



Introduction

- Muscle fatigue is a clinically important measure in fields such as rehab and sports science
- Surface electromyography (sEMG) measures muscle activation, and the signal frequency decreases with muscle fatigue [1]
- Frequency-based analyses require idealized conditions to estimate fatigue, which limits clinical applications**
- Topological data analysis (TDA) provides insight to the data that typical processing methods cannot reveal [2]
- TDA has helped with monitoring gene expression and classifying neurological disorders in EEG signals [3]

Hypothesis: TDA can provide a stronger correlation to fatigue than standard frequency-based analysis.

Methods

- Custom rig was designed to isolate FDI muscle (Figure 1)
- N= 30 subjects contracted FDI muscle for 300 seconds
- Frequency and TDA analyses performed (Figures 2, 3)

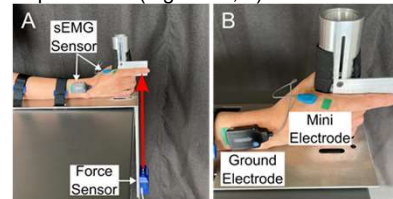


Figure 1. A) Custom rig to isolate FDI muscle. Nylon string tautly connected between the finger and force sensor. B) Close-up of sEMG electrode placement.

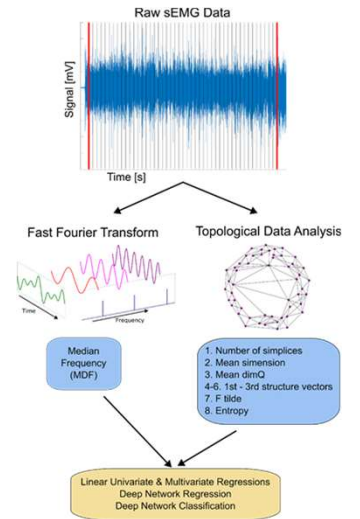


Figure 2. Overview of analysis methods

Methods

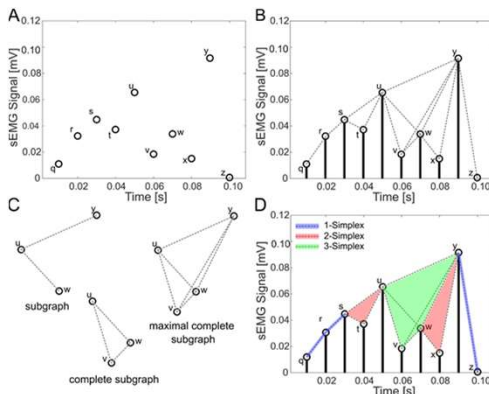


Figure 3. Representative TDA approach. A) Raw data from sEMG signal. B) Visibility graph constructed from sEMG signal. Nodes are connected if a straight line can be drawn between points without intersecting the intermediate height of another node. C) Representation of a subgraph, complete subgraph, and maximally complete subgraph from B. D) Maximal simplices resulting from visibility diagram.

Results and Discussion

- TDA provides robust scalar and vector time series data for input to machine learning and statistical analyses (Figure 4)

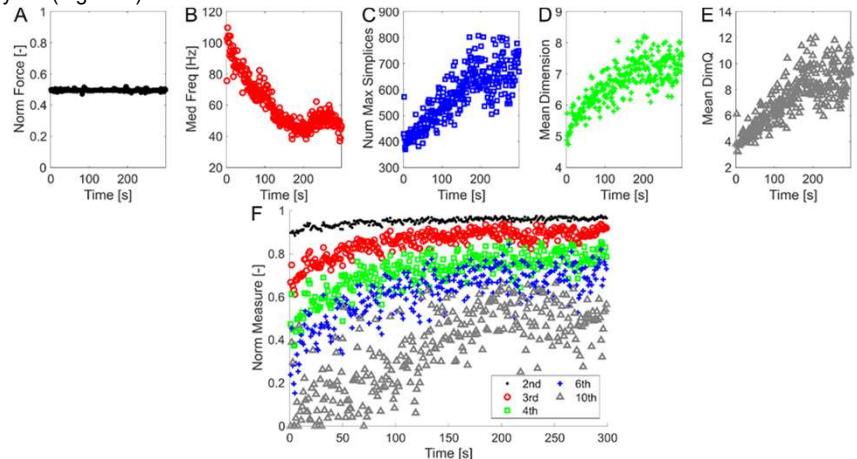


Figure 4. Force and topological data analysis characterizers for one second intervals from a representative 300 second trial. Scalar characterizers are shown in A-E and a vector characterizer is shown in F. A) Normalized force, B) median frequency, C) number of maximal simplices, D) mean dimension, E) mean DimQ, and F) third structure vector.

Results and Discussion

- Using TDA and a deep network approach improved the distribution of residuals and regression results (Figure 5, Table 1)
- Deep network classification was ~90% accurate at classifying sEMG data as fatigued or non-fatigued with fully independent testing data (Figure 6)

Table 1. R-squared and root mean square error (RMSE) results of grouped regressions (mean and stdev) using 10% of data as testing.

	MDF Linear	MDF & TDA Deep Network
R ²	0.572 (0.022)	0.803 (0.013)
RMSE [s]	34.0 (0.97)	23.0 (0.73)

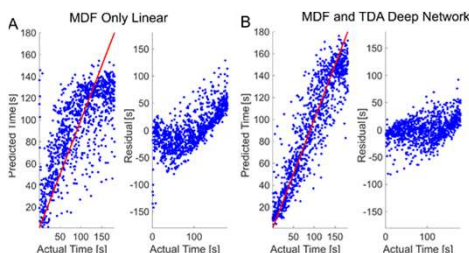


Figure 5. Representative examples of regression testing for A) linear regression using only MDF data and B) deep network regression using MDF and all TDA measures, including vector measures.

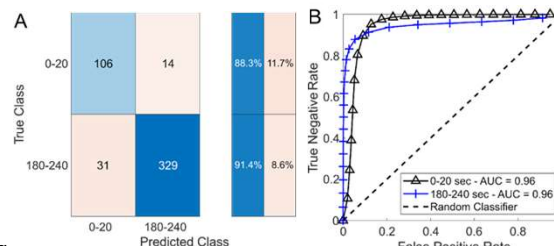


Figure 6. Deep learning classification using both MDF and all TDA measures with two classes. A) Confusion chart. B) ROC curve.

Conclusions

- TDA improved estimations of muscle fatigue from sEMG data over traditional frequency analysis
- Further work is needed to accurately measure different levels of fatigue using sEMG data alone

Acknowledgements

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References

- [1] Cifrek, M. et al. *Clin Biomech.* 2009. doi: 10.1016/j.clinbiomech.2009.01.010; [2] Chutani, M. et al., *Chaos*, 30, 013109 (2020); [3] Dey, T. et al. *BMC Bioinformatics*, 22, 627 (2021)