Covariance estimation for derivatives of functional data

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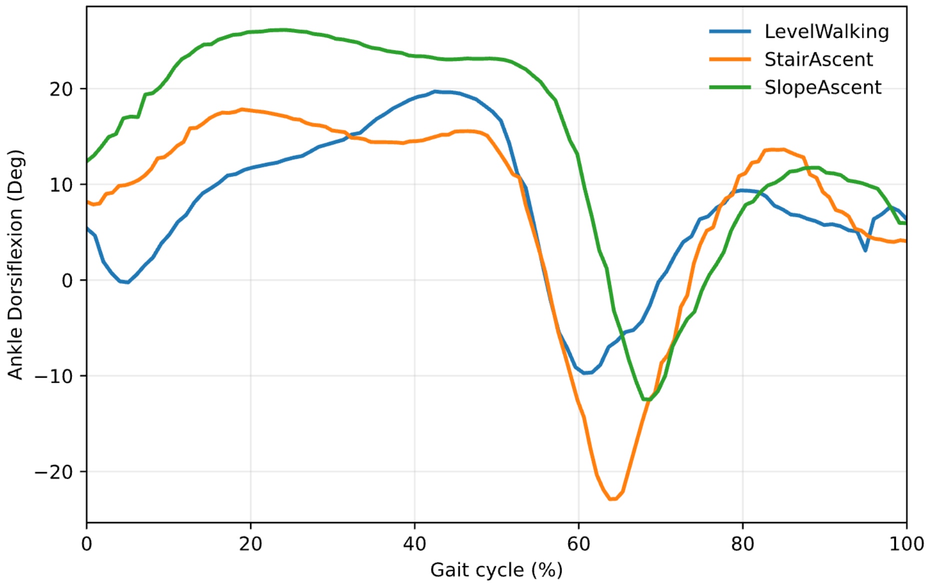
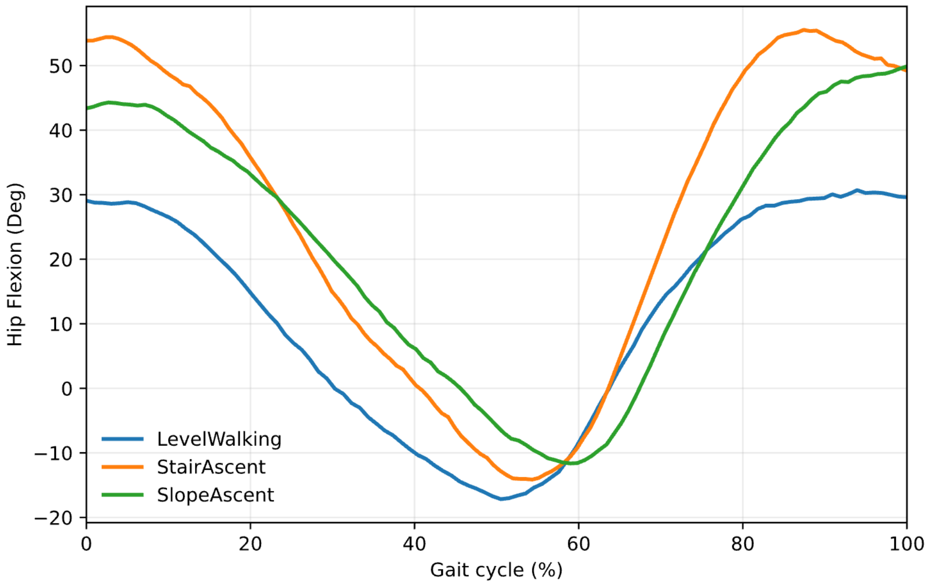
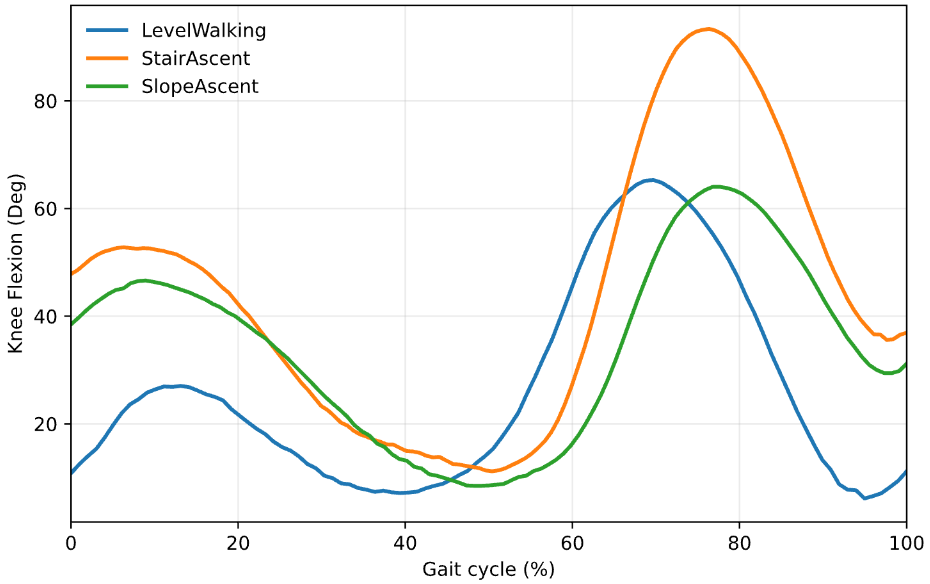






Pictures are from the authors.

Boo, J. et al., Comprehensive human locomotion and electromyography dataset: Gait120 (2025).

The target

$$\partial_s \partial_t K(s,t) = \mathbb{E}\left(\partial X(s), \partial X(t)\right)$$

Zhu, Y. et al., Covariance estimation for derivatives of functional data using an additive penalty in P-splines (2026).

FACE + additive P-spline penalty

$$\widetilde{K}(s,t) = S\widehat{K}(s,t)S$$

$$S = B\left(B^\top B + \lambda_1 P_1 + \lambda_2 P_2\right)^{-1} B^\top$$

Simpkin, A. and Newell, J., An additive penalty P-spline approach to derivative estimation (2013).
Xiao, L. et al., Fast covariance estimation for high-dimensional functional data (2016).

Derivative of the covariance

$$\widetilde{K}(s,t) = B(s)^\top \boldsymbol{\Theta} B(t)$$

$$\partial_s \partial_t \widetilde{K}(s,t) = \partial_s B(s)^\top \boldsymbol{\Theta} \partial_t B(t)$$

Zhu, Y. et al., Covariance estimation for derivatives of functional data using an additive penalty in P-splines (2026).

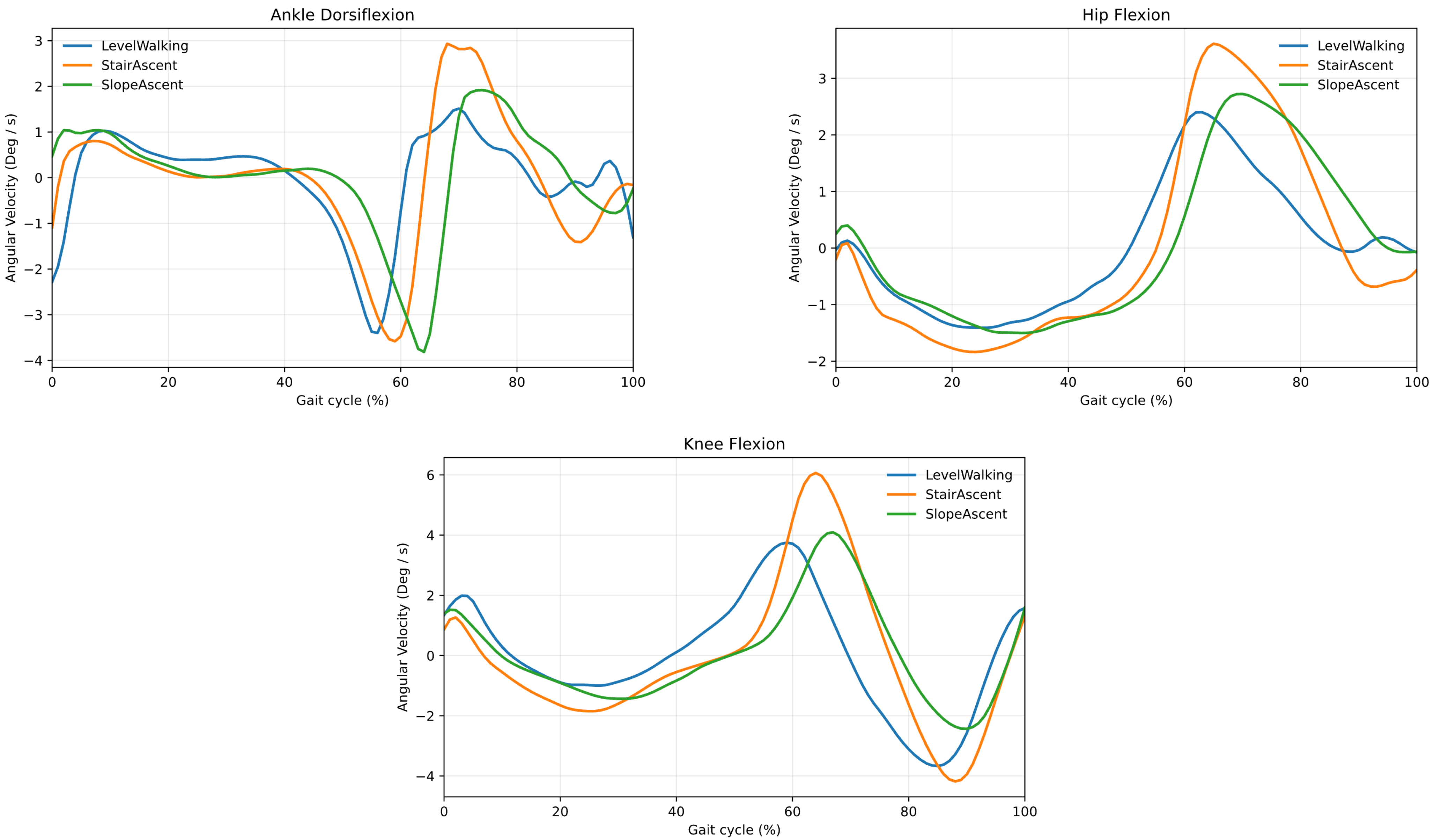
Derivative-based FPCA

$$G^{1/2}\Theta G^{1/2} = QVQ$$

$$\Phi(t) = \partial_t B(t)^\top G^{-1/2} Q$$

$$\xi_i = \left(\Phi^\top \Phi + \sigma^2 V^{-1}\right)^{-1} \Phi^\top \partial B \Theta$$

Zhu, Y. et al., Covariance estimation for derivatives of functional data using an additive penalty in P-splines (2026).



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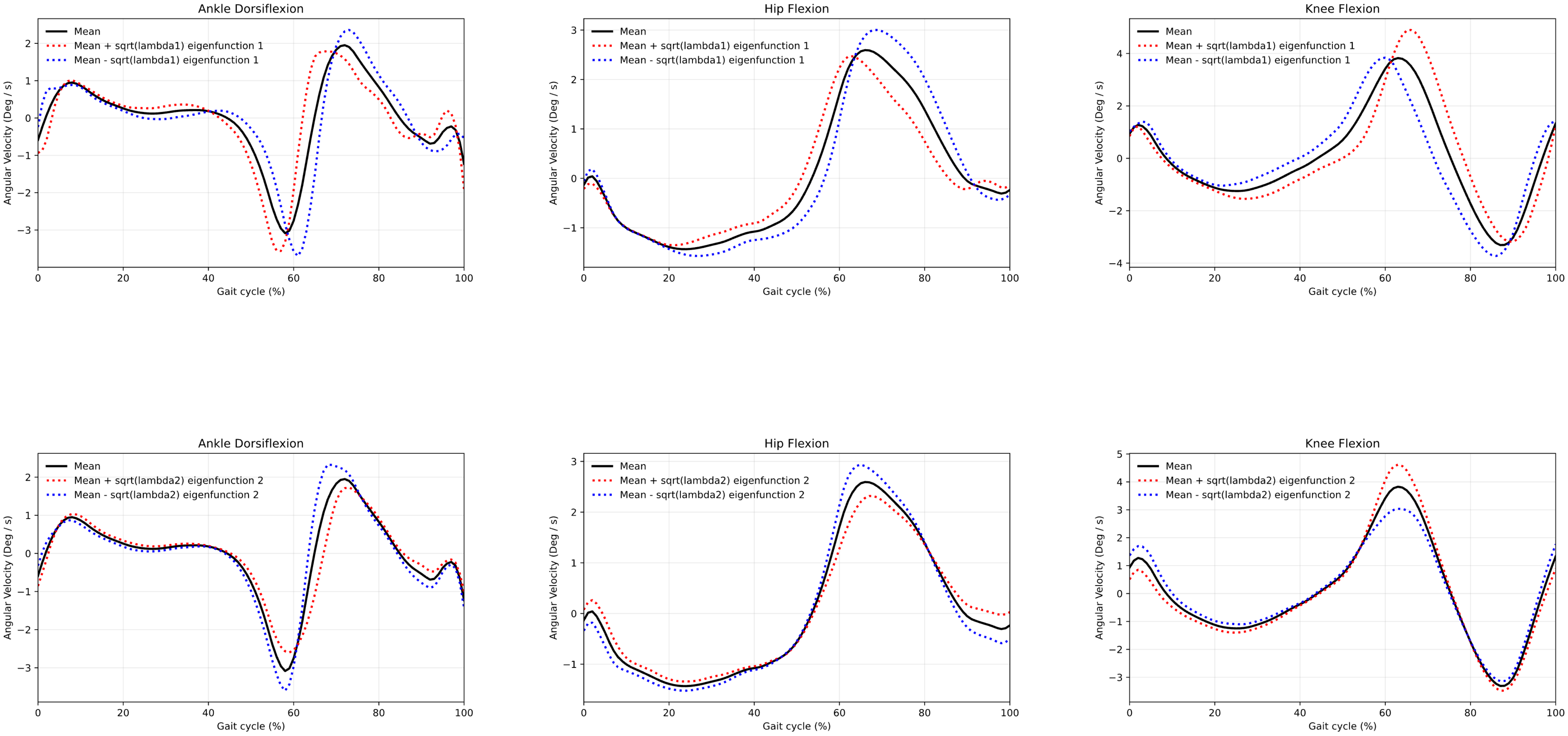

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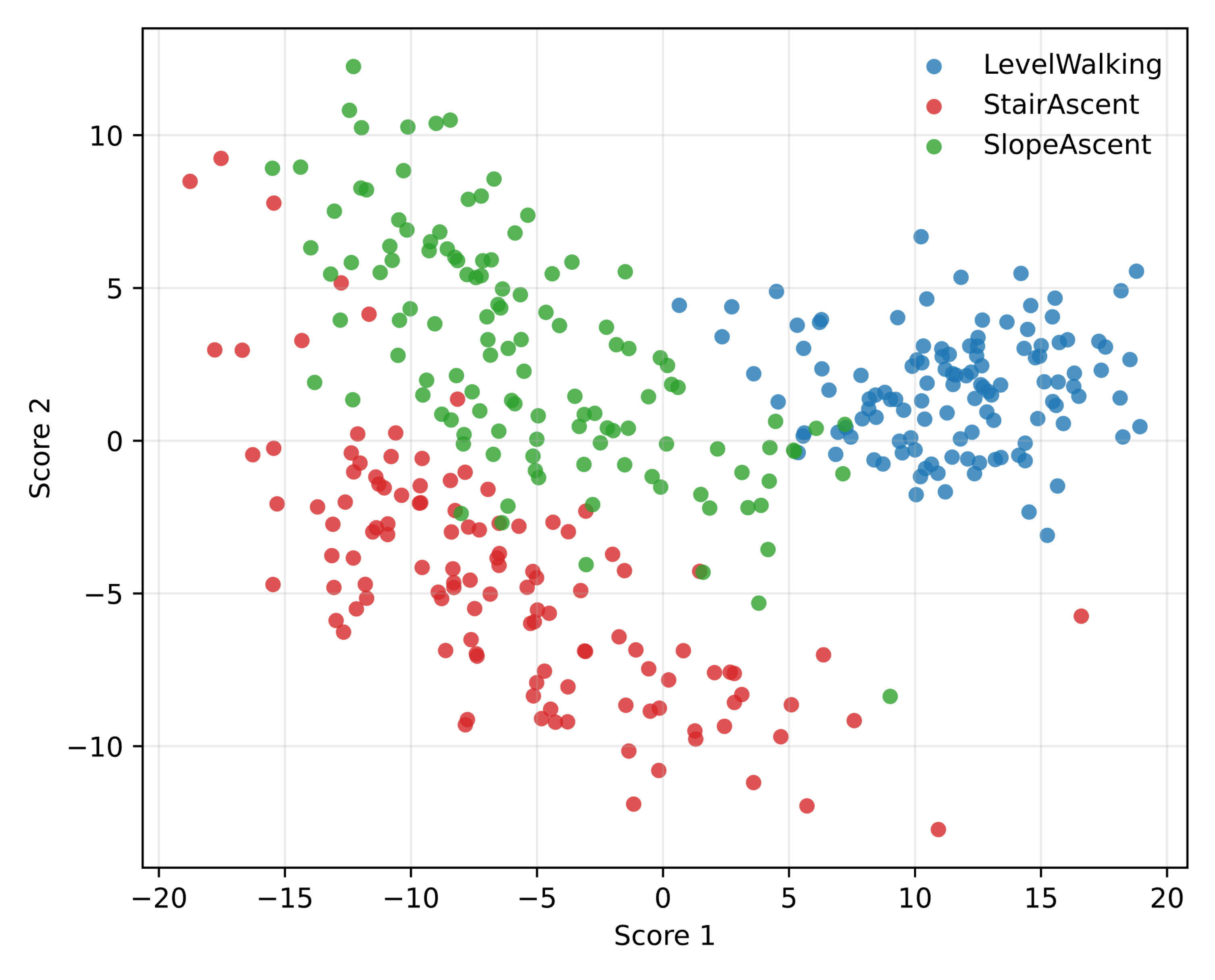

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Thanks!