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

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Introduction

Adult degenerative scoliosis (ADS) is a common musculoskeletal problem in older adults affecting up to 68% of the individuals older than 70 years old [1]. ADS causes low back pain and mobility issues. Surgical interventions to restore the original disk spacing remains as one of the treatments for ADS. However, tracking the gait improvements in ADS patients is challenging due to the high inter-subject variations such as affected side, number of the affected disks, and the position of the deformity.

Our prior research extracted a set of *muscle synergies* to explain the walking behavior of ADS patients before and after surgery [2]. Muscle synergies can be thought of as lower-dimensional building blocks of the Central Nervous System (CNS) in controlling motor tasks, where a lower number of required synergies is often associated with less complexity and quality of the motor task [3]. Although our study showed an increase in the number of walking synergies after surgery in ADS patients (i.e. higher complexity), we argue that both the quantity and quality of synergies can reveal gait improvements. Quality of muscle synergies can be examined using the concept of entropy. Higher entropy is associated with more chaotic control while a lower entropy presents more deterministic control (Fig. 1).

We intend to track the walking improvements in ADS patients following surgical procedures by measuring the entropy on their walking muscle synergies. We hypothesize that the entropy of synergies will decrease, indicating a more deterministic control, after surgery.

Methods

Thirteen ADS patients participated in this IRB-approved study. To ensure a comparable severity of their ADS condition, subjects were excluded in case of a Cobb angle greater than 50 degrees. Subjects were asked to walk at their comfortable speed before and 3 months after their surgical interventions. Surface EMG was collected from the following muscles, bilaterally: External Oblique (EO), Gluteus Maximus (GM), Multifidus (MF), Erector Spinae (ES), Rectus Femoris (RF), Semitendinosus (ST), Tibialis Anterior (TA), Medial Gastrocnemius (MG). EMG was collected and processed as described in [2], then fed into a non-negative matrix factorizer to extract seven synergies and their activation.

The summation of all activations in a synergy was then normalized to 1, to enforce each synergy to resemble a probability density function. The entropy of an individual's synergy was defined as:

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

where H is the entropy, W_i is i^{th} synergy, and $P(j)$ is the normalized activation of a muscle in a synergy. A paired t-test with a significance of 0.05 was performed to find significant differences in entropies pre- and post-surgery.

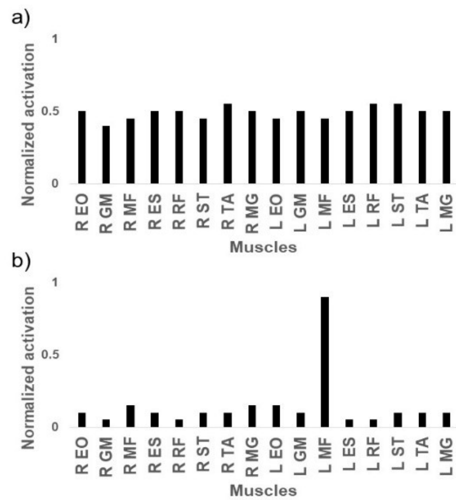

Figure 1: Examples of a high entropy (a) and low entropy (b) muscle synergy. Please note the deterministic control in (b).

Results and Discussion

The entropy values for each individual's synergy was calculated (13×7=91 values), where minimum, maximum, average, and standard deviations were 2.40, 3.76, 3.19, and 0.26, respectively. All seven muscle synergies indicated a significant decrease in their entropy following surgery with p-values < 0.001.

The higher entropy may indicate a more random and chaotic control of the muscles. This shows that surgery is helping ADS patients to have more complex control while walking. In other words, lower entropy may indicate that the CNS is more likely to deliberately choose to activate a muscle to reach a certain kinematic or kinetic goal (Fig. 1). Consistently, researchers claimed that a lower entropy in quiet standing indicated a more deterministic control of the COM to maintain balance [4].

Significance

Using muscle synergies are generally advantageous to kinematic analysis due to its robustness to different conditions. However, synergies can be challenging to interpret due to its numerous dimensions. Specifically, in ADS patients, individuals show improvements on different sides and different muscles due to the nature of the disease. Our introduced method can help track the possible improvements despite the high variation of scenarios in different patients and can be a novel method of assessment.

References

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