

# **Additional file 1**

Beyond the Romberg Ratio: Direction-Resolved  
Modeling Reveals Reduced Visual Stabilization on  
Compliant Surfaces in Aging

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## Supplementary Tables

**Table S1: Feature-selection frequency in the repeated nested cross-validation.** In each of 100 random outer partitions, the five-fold nested cross-validation selected, within every outer fold, the feature with the highest inner cross-validated AUROC for discriminating older from younger adults, using the absolute Firm-to-Foam surface cost computed under the eyes-open condition as the univariate predictor. This yielded 500 fold-level selections in total. The table lists every feature selected at least once, ordered by selection frequency. *Times selected* is the number of fold-level selections (out of 500); *Frequency* is the corresponding proportion. The *Velocity-domain* column indicates whether the feature belongs to the velocity-domain family. All but one of the selected features was a mediolateral (ML) measure (499 of 500 selections); 487 of 500 selections (97.4%) were velocity-domain ML measures.

| Rank         | Feature                          | Velocity-domain | Times selected | Frequency |
|--------------|----------------------------------|-----------------|----------------|-----------|
| 1            | Peak velocity (positive SPD), ML | Yes             | 275            | 0.550     |
| 2            | Peak velocity (all SPD), ML      | Yes             | 139            | 0.278     |
| 3            | Mean velocity, ML                | Yes             | 64             | 0.128     |
| 4            | Phase-plane parameter, ML        | No              | 13             | 0.026     |
| 5            | Peak velocity (negative SPD), ML | Yes             | 8              | 0.016     |
| 6            | Mean velocity, ML & AP           | Yes             | 1              | 0.002     |
| <i>Total</i> |                                  |                 | 500            | 1.000     |

*Note.* Nested cross-validation: 5-fold outer loop (performance estimation)  $\times$  5-fold inner loop (feature selection), 100 repeated random partitions (seeds 1–100). Classifier: binary logistic regression with no regularization, predictor standardized within each training fold. Inner AUROC computed by pooling held-out scores across all inner folds before applying `roc_auc_score` (pooled estimator). Overall nested AUROC: mean = 0.984, SD = 0.009, 95% range [0.962, 0.993]. Analysis performed in Python (numpy 2.3.3, pandas 2.3.3, scikit-learn 1.7.2).

**Table S2:** Group separation for absolute sensory costs versus sensory challenge ratios across the top-ranked posturographic features. For each transition the ten features with the largest age-group separation are listed. Separation is Cliff’s  $\delta$ (older – young); positive values indicate larger values in older adults, negative values larger in younger adults. For the surface transition, the difference and ratio were computed under eyes-open; for the visual transition, on foam.  $\delta_{\text{Diff}}$  is the absolute difference between perturbed and reference conditions;  $\delta_{\text{Ratio}}$  the corresponding ratio. Cliff’s  $\delta = 2\text{AUC} - 1$ . The ranking is exploratory (ordered by  $|\delta_{\text{Diff}}|$  in this sample) and is not a validated selection. 95% CIs in brackets.

| Rank                                    | Feature                                | $\delta_{\text{Diff}}$ [95% CI] | $\delta_{\text{Ratio}}$ [95% CI] |
|---|--|---------------------------------|----------------------------------|
| <b>Surface Transition (Firm → Foam)</b> |  |                                 |                                  |
| 1                                       | Peak velocity pos SPD ML (EO)          | 0.99 [0.96, 1.00]               | 0.62 [0.42, 0.76]                |
| 2                                       | Peak velocity all SPD ML (EO)          | 0.98 [0.94, 0.99]               | 0.58 [0.38, 0.73]                |
| 3                                       | Mean velocity ML (EO)                  | 0.98 [0.94, 0.99]               | 0.61 [0.41, 0.76]                |
| 4                                       | Mean velocity ML & AP (EO)             | 0.96 [0.90, 0.99]               | 0.57 [0.36, 0.72]                |
| 5                                       | Peak velocity neg SPD ML (EO)          | 0.96 [0.90, 0.98]               | 0.54 [0.32, 0.70]                |
| 6                                       | Phase plane parameter ML (EO)          | 0.96 [0.89, 0.98]               | 0.57 [0.37, 0.72]                |
| 7                                       | Energy content >2 Hz PSD ML (EO)       | 0.93 [0.84, 0.97]               | 0.67 [0.48, 0.80]                |
| 8                                       | Energy content 0.5–2 Hz PSD ML (EO)    | 0.93 [0.84, 0.97]               | 0.42 [0.19, 0.60]                |
| 9                                       | Short time diffusion ML (EO)           | 0.92 [0.79, 0.97]               | 0.36 [0.13, 0.55]                |
| 10                                      | Mean distance peak sway density (EO)   | 0.90 [0.76, 0.96]               | 0.37 [0.14, 0.56]                |
| <b>Visual Transition (EO → EC)</b>      |  |                                 |                                  |
| 1                                       | Mean peak sway density (Foam)          | 0.80 [0.61, 0.90]               | 0.57 [0.35, 0.73]                |
| 2                                       | Fractal dimension ML & AP (Foam)       | -0.60 [-0.75, -0.39]            | -0.62 [-0.76, -0.41]             |
| 3                                       | Mean frequency ML & AP (Foam)          | -0.53 [-0.69, -0.32]            | -0.61 [-0.76, -0.40]             |
| 4                                       | Mean frequency ML (Foam)               | -0.49 [-0.66, -0.27]            | -0.62 [-0.78, -0.40]             |
| 5                                       | LFS ML & AP (Foam)                     | -0.44 [-0.62, -0.22]            | -0.46 [-0.63, -0.24]             |
| 6                                       | Mean distance peak sway density (Foam) | -0.41 [-0.60, -0.17]            | -0.65 [-0.79, -0.44]             |
| 7                                       | Mean frequency AP (Foam)               | -0.40 [-0.58, -0.18]            | -0.38 [-0.57, -0.16]             |
| 8                                       | Power frequency 50PSD AP (Foam)        | -0.34 [-0.53, -0.12]            | -0.34 [-0.53, -0.12]             |
| 9                                       | Frequency mode PSD ML (Foam)           | -0.34 [-0.54, -0.11]            | -0.36 [-0.55, -0.14]             |
| 10                                      | Power frequency 50PSD ML (Foam)        | -0.34 [-0.53, -0.11]            | -0.37 [-0.56, -0.14]             |

**Table S3: Positive peak sway velocity by cohort and sensory condition.** Values are median [first quartile, third quartile] in cm/s, for the mediolateral (ML) and anteroposterior (AP) directions. Each cell summarizes one cohort (older,  $n = 50$ ; younger,  $n = 48$ ) under one of the four sensory conditions of the  $2 \times 2$  (Surface  $\times$  Vision) design. Medians and interquartile ranges are reported because the distributions are right-skewed and bounded below by zero; they correspond to the boxplots in Fig. 1A,B.

| Cohort  | Surface | Vision      | ML [cm/s]         | AP [cm/s]         |
|---------|---------|-------------|-------------------|-------------------|
| Older   | Firm    | Eyes open   | 0.99 [0.82, 1.21] | 0.54 [0.41, 0.72] |
|         |         | Eyes closed | 1.08 [0.89, 1.28] | 0.51 [0.43, 0.74] |
|         | Foam    | Eyes open   | 3.70 [3.27, 4.32] | 2.29 [1.84, 2.63] |
|         |         | Eyes closed | 4.39 [3.61, 5.31] | 2.69 [2.18, 3.35] |
| Younger | Firm    | Eyes open   | 0.69 [0.57, 0.86] | 0.48 [0.36, 0.59] |
|         |         | Eyes closed | 0.71 [0.62, 0.97] | 0.45 [0.41, 0.68] |
|         | Foam    | Eyes open   | 1.86 [1.70, 2.07] | 1.61 [1.40, 1.93] |
|         |         | Eyes closed | 2.65 [2.25, 3.15] | 2.21 [1.78, 2.48] |

**Table S4: Sensory challenge ratios by cohort and condition.** Values are median [first quartile, third quartile], for the mediolateral (ML) and anteroposterior (AP) directions. Visual ratios (Visual Firm, Visual Foam) are eyes-closed / eyes-open quotients at a fixed surface; surface ratios (Surface Open, Surface Closed) are foam / firm quotients at a fixed vision condition. A ratio of one indicates no effect of the perturbation. Ratios were computed per subject and summarized across subjects (older,  $n = 50$ ; younger,  $n = 48$ ); they correspond to the boxplots in Fig. 1E,F. Note the paradoxical pattern in the Visual Foam condition, where younger adults show higher ratios than older adults despite their lower absolute sway.

| Condition      | Cohort  | ML                | AP                |
|----------------|---------|-------------------|-------------------|
| Visual Firm    | Older   | 1.05 [0.89, 1.23] | 1.01 [0.85, 1.16] |
|                | Younger | 1.07 [0.96, 1.17] | 1.07 [0.95, 1.19] |
| Visual Foam    | Older   | 1.20 [1.09, 1.28] | 1.18 [1.09, 1.36] |
|                | Younger | 1.43 [1.29, 1.55] | 1.35 [1.23, 1.47] |
| Surface Open   | Older   | 3.47 [2.97, 4.25] | 4.01 [3.31, 5.31] |
|                | Younger | 2.64 [2.33, 3.00] | 3.44 [2.53, 3.91] |
| Surface Closed | Older   | 4.01 [3.15, 5.53] | 4.79 [3.90, 6.54] |
|                | Younger | 3.58 [3.00, 4.11] | 4.06 [3.46, 5.11] |