Force, recruitment threshold, and muscle as determinants of discharge rate and variability in human motor units

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Introduction

Force is graded by recruiting motor units (MUs) and modulating their discharge rate. How regularly they fire, which shapes force steadiness, is far less understood across the full recruitment range.

We modelled both **discharge rate** and its **variability** in Tibialis Anterior (TA) and Vastus Lateralis (VL) and found that they are not governed by the same factors.

Methods

Dataset[1]:

- HD-sEMG dataset
- Contractions at 10–80% of maximal voluntary contraction (%MVC)
- TA: 8 participants (~129 MUs each)
- VL: 6 participants (~162 MUs each)
- **ΔForce** = contraction level (CL)– recruitment threshold (RT)

Linear mixed-effects models:

- Dependent variables : **discharge rate (DR), inter-spike interval variability (CoV ISIs)**
- Fixed effects: CL, RT, Muscle
- Random effects: Subjects, MUs

Results

Discharge rate

- Rises with force, falls with motor unit size
- Steeper in TA (~2.7Hz / 10% MVC) than VL (~1.3Hz / 10% MVC)

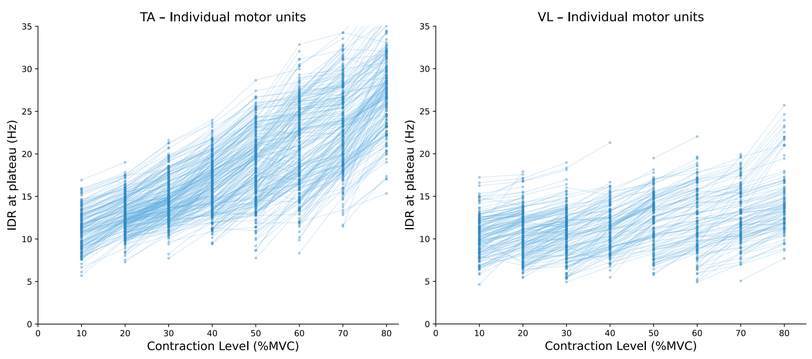

Figure 1: Individual MUs. Plateau discharge rate of every tracked MU across contraction levels, in TA (left) and VL (right). Each line is one MU.

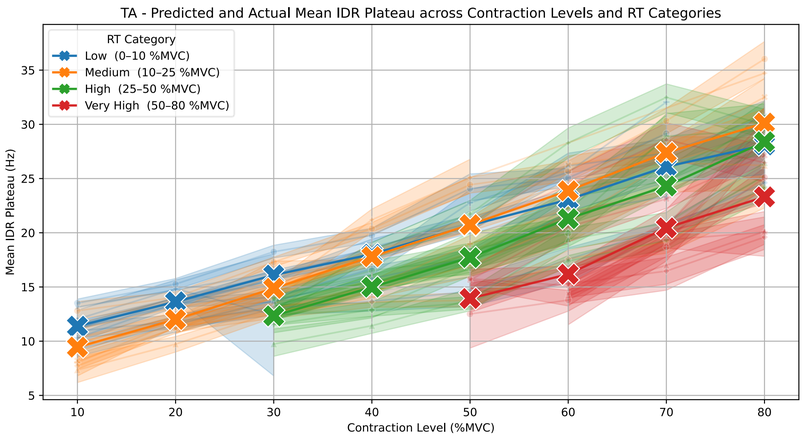

Figure 2: TA – motor units grouped into four RT categories. Larger, higher-threshold units fire slower and rise more steeply with force.

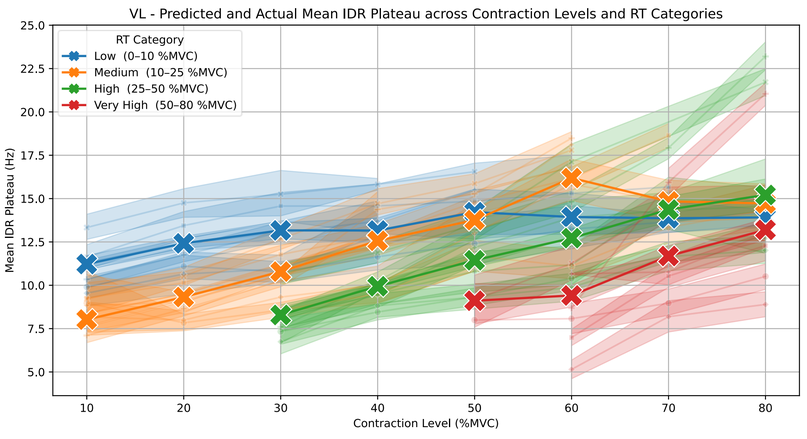

Figure 3: VL – motor units grouped into four RT categories. Larger, higher-threshold units fire slower and rise with force.

CoV ISIs

- Two regimes split at a breakpoint δ ≈ 11.3 %MVC above recruitment
- AIC profile identifies δ sharply

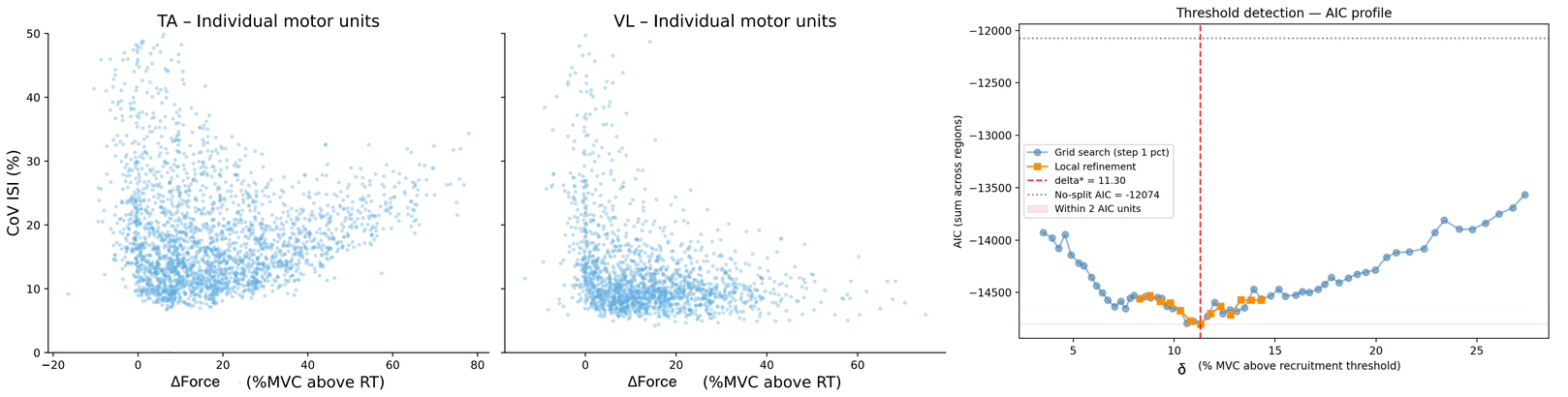

Figure 4: CoV vs relative force (ΔForce) in TA (left) and VL (centre). U-shaped: high near recruitment, rising at higher force. AIC search (right) locates the breakpoint δ ≈ 11.3 %MVC.

CoV ISIs - Above Threshold

- CL and muscle govern but size no longer significant
- TA: (0.10 → 0.23) vs VL: (0.10 → 0.12)

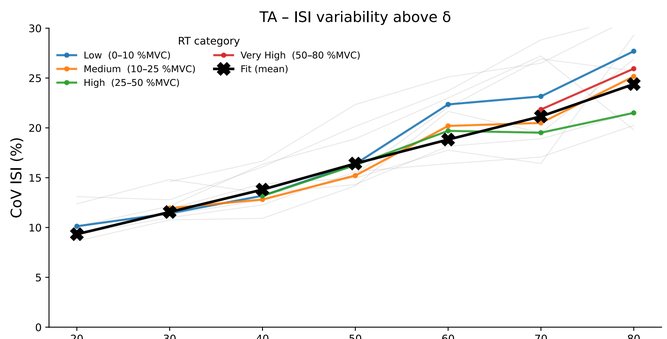

Figure 5: TA- CoV vs CL, split by RT category. Grey: individual subjects; black: model fit above threshold.

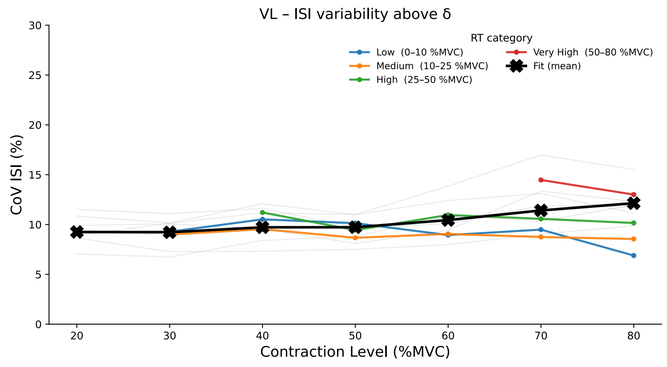

Figure 6: VL- CoV vs CL, split by RT category. Grey: individual subjects; black: model fit above threshold.

CoV ISIs - Below Threshold

- Motor unit size governs
- Both muscles alike

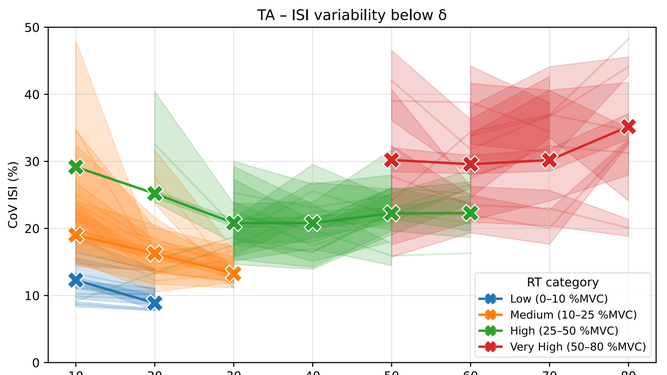

Figure 7: TA- Below δ – CoV vs CL, split by RT category. At every CL, higher-threshold (larger) MUs show greater variability

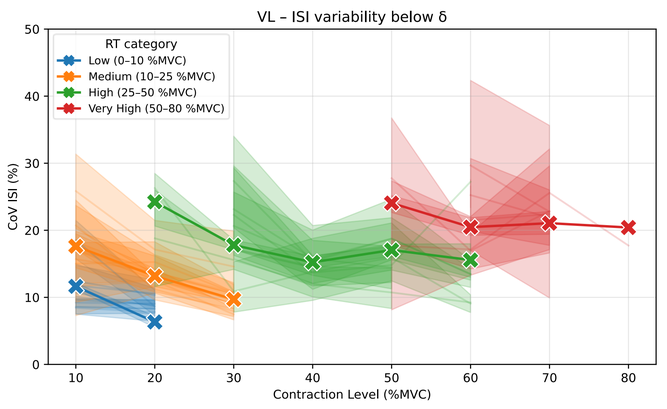

Figure 8: VL- Below δ- CoV vs CL, split by RT category. At every CL, higher-threshold (larger) MUs show greater variability

Conclusion

Discharge rate rises with force and falls with motor unit size. Variability instead shifts at ~11.3% MVC above threshold: size governed below, force and muscle governed above. Its drivers change with force and differ between muscles.

References

[1]Avrillon S et al. The identification of extensive samples of motor units in human muscles reveals diverse effects of neuromodulatory inputs on the rate coding. Elife. 2024 Dec 9;13:RP97085