Aligned accelerometer data can improve understanding of chronotypes

Erin McDonnell[1], Vadim Zipunnikov[2], Jennifer Schrack[2], Jeff Goldsmith[1], and Julia Wrobel[3]

[1] Columbia University, New York, NY
[2] Johns Hopkins University, Baltimore, MD
[3] University of Colorado Denver, Denver, CO

Correspondence: eim2117@cumc.columbia.edu

This research was supported by Award R01 NS097423-01 from NIH / NINDS.

Motivation

- **Accelerometers** provide minute-level activity counts over 24-hours.
- When binarized (active vs. sedentary) and treated as a functional data problem, **registration** may reveal new features of **chronotypes** that other circadian rhythms analysis methods may not.
- We analyze 492 patients from the **Baltimore Longitudinal Study of Aging**.

Methods

In **functional data analysis**, each unit of observation is a function. Across functions, there is both **horizontal** and **vertical** variability.

Registration aligns the functions by shared features. Using subject-specific **warping functions** $\boldsymbol{h_i^{-1}(t_i^*)}$, we can stretch or compress periods of **chronological time** $\boldsymbol{t_i^*}$ into **registered time** $\boldsymbol{t}$ such that the horizontal variability is removed.

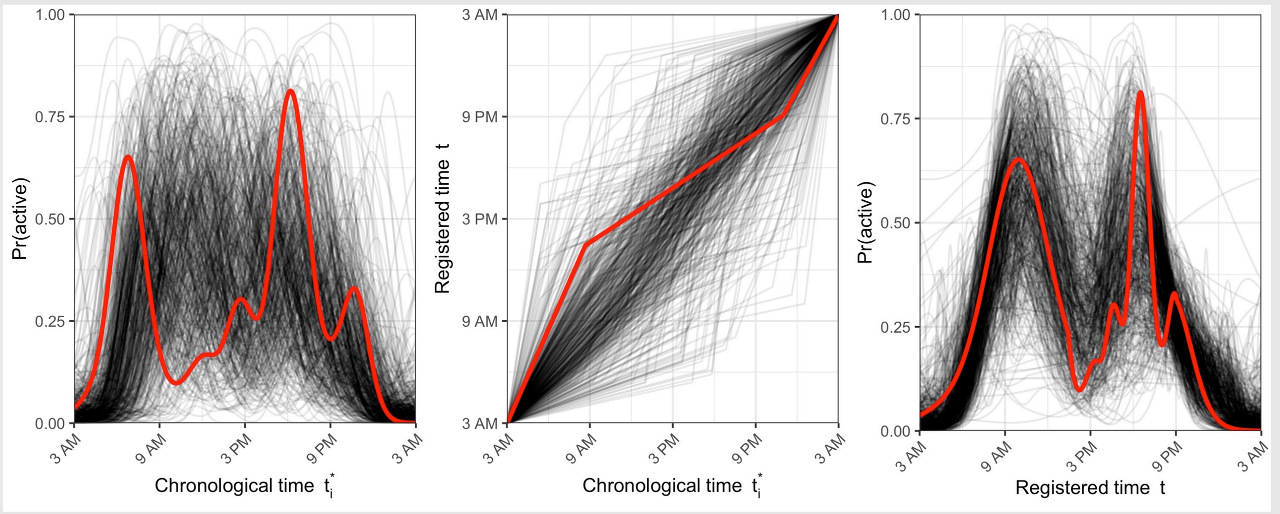
In this analysis, $h_i^{-1}(t_i^*)$ are **2-knot piecewise linear** functions.

Use a **2-step iterative process** to estimate 1) warping functions via **maximum likelihood**, and 2) subject-specific template curves using **binary functional principal components analysis (FPCA):**

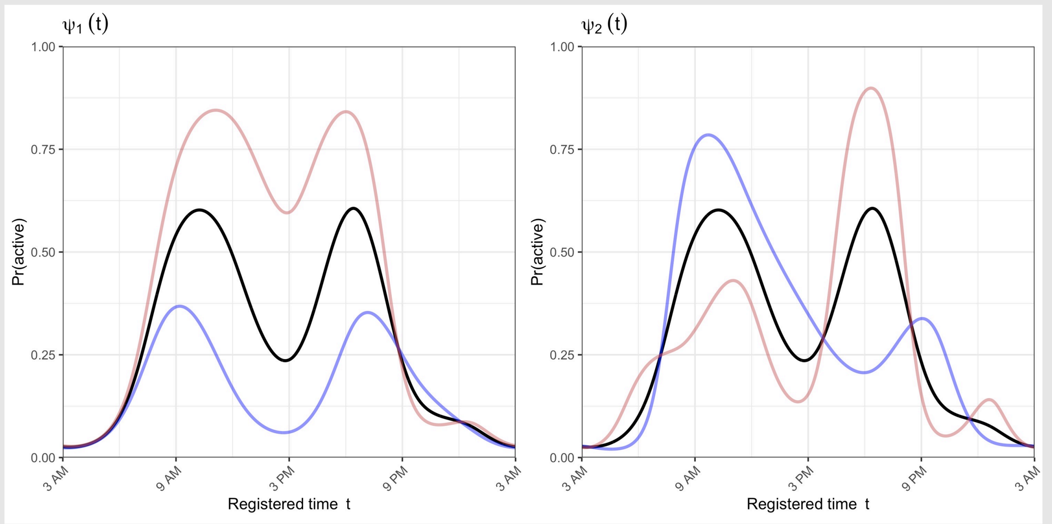
$$E\left[Y_i\left(h^{-1}(t_i^*)\right) \mid c_i, h_i^{-1}\right] = \mu_i(t),$$

$$logit[\mu_i(t)] = \alpha(t) + \sum_{k=1}^{K} c_{ik}\psi_k(t).$$

Registration results

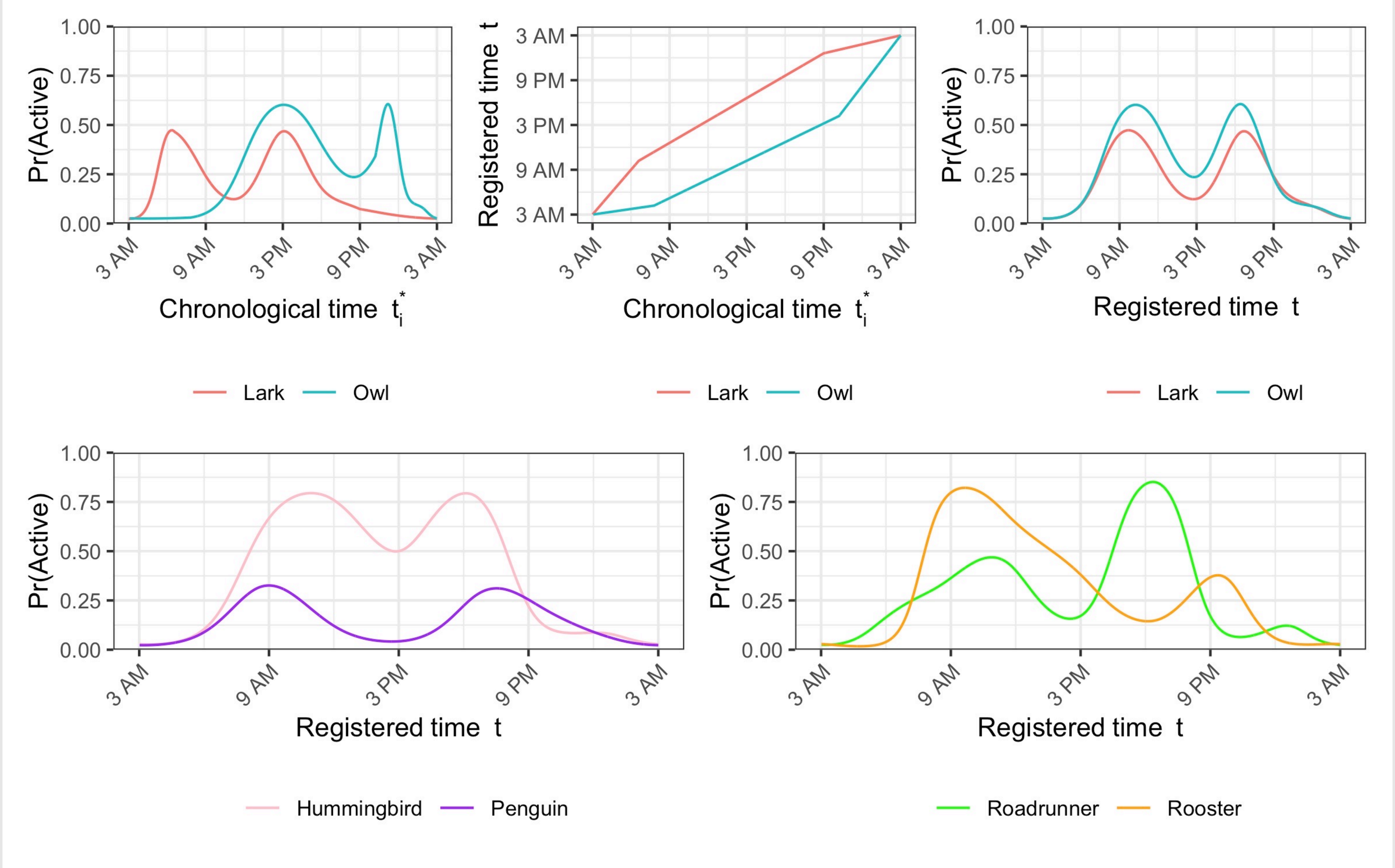


Warping function step



Binary FPCA step

Registration parameters can reveal chronotypes

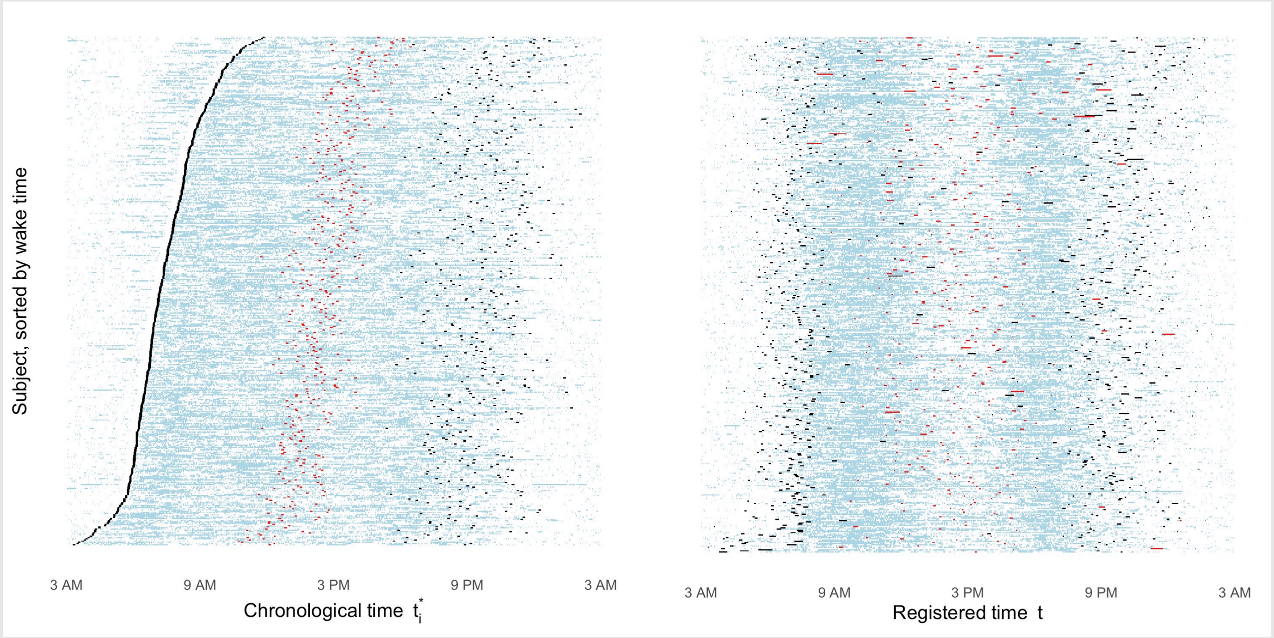


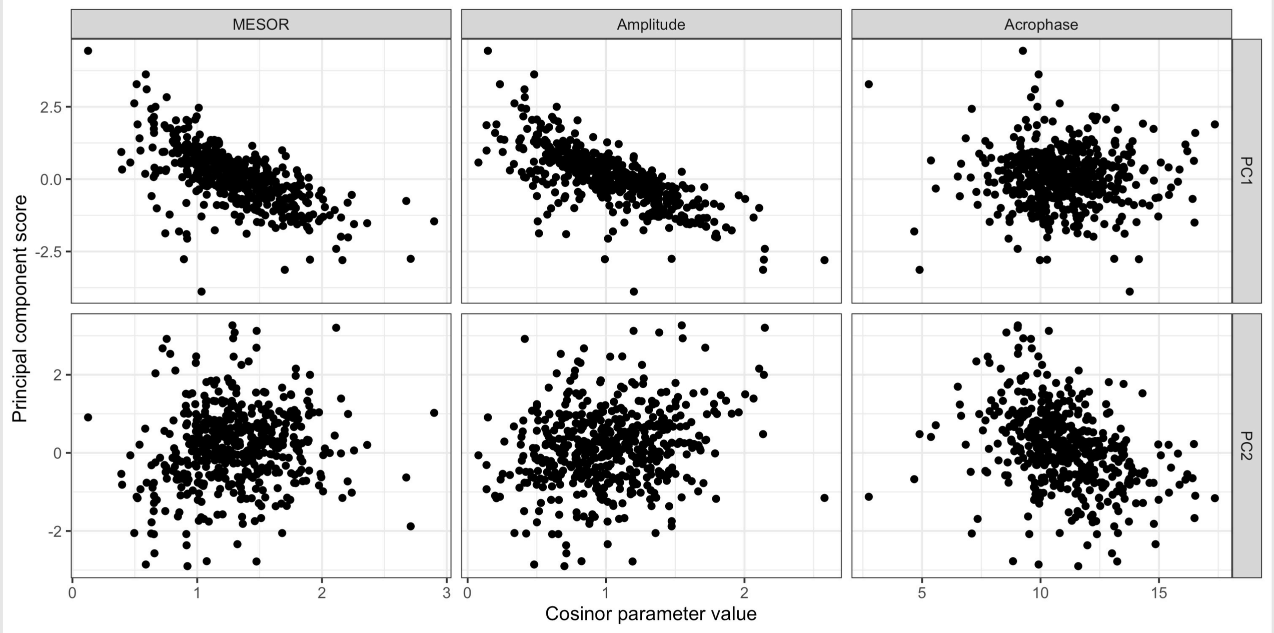
Slopes of the inverse warping functions can separate **Larks** (earlier wake time) from **Non-larks** (later wake time), and **Owls** (later sleep time) from **Non-owls** (earlier sleep time).

PC scores can separate **Hummingbirds** (more active) from **Penguins** (less active), and **Roadrunners** (more active in afternoon) from **Roosters** (more active in morning).

Comparison with existing approaches

Landmark methods (right): Registration aligns wake and sleep times nicely (in black), but the daytime interval midpoint (in red) does not consistently map to any meaningful time of day post-registration.





Cosinor method (left): Registration's second principal component does not correlate with any cosinor parameters, suggesting this is new information beyond what the cosinor model can provide.

Binary FPCA (right): Without registration, we see a less distinct 2-peak mean profile, and less interpretable PCs that conflate horizontal and vertical variability.