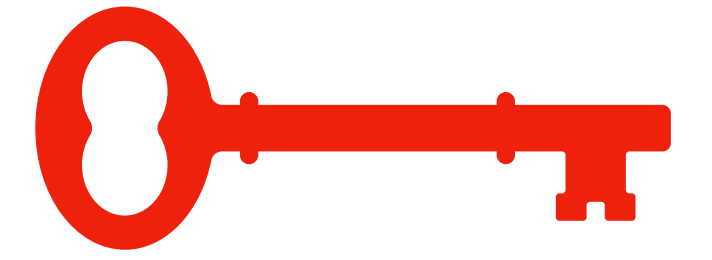


- Sinoatrial node — spontaneously depolarizes
- Efferent and afferent fibres — nervous system senses the heart
- Heart influences vasculature — allows for non-invasive sensing



(Berntson, 2017)

(Purves, 2018)



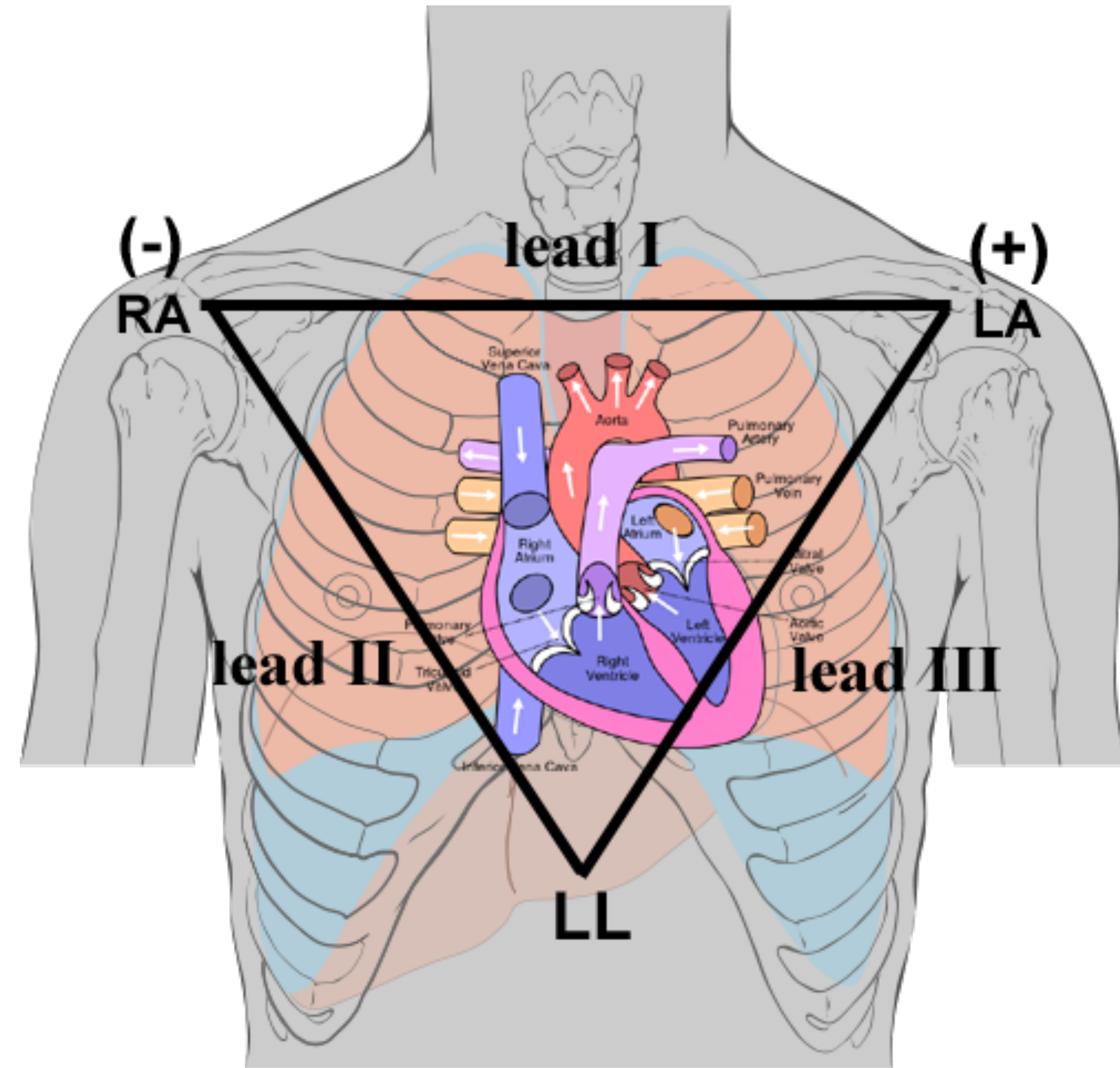
Mechanism

Takeaways

- Our bodies and brains are one
- Complex system
- Continuous and non-invasive access

Methods

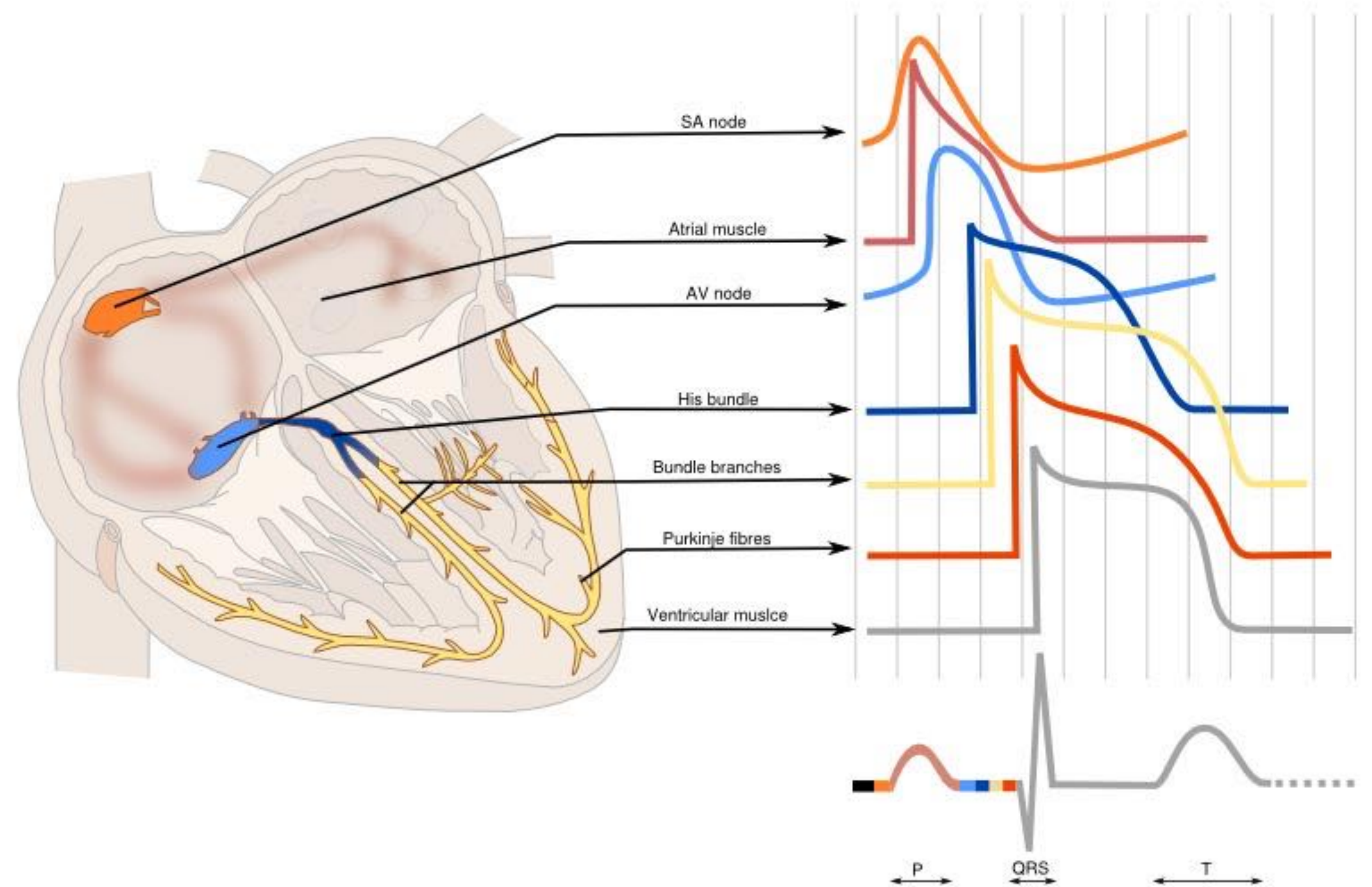
ECG



Img: <https://researchguides.library.vanderbilt.edu/c.php?g=156859&p=1125029>
ECG (EKG) - Bundle branch block - Oxford Medical Education, 2014.

Methods

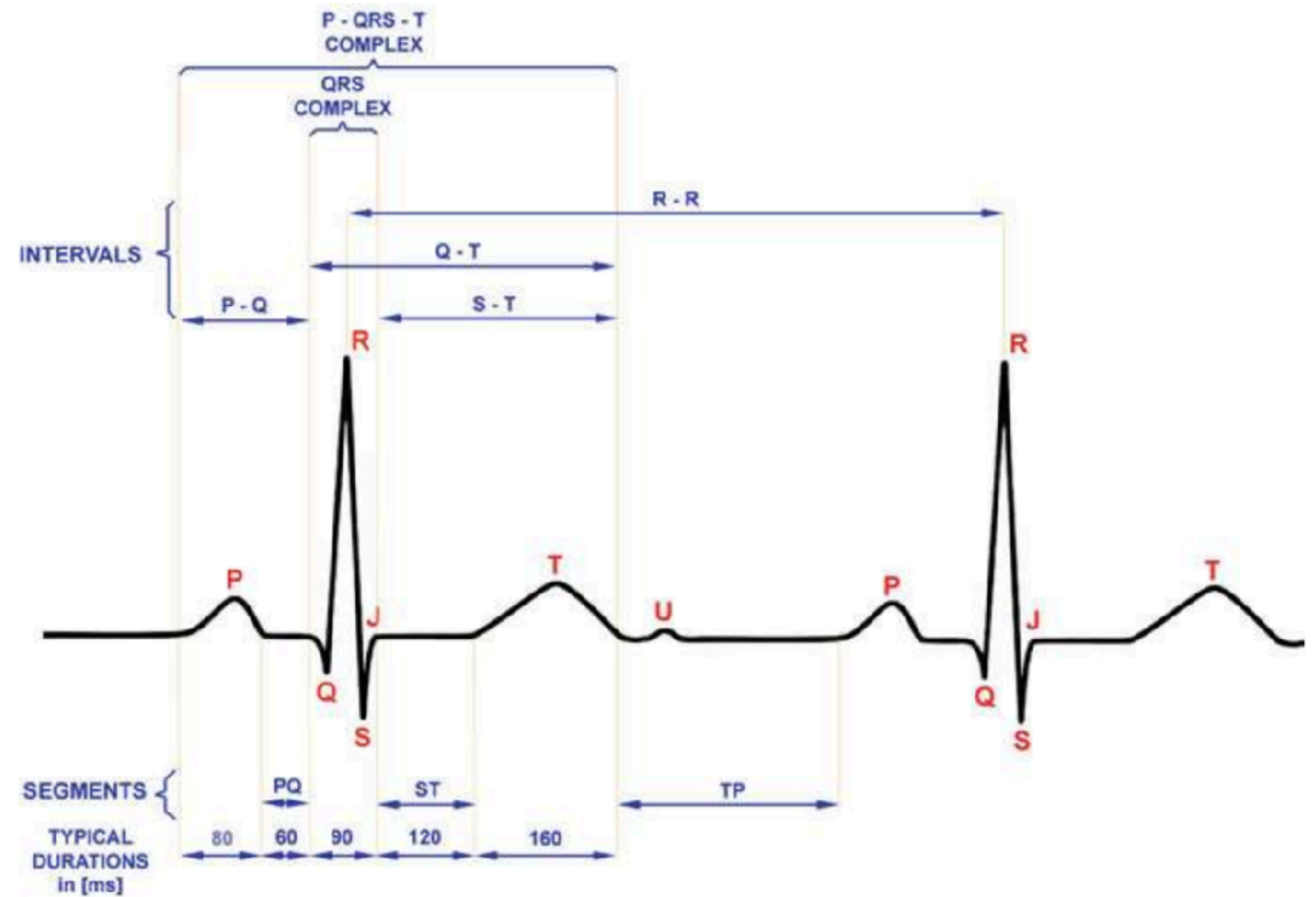
ECG



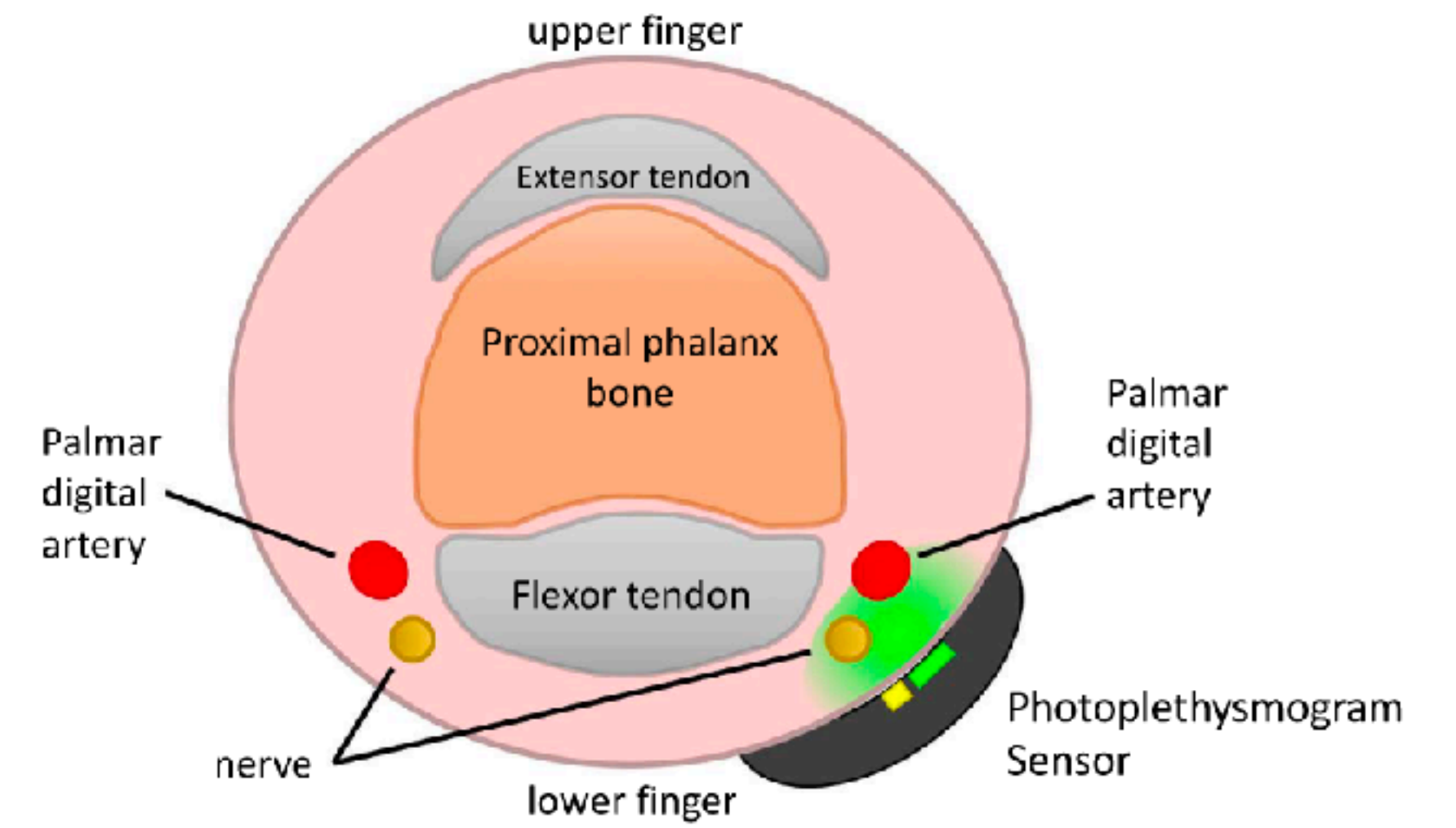
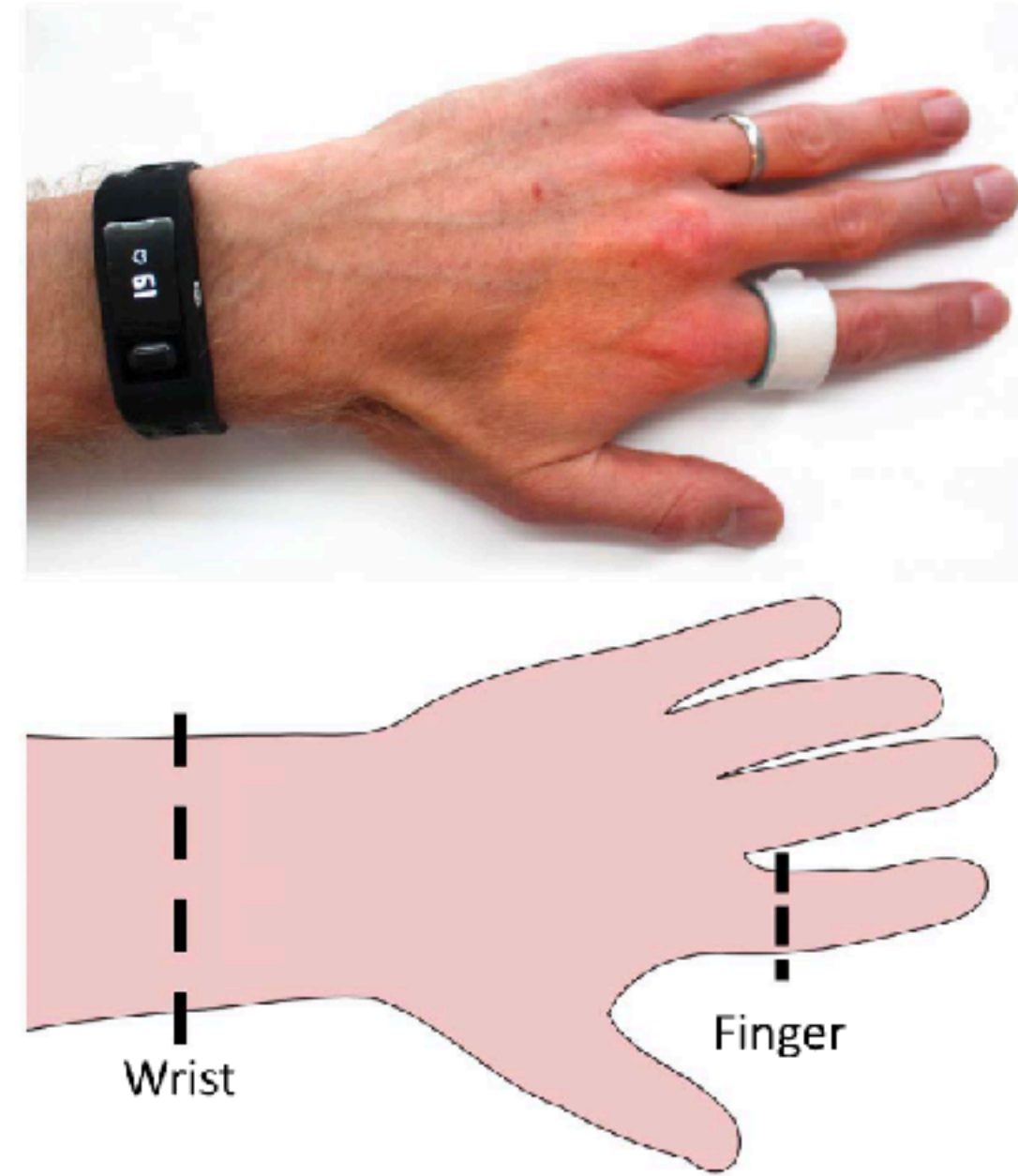
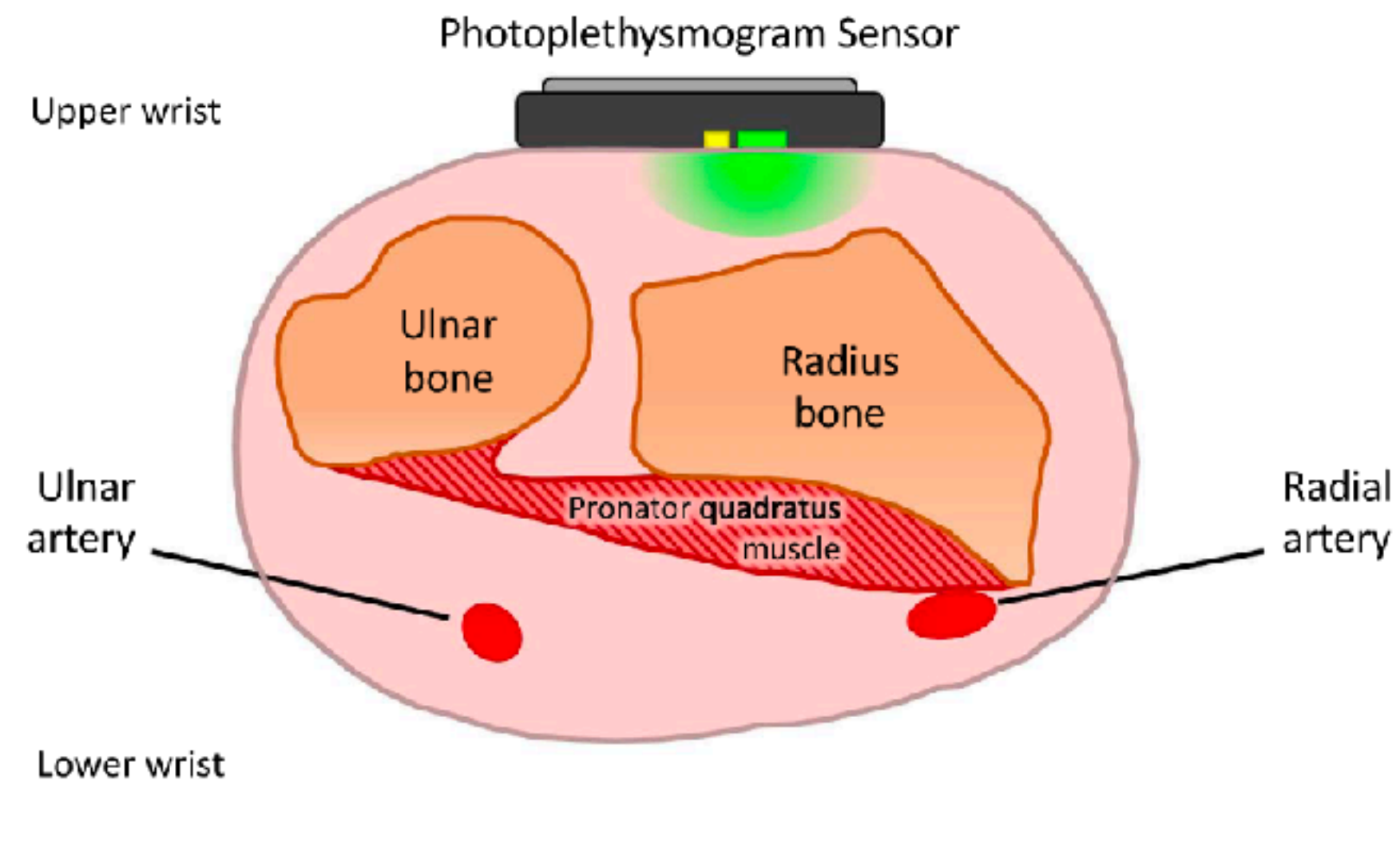
Img: <https://researchguides.library.vanderbilt.edu/c.php?g=156859&p=1125029>
ECG (EKG) - Bundle branch block - Oxford Medical Education, 2014.

Methods

ECG



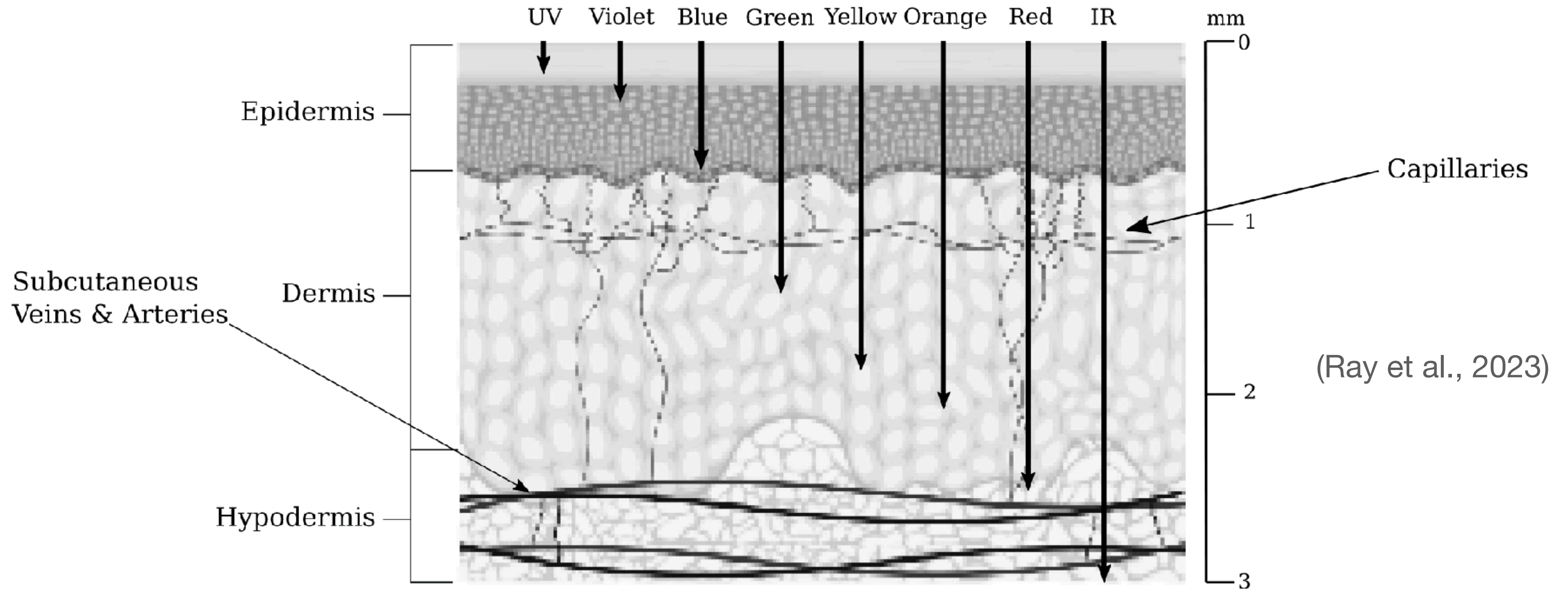
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(Charlton, 2022)

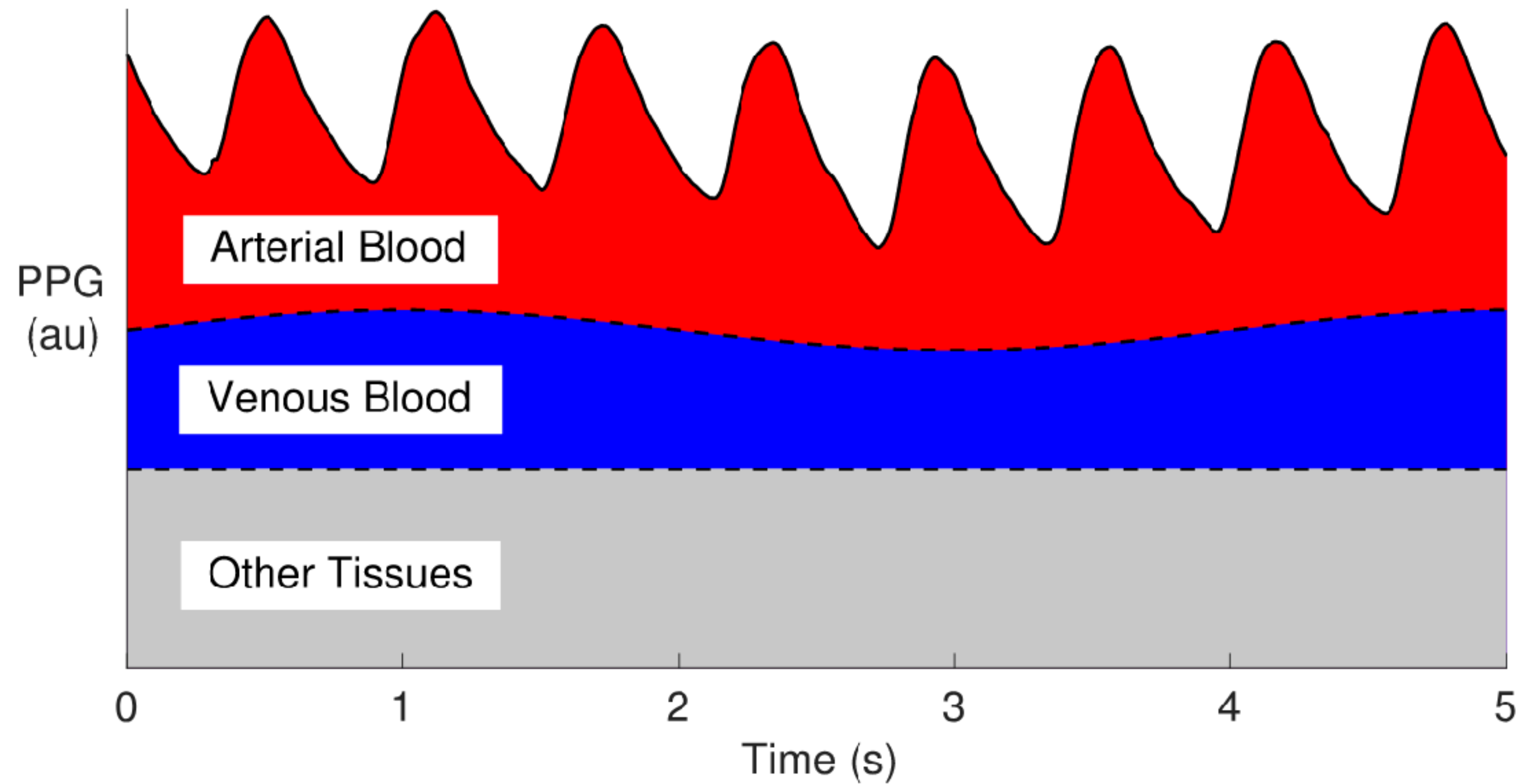
Methods

Photoplethysmogram (PPG)



Methods

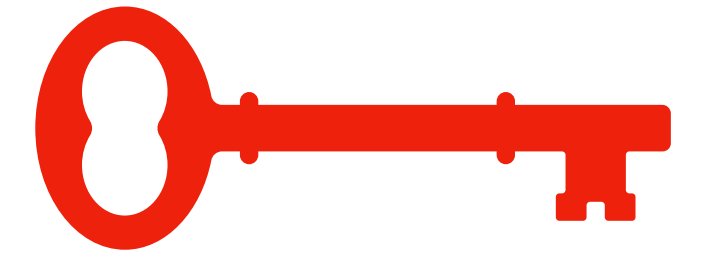
Photoplethysmogram (PPG)



(Charlton, 2022)

Methods

Photoplethysmogram (PPG)



Methods

Takeaways

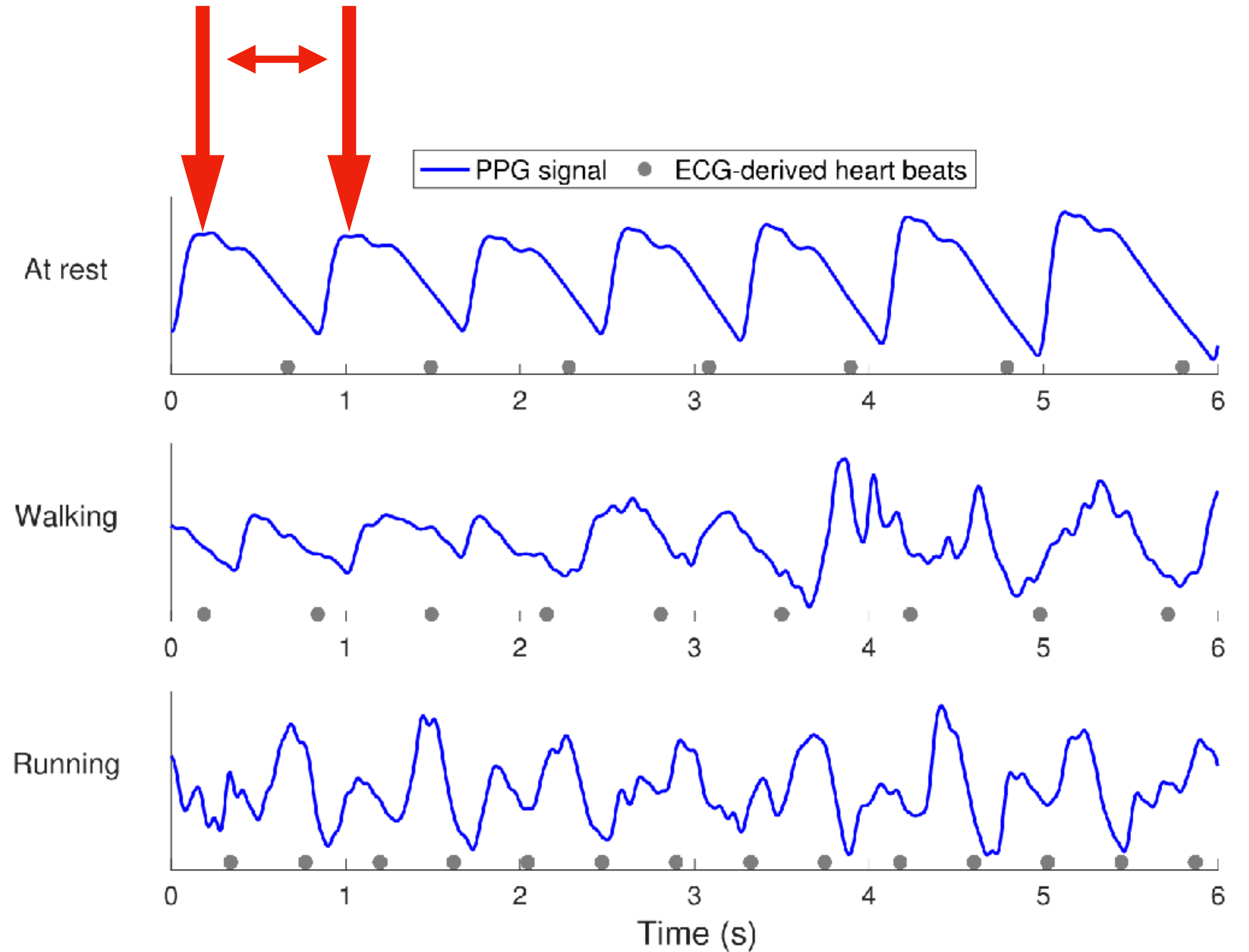
- ECG — Heart related voltage, accurate, expensive, invasive
- PPG — Blood pulse volume, variable accuracy, inexpensive, non-invasive

Metrics

Heart rate (HR)

Heart rate variability (HRV)

Inter-beat Interval (IBI)



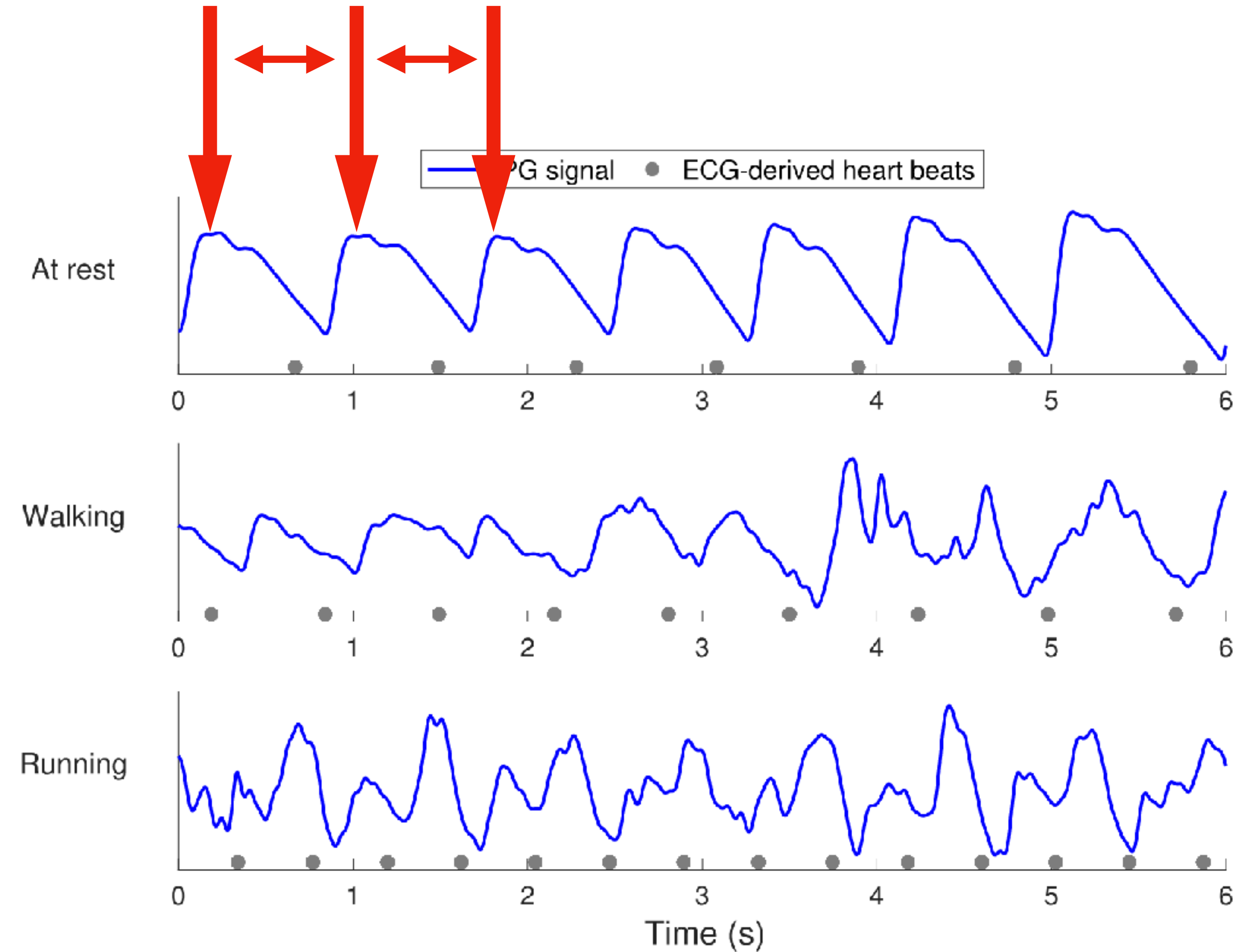
(Charlton, 2022)

Metrics

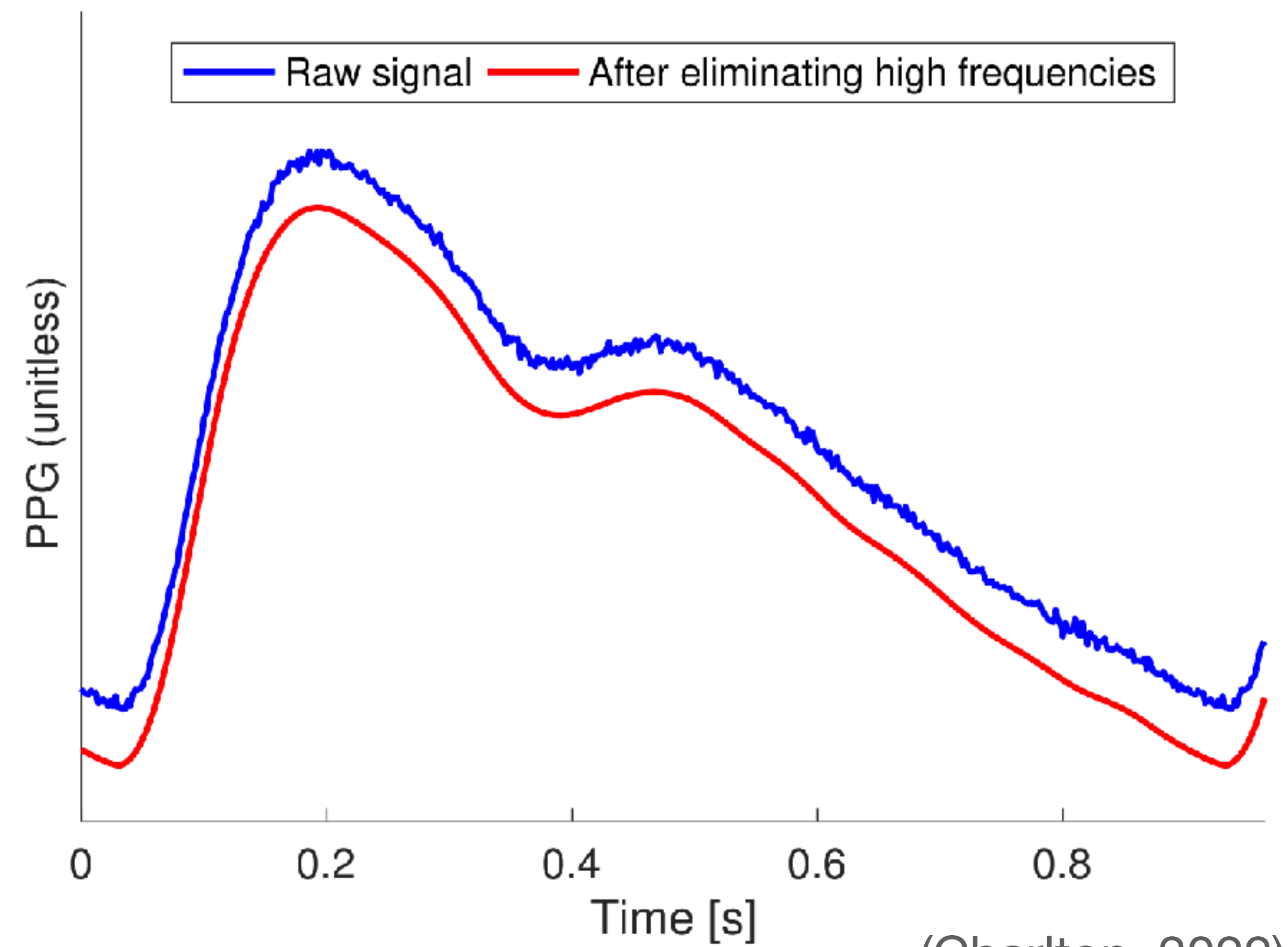
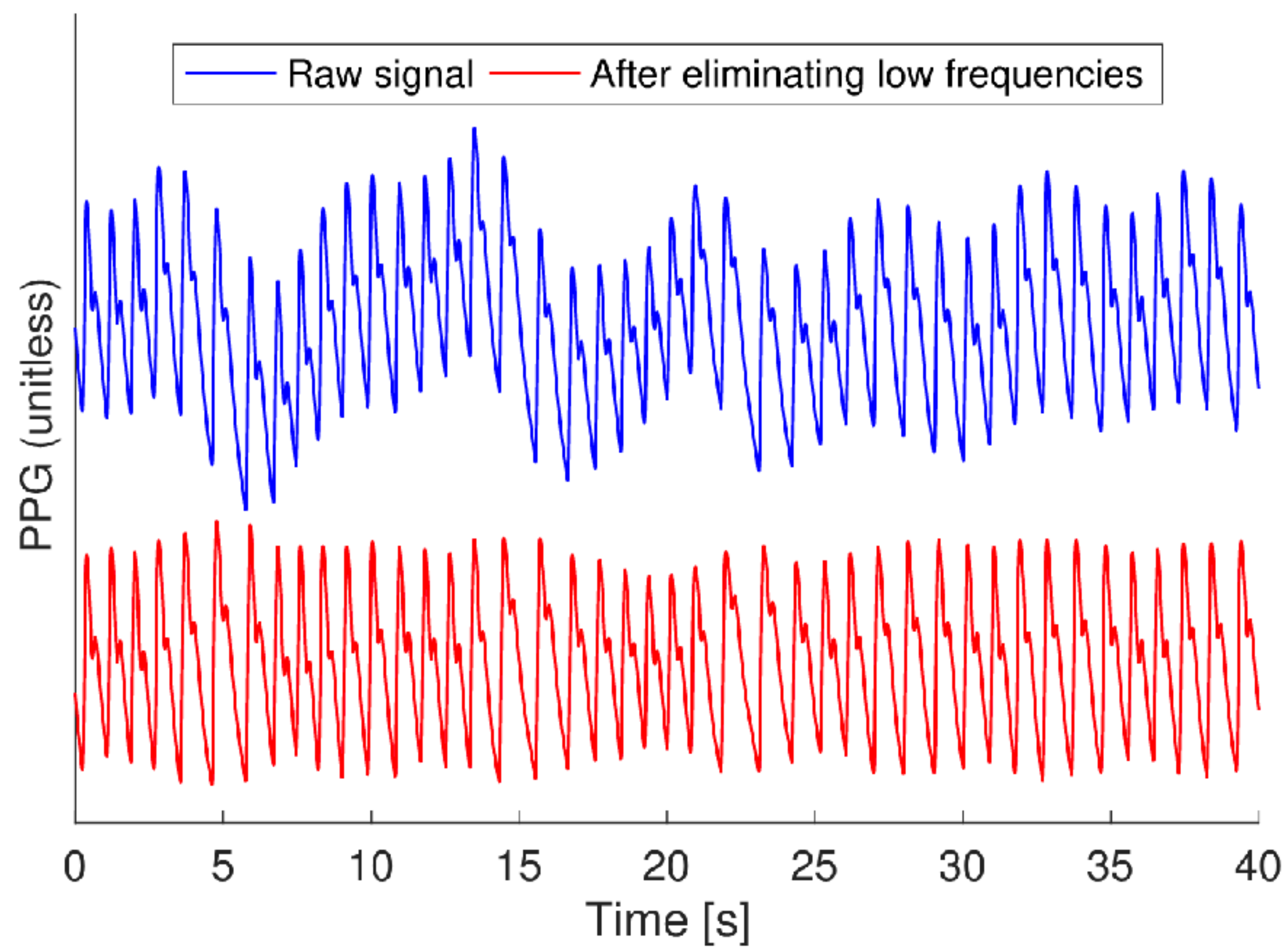
Heart rate (HR)

Heart rate variability (HRV)

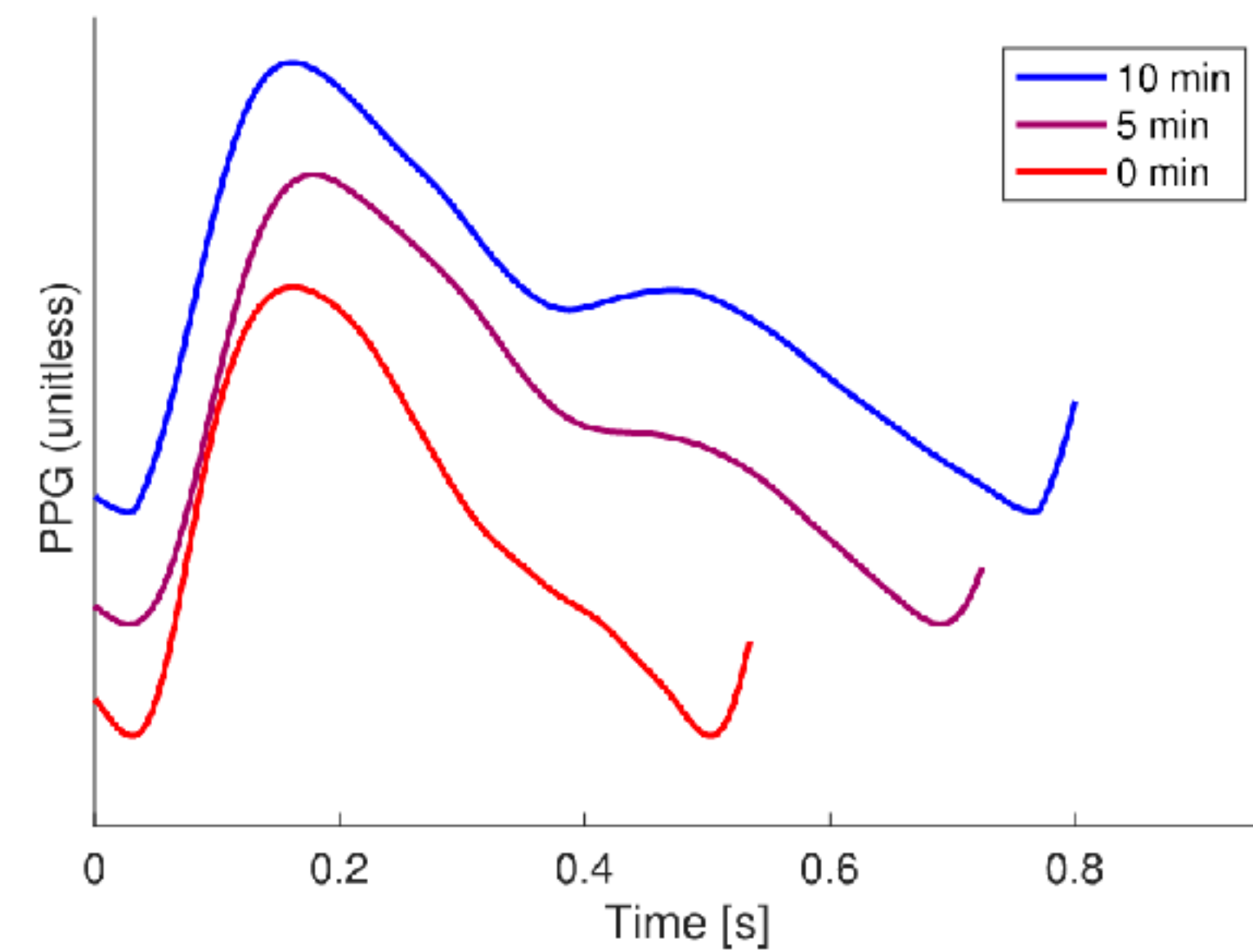
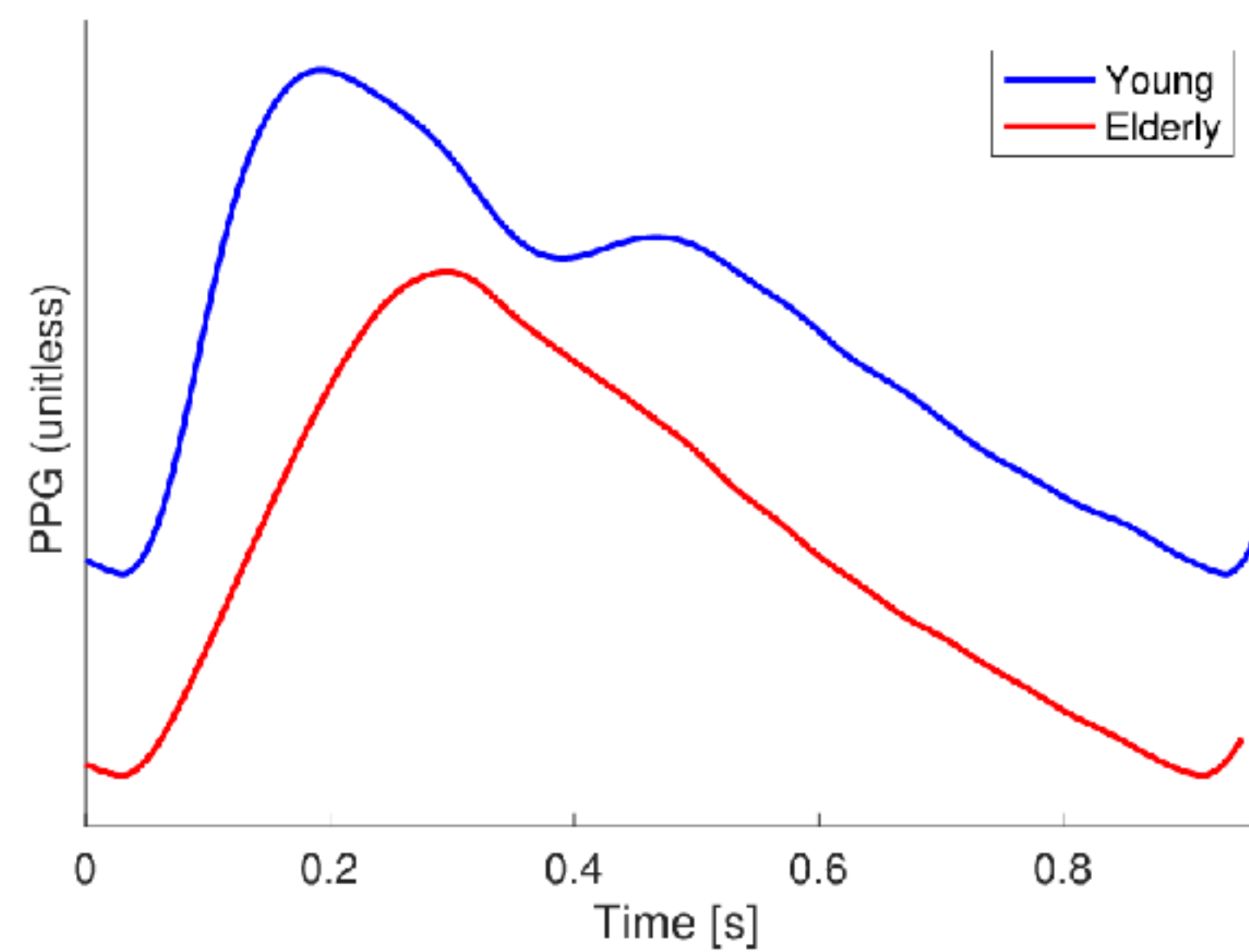
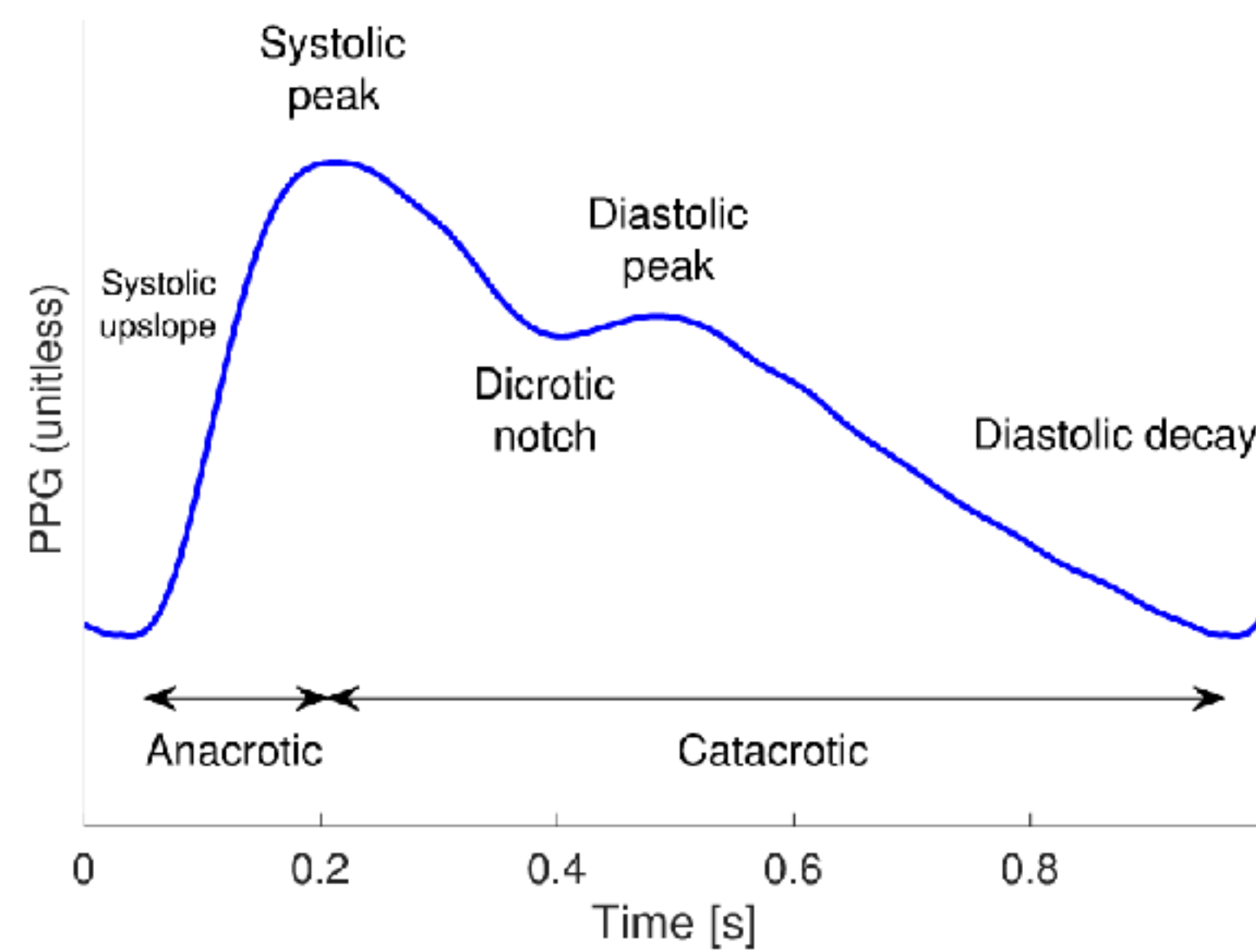
Heart rate variability (HRV)



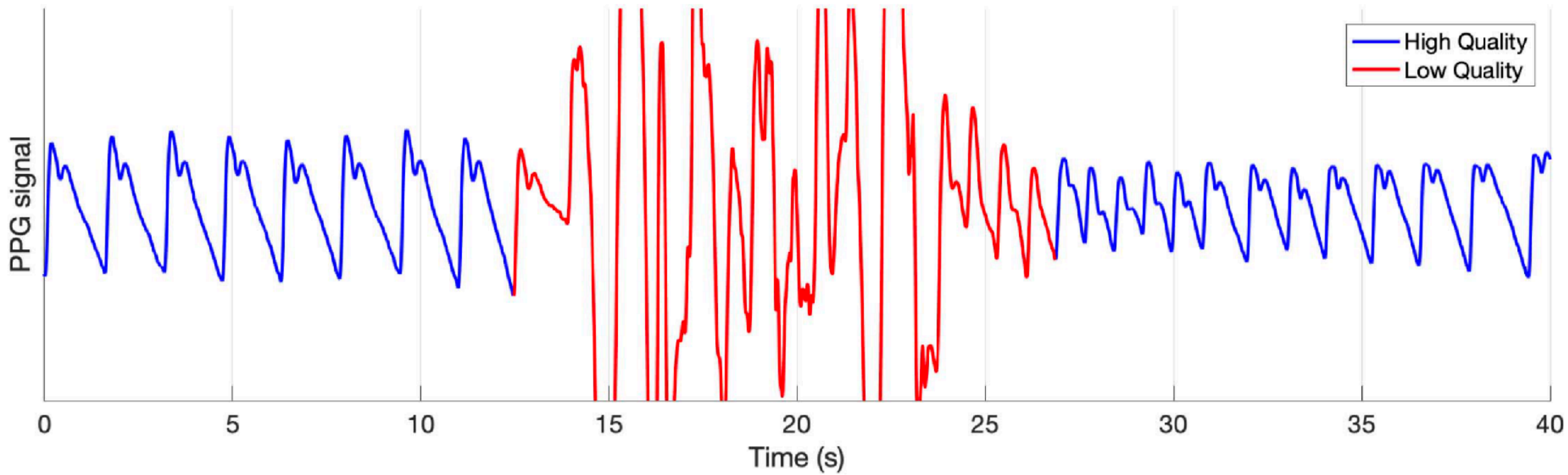
(Charlton, 2022)



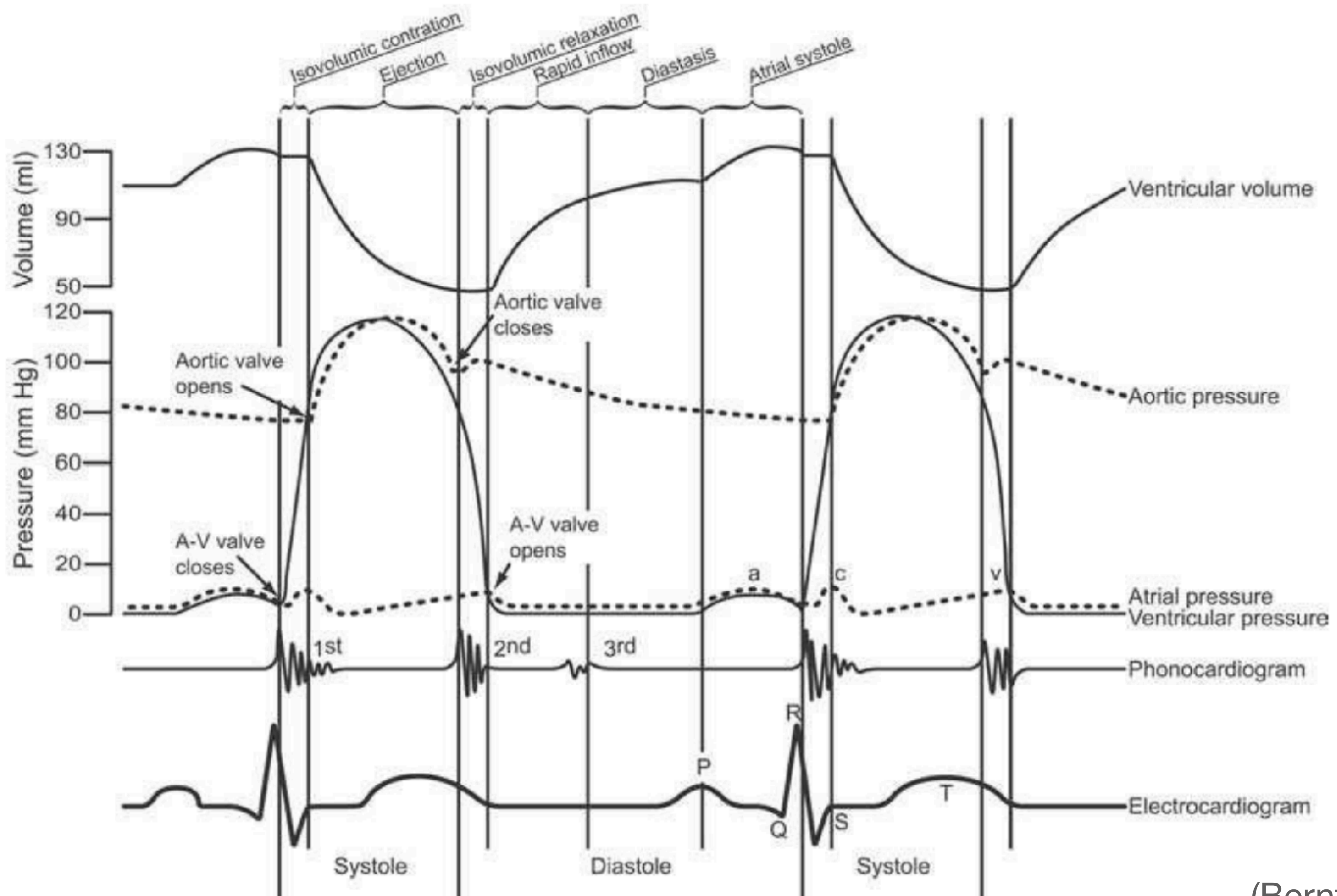
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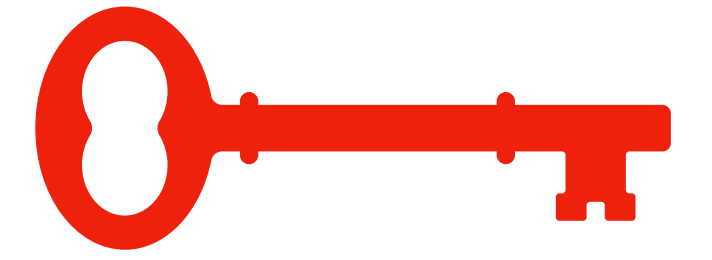
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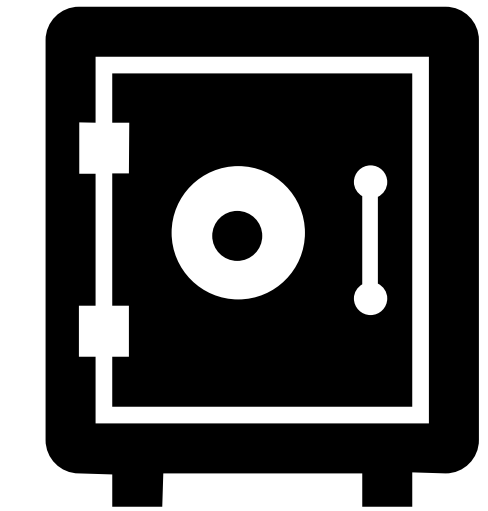
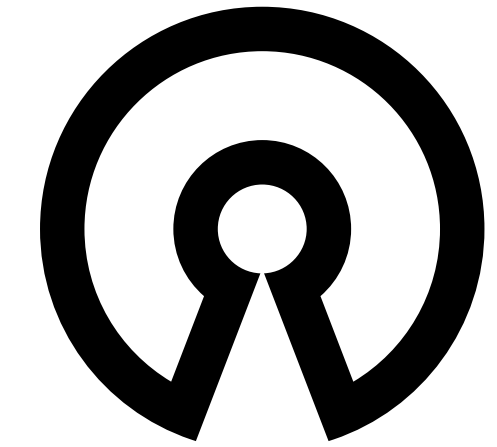
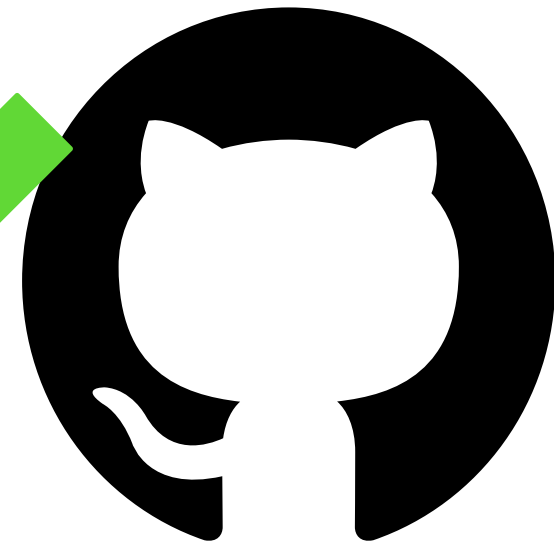
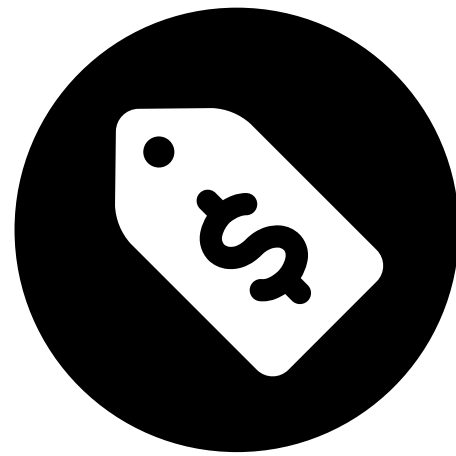
(Berntson, 2017)



Metrics

Takeaways

- HR — extracted by finding peaks in the PPG signal
- HRV — variation between the differences between peaks
- Proper setup is very important



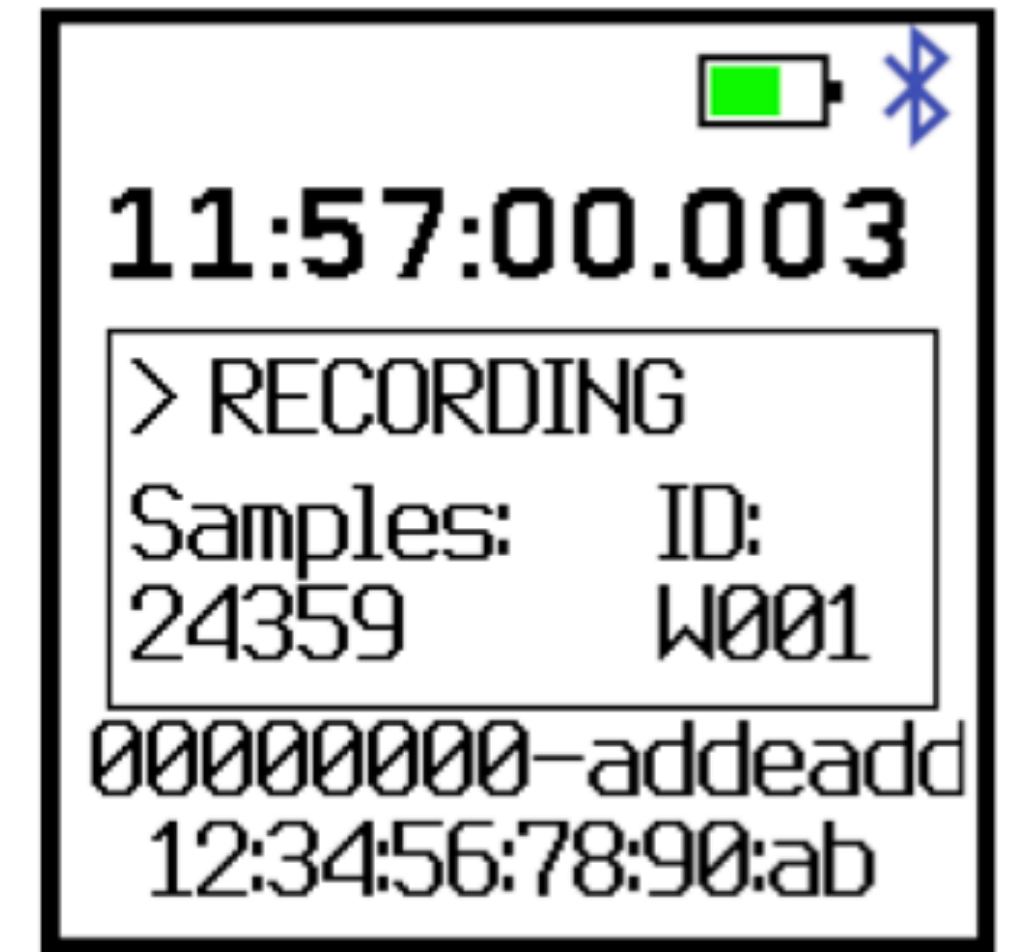
Bangle.js 2 Smartwatch

BEATmonitor

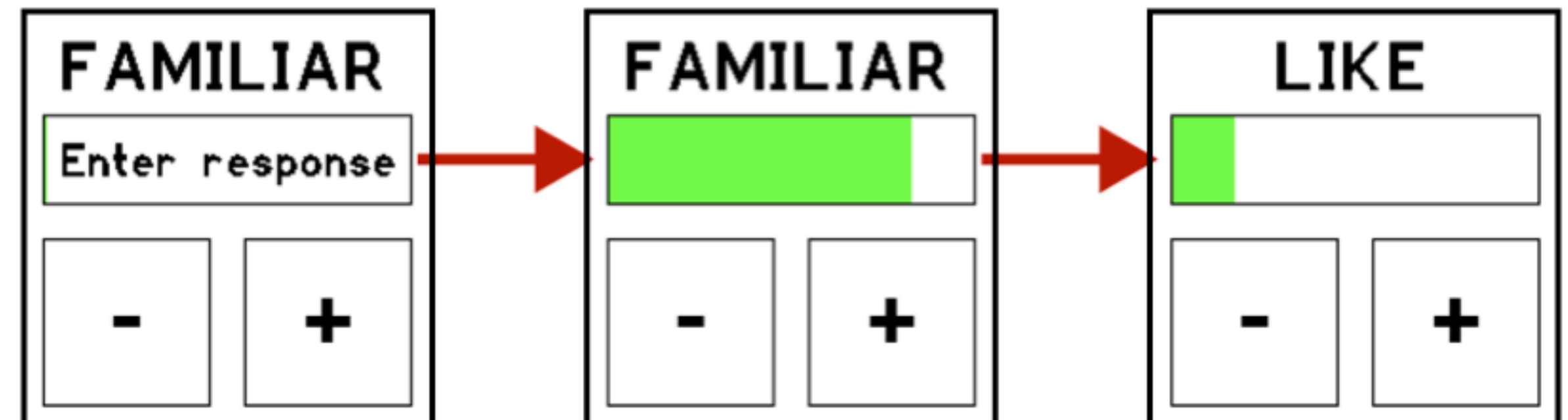
(A) Watch front and back



(B) Watch application interface



(C) Custom screens (survey response)



BEATmonitor

BEATLab

Help

Docs

GitHub

BEATmonitor: Bangle.js 2 Dashboard

Institute for Music & The Mind

McMaster University

Reconnect

Get Name

Get Storage

Get File

Verify Files

Sync Time

Start Rec

Stop Rec

Get Drift

Send Survey

Send Cmd:

Bangle.js watch list

Watch/Participant ID	Device Name	Bluetooth Signal	Connection Status	Watch Status	Synchronization Offset
W002	BEATwatch 0510	-53		Waiting	0.5 ms
Reconnect Get Name Get Storage Get File Verify Files Sync Time Start Rec Stop Rec Get Drift Send Survey Send Cmd:					
W005	BEATwatch 21da	-59		Waiting	1 ms
Reconnect Get Name Get Storage Get File Verify Files Sync Time Start Rec Stop Rec Get Drift Send Survey Send Cmd:					
W010	BEATwatch 2cee	-55		Waiting	-0.5 ms
Reconnect Get Name Get Storage Get File Verify Files Sync Time Start Rec Stop Rec Get Drift Send Survey Send Cmd:					
W003	BEATwatch 37ca	-61		Waiting	-0.5 ms
Reconnect Get Name Get Storage Get File Verify Files Sync Time Start Rec Stop Rec Get Drift Send Survey Send Cmd:					
W001	BEATwatch 3fd9	-59		Waiting	-0.5 ms

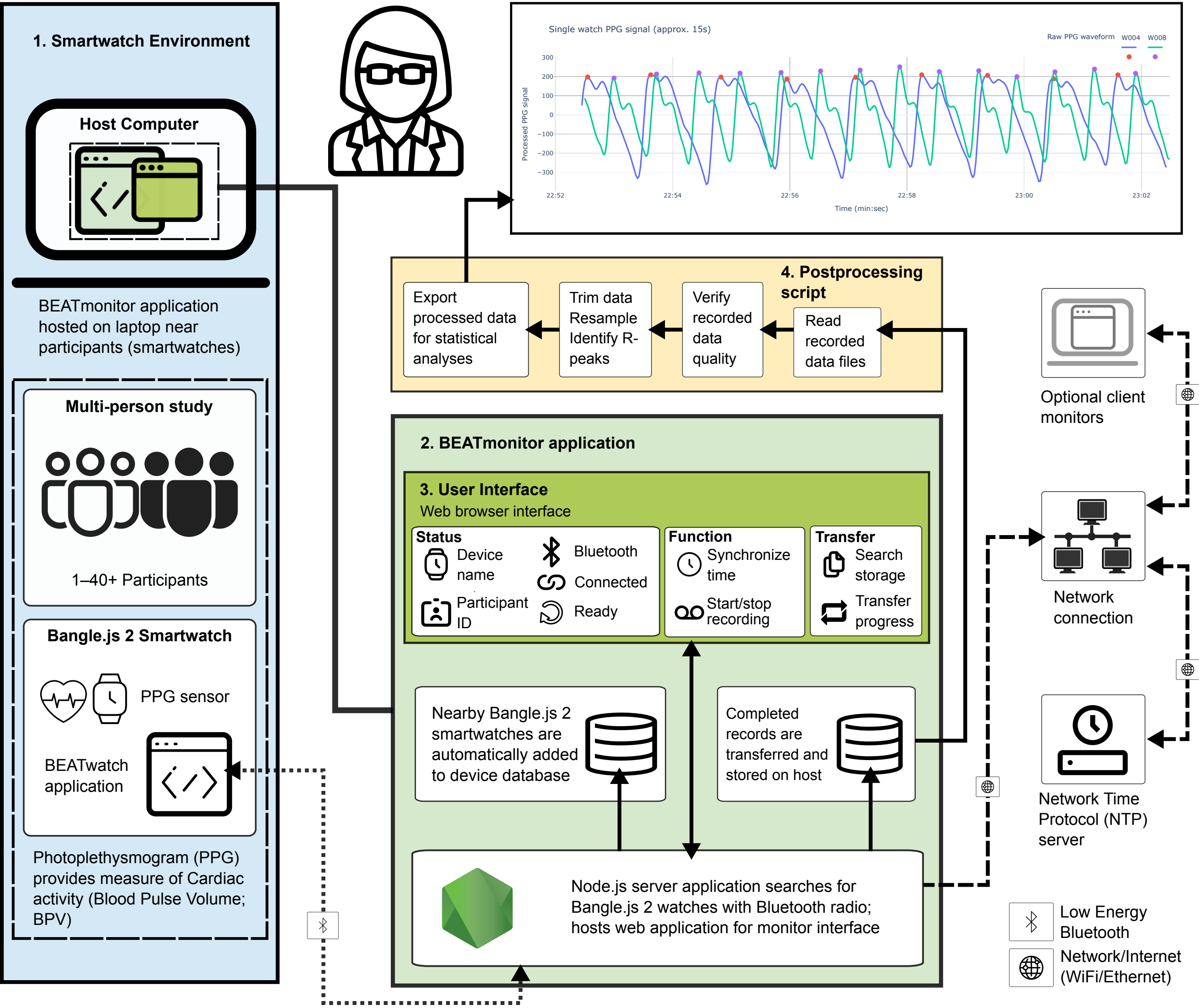
Enter note:

Section: Start End

Create Note

BEATLab 2025

BEATmonitor

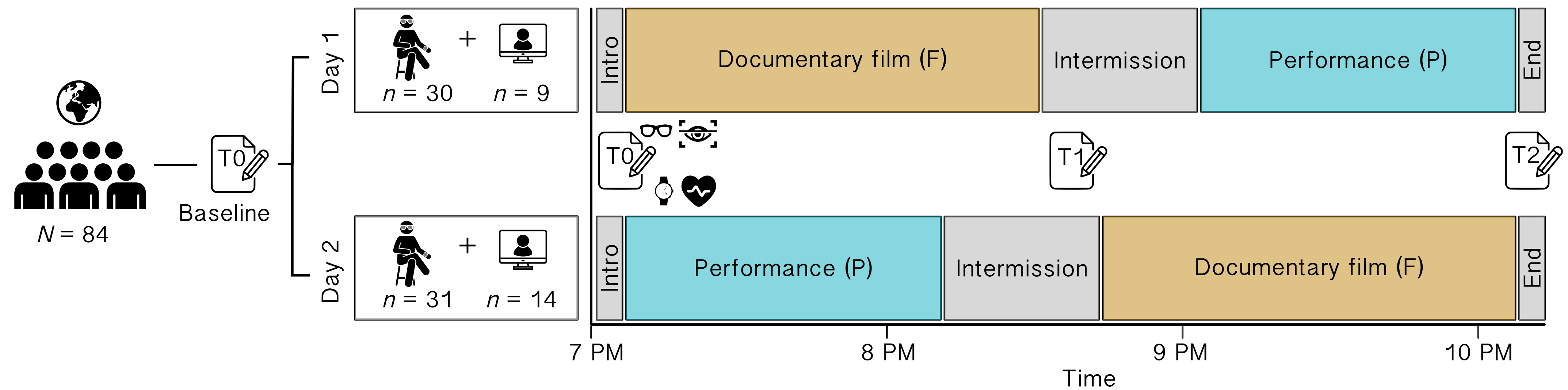




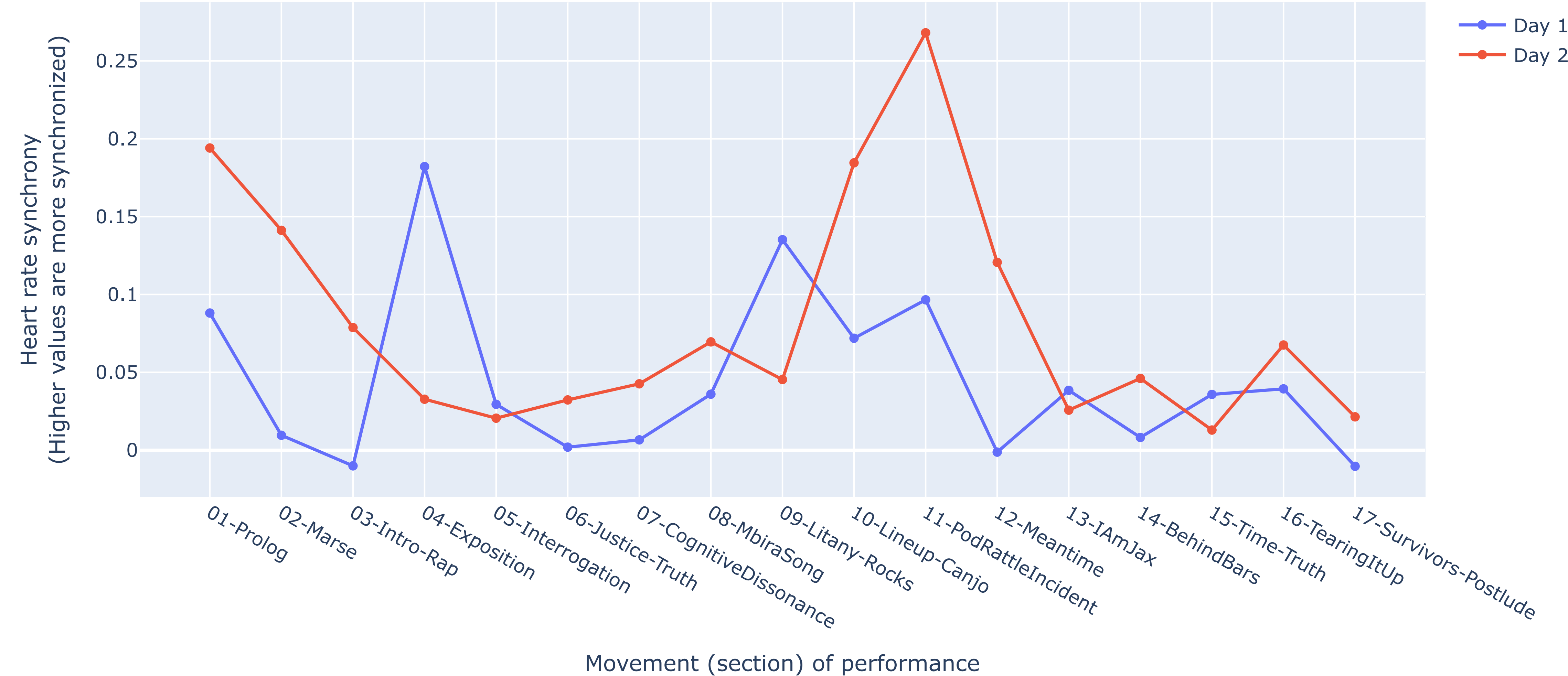
Research Design

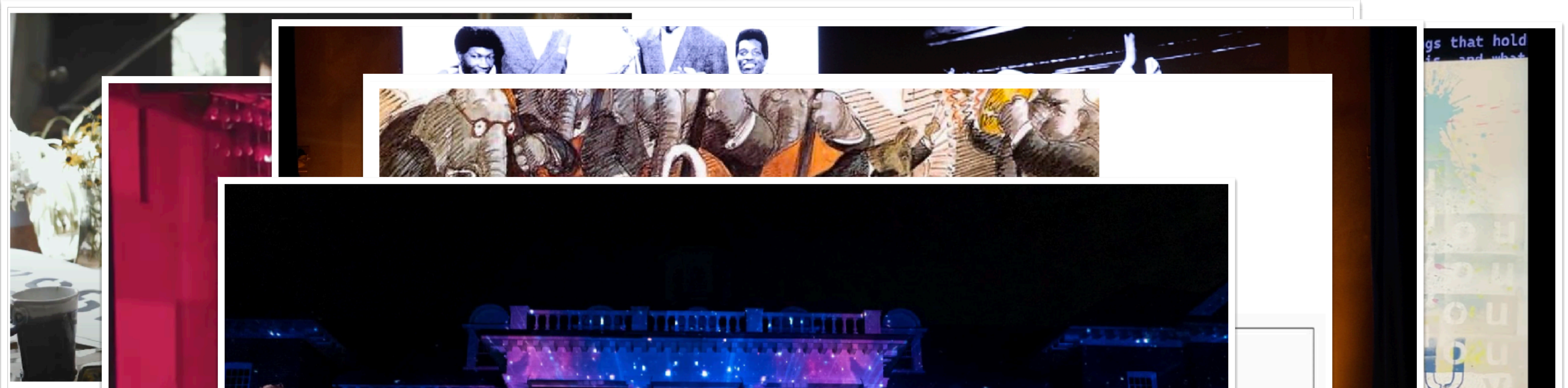


Research Design



Audience heart rate synchrony changes over the period of the performance





Six(+) studies

Ten(+) sessions

398 participants

Over 500 hours of heart rate data!

Demonstration

Recommended Literature

Quigley, K. S., Gianaros, P. J., Norman, G. J., Jennings, J. R., Berntson, G. G., & de Geus, E. J. C. (2024). Publication guidelines for human heart rate and heart rate variability studies in psychophysiology—Part 1: *Physiological underpinnings and foundations of measurement*. *Psychophysiology*, 61, e14604. <https://doi.org/10.1111/psyp.14604>

References

- Berntson GG, Quigley KS, Lozano D. Chapter 8: Cardiovascular Psychophysiology. Handbook of psychophysiology. 4th ed, Cambridge, United Kingdom: Cambridge university press; 2017, p. 182–210.
- Charlton PH, Kyriacou PA, Mant J, Marozas V, Chowienczyk P , Alastruey J. 2022. Wearable Photoplethysmography for Cardiovascular Monitoring. Proceedings of the IEEE Institute of Electrical and Electronics Engineers 2022;110:355–81. <https://doi.org/10.1109/JPROC.2022.3149785>
- Engelen, T., Solcà, M., & Tallon-Baudry, C. (2023). Interoceptive rhythms in the brain. Nature Neuroscience, 26(10), 1670–1684. <https://doi.org/10.1038/s41593-023-01425-1>
- Hammond, H., Armstrong, M., Thomas, G. A., & Gilchrist, I. D. (2023). Audience immersion: Validating attentional and physiological measures against self-report. Cognitive Research: Principles and Implications, 8(1), 22. <https://doi.org/10.1186/s41235-023-00475-0>
- Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. Biological Psychology, 84(3), 394–421. <https://doi.org/10.1016/j.biopsycho.2010.03.010>
- Madsen, J., & Parra, L. C. (2022). Cognitive processing of a common stimulus synchronizes brains, hearts, and eyes. PNAS Nexus, 1(1), pgac020. <https://doi.org/10.1093/pnasnexus/pgac020>
- Purves D, Augustine G, Fitzpatrick D, Hall W, LaMantia A, Mooney R, et al. Neuroscience. Sixth. Oxford University Press; 2018.
- Ray, D., Collins, T., Woolley, S., & Ponnappalli, P. (2023). A Review of Wearable Multi-Wavelength Photoplethysmography. IEEE Reviews in Biomedical Engineering, 16, 136–151. <https://doi.org/10.1109/RBME.2021.3121476>
- Souza, H. C. D., Philbois, S. V., Veiga, A. C., & Aguilar, B. A. (2021). Heart Rate Variability and Cardiovascular Fitness: What We Know so Far. Vascular Health and Risk Management, Volume 17, 701–711. <https://doi.org/10.2147/VHRM.S279322>



Thank you!

