Ultra-fast Strain Imaging for Real Time Quantitative Muscle Function Assessment

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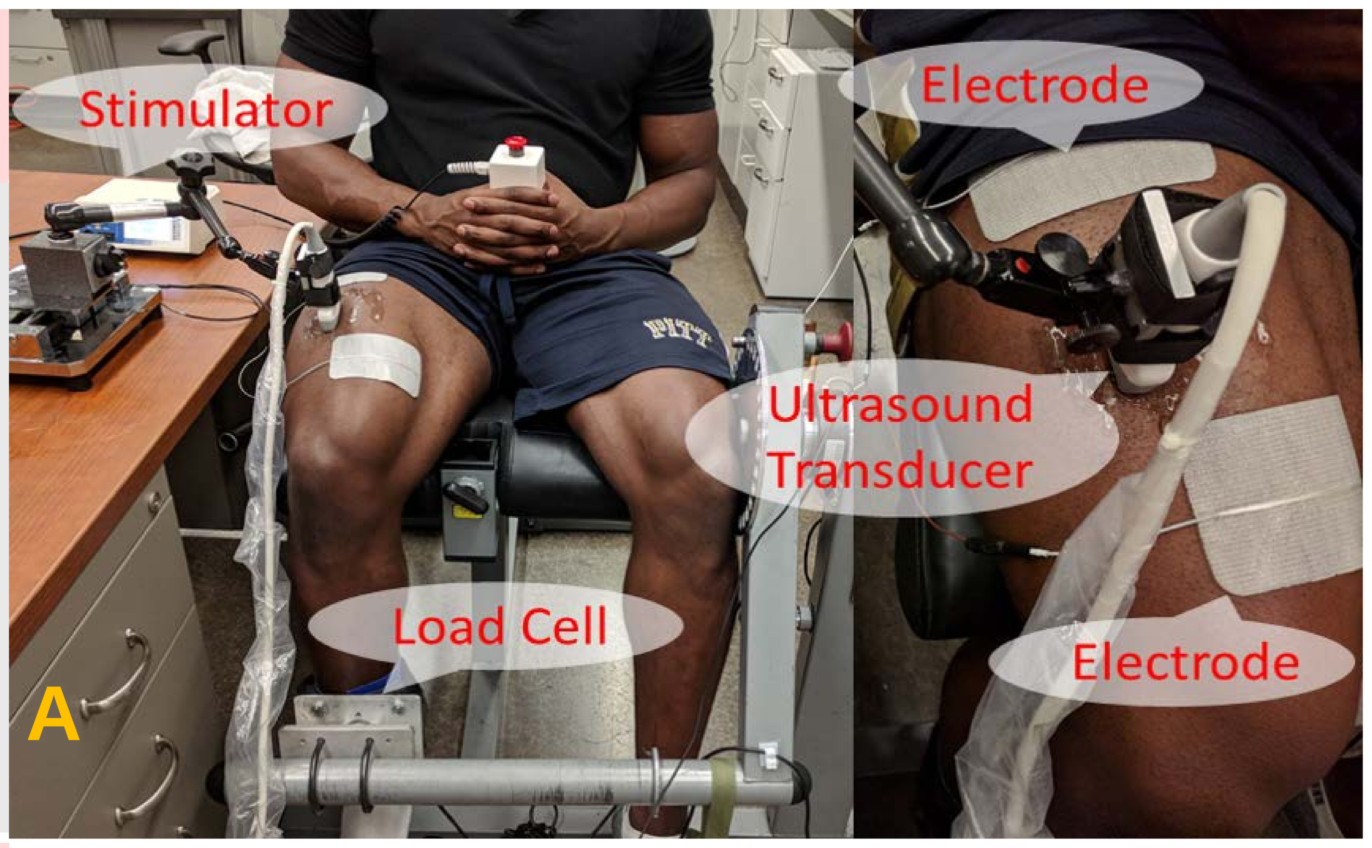
Motivation

- Neuromuscular electrical stimulation (NMES) can be used to restore limb function in persons with neurological disorders.
- **NMES-induced muscle fatigue** significantly limits its operation time and causes ineffective closed-loop control.
- **Ultrasound (US) imaging** is proposed as a sensing modality for **direct fatigue assessment.**



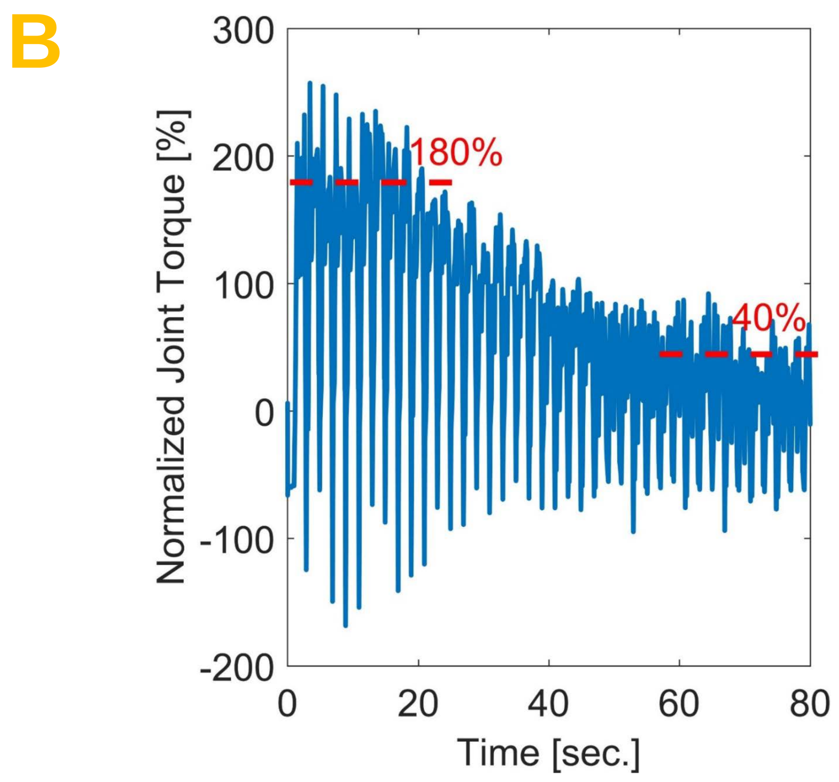


Figure 1. (A) Experiment setup. (B) Transition period and decay of the normalized joint torque under the fatiguing protocol.

Methods

Recent research results indicate US can be used to predict NMES-induced muscle fatigue

- **Knee extension experiments** were conducted to record synchronized isometric knee force data and ultrasound images of the electrically stimulated quadriceps muscle.
- Data was collected in a **pre-fatigue stage** and a **post-fatigue stage**.
- During the transition period, a **fatiguing protocol** was applied.
- Ultrasound images were processed using a **contraction rate adaptive speckle tracking algorithm**

Analysis of the Strain Measure between Pre-fatigue and Post-fatigue Stage

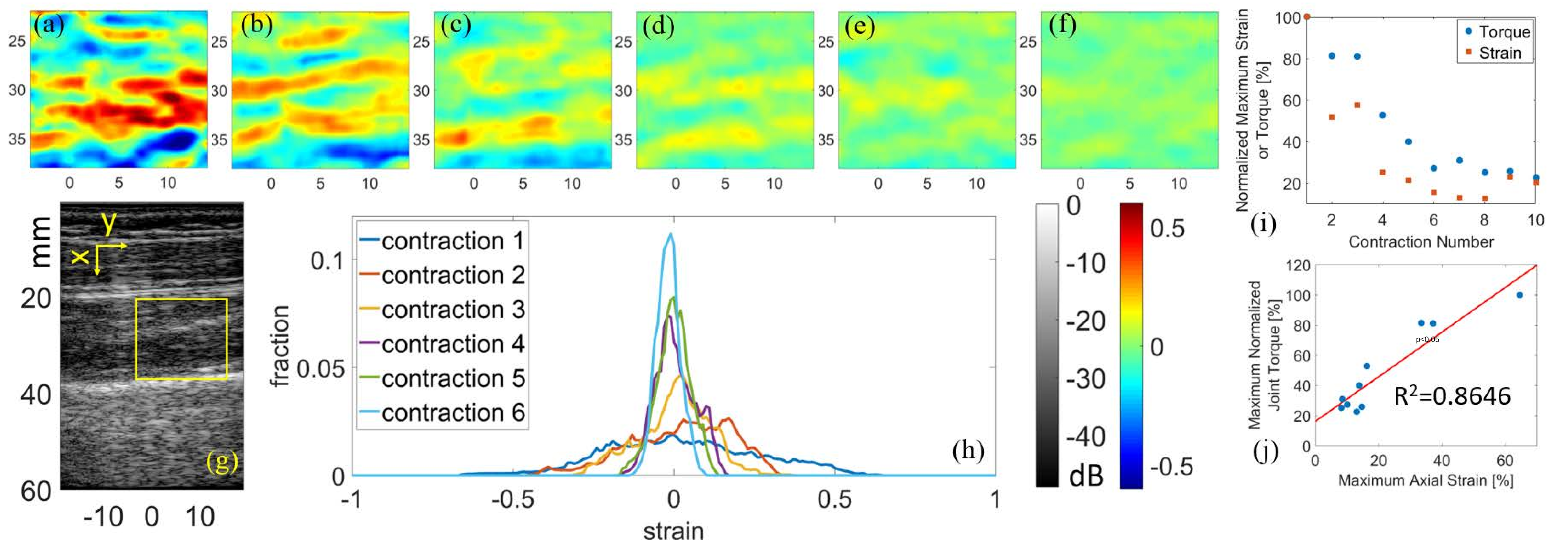


Figure 2 (a-f) Strain Maps of the first six contractions **(g)** B-mode ultrasound image of the quadriceps showing the ROI where strain is computed **(h)** histograms corresponding to the maximum axial strain images **(i)** Maximum torque and maximum axial strain **(j)** Correlation between maximum normalized torque T_max and the maximum axial strain

Real-Time Application

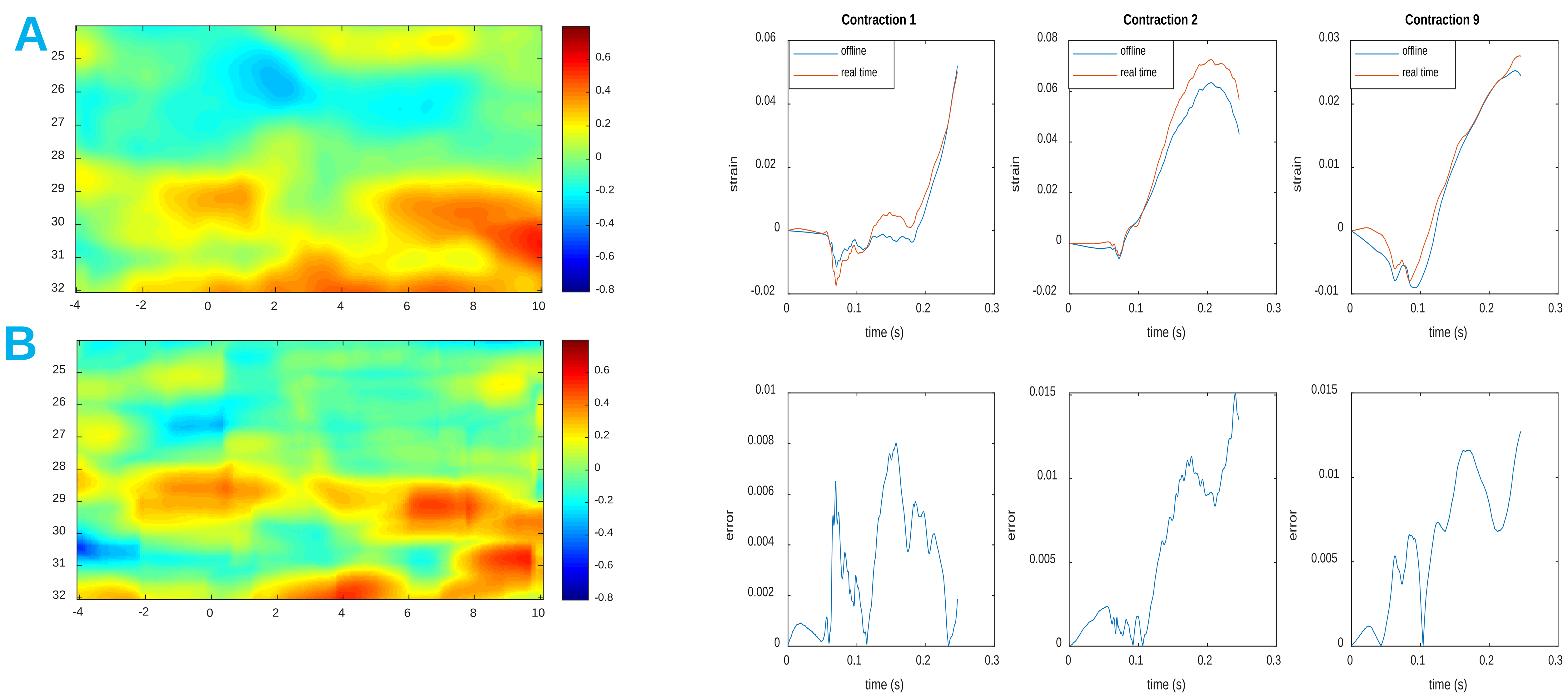


Figure 3 (A) Strain map using offline speckle tracking algorithm (B) Strain map using speckle tracking algorithm coded on GPU hardware for case B, It takes 3 sec for obtaining an instantaneous strain map. (C) Comparison between mean strain values during offline and real-time processing for different contractions along with the error in each case

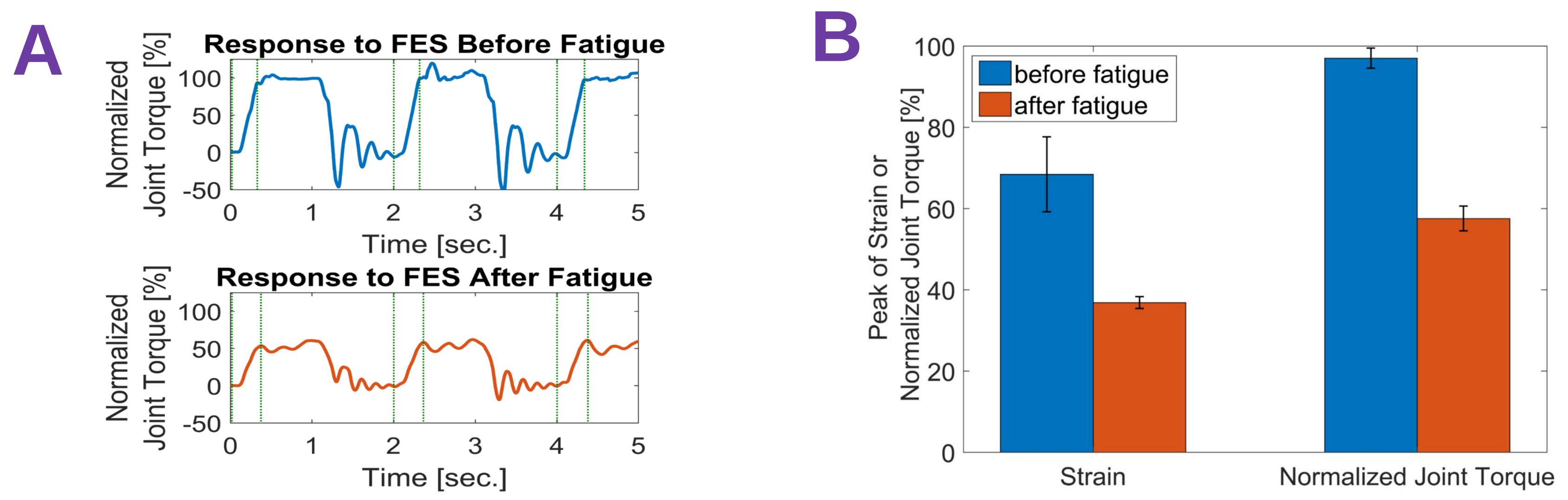


Figure 4. (A) **Normalized force data** before (**BF**: top) and after (**AF**: bottom) fatiguing protocol (B) Comparison of **peak reductions** of both strain and normalized joint torque.

Conclusions

- Fatigue effect by NMES can be quantified by the reduction in strain peak and difference is strain distribution during each stimulated contraction,
- This application can be implemented in real-time for future work in implementing in closed-loop hybrid neuroprosthetic systems