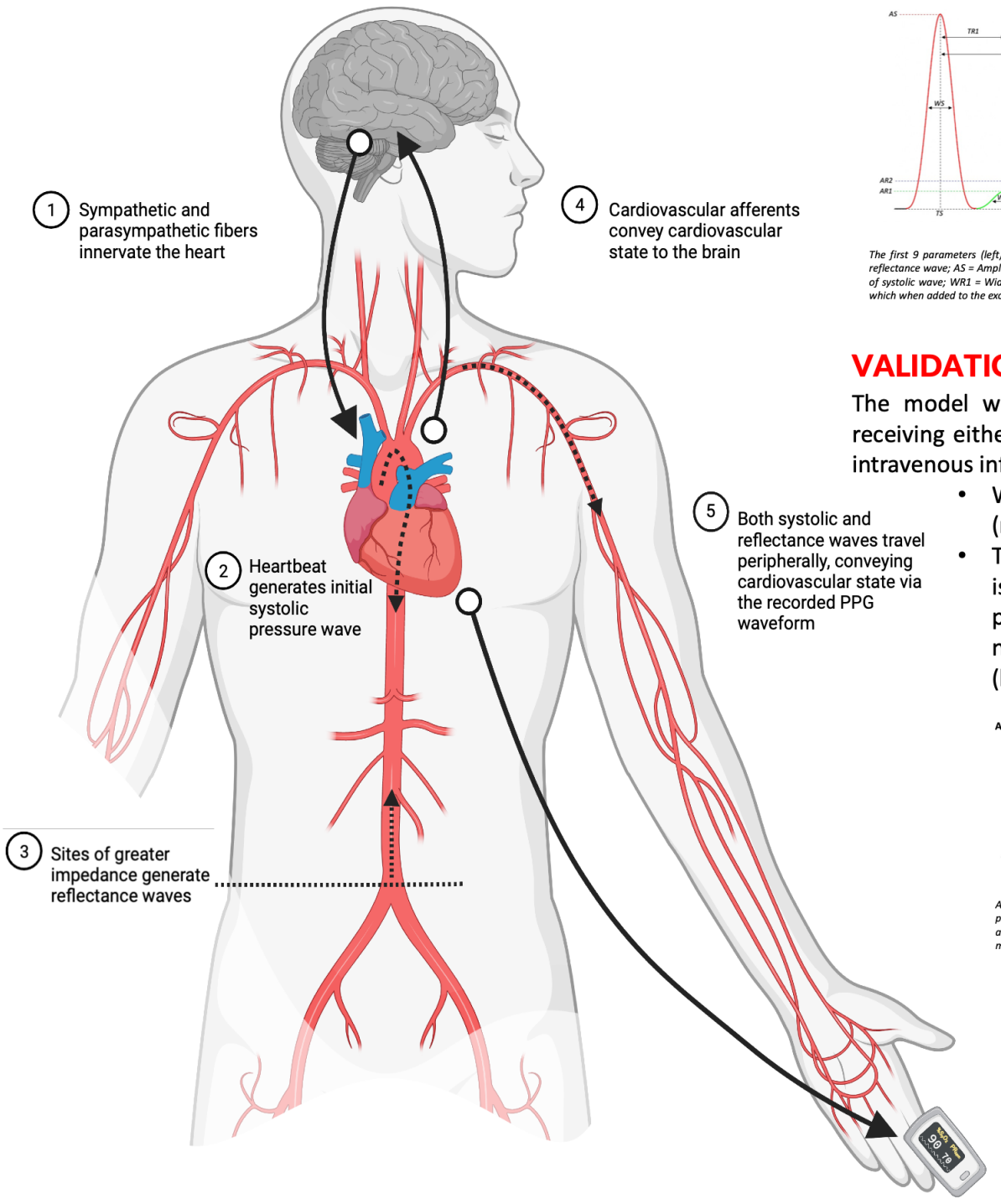
Photoplethysmography: a window onto psychological processes?

Simon Williamson, Lucie Daniel-Watanabe, Johanna Finnemann, Craig Powell, Adam Teed, Micah Allen, Martin Paulus, Sahib S. Khalsa, Paul C. Fletcher

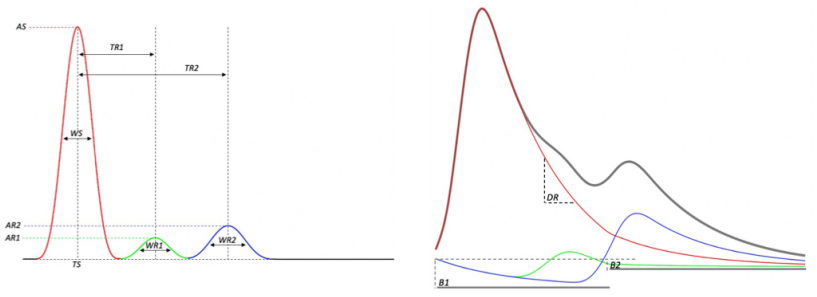
INTRODUCTION

- The photoplethysmography (PPG) signal is often used for **basic assessment** of heart rate and heart rate variability. The signal's waveform, however, is **rich in cardiovascular information.** It is shaped by both **psychological** and **physiological** factors that influence **the entire arterial tree**.
- By harnessing the waveform, neuroscience studies could **better characterize** psychophysiological states within and between individuals. We developed an **automated pipeline** and model for systematic analysis of PPG waveforms.



THE 'PulseWaveform' PACKAGE

- PulseWaveform is a PPG analysis pipeline that isolates waveforms to extract features reflective of cardiovascular state.
- As well as traditional measures of morphology (fiducial points), PulseWaveform enables the decomposition of waveforms into three underlying pressure waves – one systolic and two reflectance.
- Decomposition is achieved using the Hybrid Excess and Decay (HED) Model, which models waveforms as three component waves and an exponential decay:

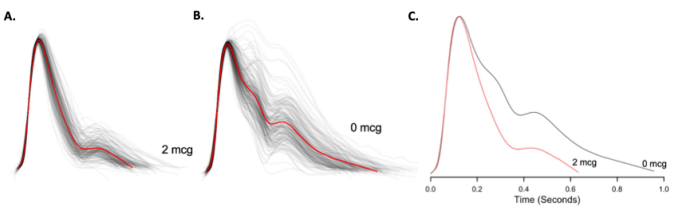


The first 9 parameters (left) are the excess element. TS = Timing of systolic wave; TR1 = Timing of 1st reflectance wave; TR2 = Timing of 2nd reflectance wave; AS = Amplitude of systolic wave; AR1 = Amplitude of 1st reflectance wave; AR2 = Amplitude of 2nd reflectance wave; WS = Width of systolic wave; WR1 = Width of 1st reflectance wave; WR2 = Width of 2nd reflectance wave. 2b: The final 3 parameters are the decay element, which when added to the excess yield the final modelled waveform (right). DR = Decay rate; B1 = 1st baseline; B2 = 2nd baseline.

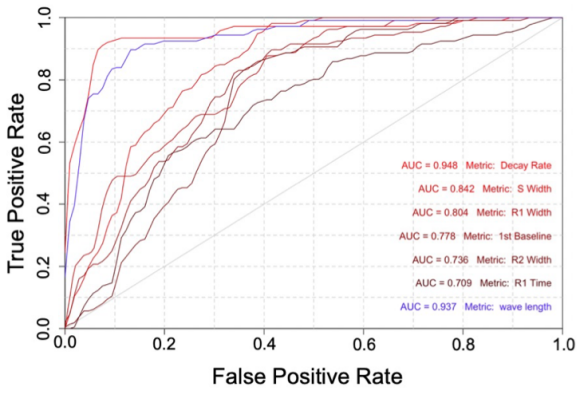
VALIDATION OF THE HED MODEL

The model was applied to PPG data of participants (n = 105) receiving either saline or the adrenaline-like drug isoproterenol by intravenous infusion:

- Waveforms were modelled with high precision (median NRMSE = 0.9).
- The change in waveform shape induced by isoproterenol was best classified by a model parameter (Decay rate; AUC = 0.948), which numerically outperformed all traditional measures (heart rate; AUC = 0.931).



A: Averaged waveforms (black) during pharmacological manipulation (one per subject/time series) aligned by systolic peak. The mean of these (red) is overlaid. B: Averaged waveforms during infusion of saline (one per subject/time series) aligned by systolic peak. The mean (red) is overlaid. C: The mean waves derived from A and B, overlaid to display the morphological change between saline and 2 mcg isoproterenol infusion.



ROC curve of top performing (highest AUC) model parameters (with best performing morphological feature, wavelength, overlaid in blue) in classifying between 0 mcg and 2 mcg morphologies.

DISCUSSION

- PulseWaveform offers a new level of nuance in non-invasive cardiovascular measurement, and a new means to characterize brain-body interactions. This is directly relevant to disorders of perturbed interoception (e.g. panic disorder) and those with established vascular changes (e.g. schizophrenia or depression).
- With the rise in popularity of wearable devices, the potential for PPG to aid in the study and monitoring of mental health conditions is significant.

UNIVERSITY OF CAMBRIDGE
LIBR Laureate Institute for Brain Research
NINJA THEORY

Scan to **access** the **pipeline** and **preprint**