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Can entropy of muscle synergies help track the gait improvements in ADS patients?

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INTRODUCTION

Motivation

- Adult degenerative scoliosis (ADS) is a common musculoskeletal problem in older adults affecting up to 68% of the individuals older than 70 years old, causing low back pain and mobility issues. [1]
- Surgical intervention for ADS can improve gait, balance and other health related clinical scores.
- Due to the high variation in ADS patients (e.g., severity of ADS (Cobb angle), affected side, and position /number of disks involved) tracking the improvements following a surgery is challenging.
- Muscle synergies, a potential way that the CNS controls the muscles, have been extracted and have shown promise in explaining post-surgery enhancements in ADS patients [2]. A greater number of synergies were required for walking following a surgery, verifying a more complex and advanced gait control [2].
- Entropy, an indicator of the randomness and disorder, may uncover the enhancements in control. High entropy is associated with randomness while low entropy shows a deliberate control (Fig. 1).
- Entropy takes all the muscles into account. Hence, it can track the enhancements in patients despite their high variations.

Objectives

- To compare the entropy of the walking muscle synergies before and after surgical alignment in ADS patients.

Hypotheses

- We hypothesize that the entropy associated with walking muscle synergies of ADS patients will decrease following a surgery, indicating a more deterministic control.

METHODS

Subjects

- Thirteen ADS patients participated in this IRB-approved study with their own written consent.
- Subjects were excluded in case of a Cobb angle more than 50 degrees.

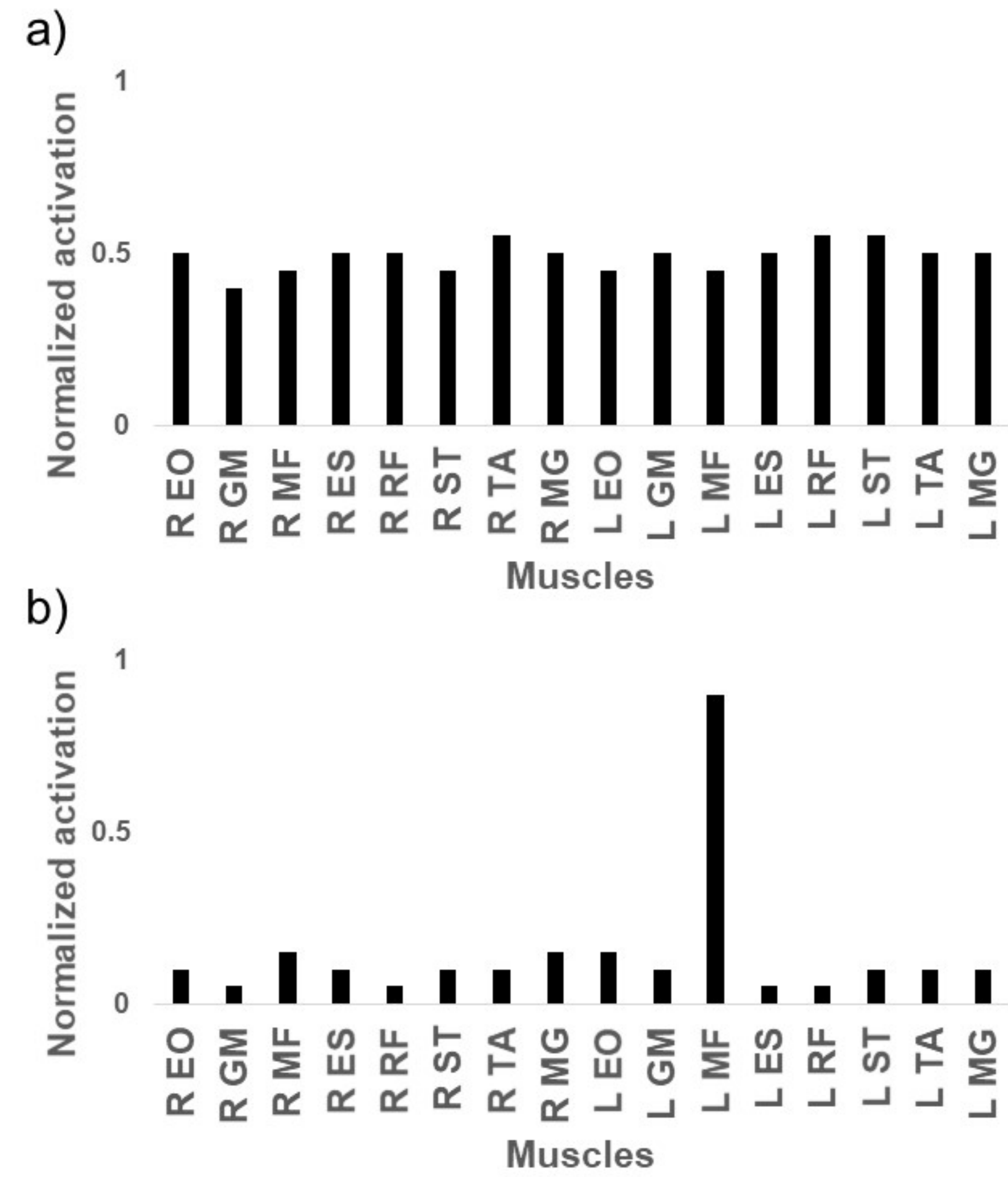

Fig. 1: Examples of a high (a) and low (b) entropy.

Procedures

- Subjects were asked to walk with their self-selected speed in a walkway. The starting location of the gait ensured foot strikes on the first force plates.
- The procedures were performed one week before and 3 months after surgery.

Data Collection

- Surface electromyography (EMG) electrodes were recorded at 2000 Hz bilaterally from 16 trunk and lower extremity muscles: External Oblique, Gluteus Maximus, Multifidus, Erector Spinae, Rectus Femoris, Semitendinosus, Tibialis Anterior, Medial Gastrocnemius. Force plates were used to identify the heel strikes.

Analysis

- EMG data was demeaned, rectified, band passed (20-450 Hz), low-passed at 35 Hz, normalized, and fed into a non-negative matrix factorizer to extract synergies [3].
- According to our previous studies, seven muscle synergies were extracted for each subjects [2].
- The summation of all activations in the i-th synergy was normalized to 1 ($W_i(j)$) to enforce each synergy to resemble a probability density function. Then, an entropy was computed as follows:

$$H(W_i) = -\sum_{j=1}^{n} W_i(j)\log_2 W_i(j)$$

- A paired t-test with a significance of 0.05 was performed to find significant differences in entropies.

RESULTS

- The entropy values for each individual's synergy was calculated (minimum, maximum, average, and standard deviations were 2.40, 3.76, 3.19, and 0.26, respectively). All synergies indicated a significant decrease in their entropy following surgery (p-values < 0.001) (Table 1).

Synergy	W1	W2	W3	W4	W5	W6	W7
Pre-surgery	3.26 ± 0.24	3.41 ± 0.17	3.22 ± 0.25	3.31 ± 0.19	3.30 ± 0.18	3.36 ± 0.21	3.30 ± 0.22
Post-surgery	2.99 ± 0.30	3.22 ± 0.17	2.87 ± 0.28	3.09 ± 0.23	3.14 ± 0.22	3.17 ± 0.22	3.02 ± 0.25
p-value	<0.001	<0.001	<0.001	<0.001	0.0013	0.0003	<0.001

Table 1: Pre- and post-surgery entropy values for synergies (average and SD).

DISCUSSION and CONCLUSION

- Low back pain, has the potential to affect motor control by reducing the joint movements to reduce the pain.
- Surgery may change the motor control and walking by reducing the pain levels, the geometric deformity, and the asymmetry in ADS patients.
- Lower entropy values following a surgery may indicate that the CNS is more likely to deliberately activate a muscle to reach a certain kinematic or kinetic goal rather than unwanted co-activations to restrain the joint movements, and consequently, pain reduction.
- The higher entropy may indicate a more random and chaotic control of the muscles before surgery [4].
- Prior research has also shown a similar association between lower entropy a more deterministic COM control in quiet standing [4].
- Surgery is helping ADS patients to have more complex and deterministic control while walking.
- The findings are not limited to ADS patients and propose a novel method to track the improvements in different patients following different treatments.

References

1. Cho et al. ***Asian Spine J.***, 2014.
2. Nazifi et al. ***ASB (Rochester, MN)***, 2018.
3. Nazifi et al. ***FIHN***, 2017.
4. Hur et al. ***Scientific Reports***, 2019.