

the antecubital fossa [8].

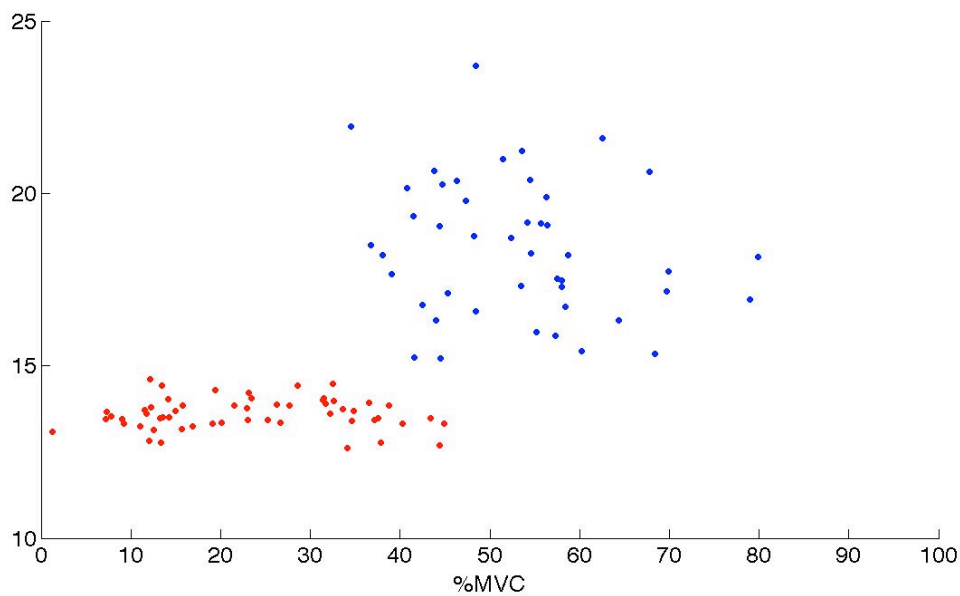


Fig 2. The firing frequency of each MU (vertical axis) and the threshold at which the MU is recruited.

During the experiment, the participants were seated in a sturdy chair with their feet flat on the floor. The upper arm was rested on the surface of a desk, in a horizontal position with the palm facing upward. The elbow was fixed at 90 degrees, with the fingers in line with a wall mounted force sensor attached to a wrist strap held in the hand. The subject was asked to pull their fingers back towards the forearm (resisted by the wrist strap), resulting in isometric muscle flexion. The maximum voluntary contraction (MVC) was determined by the average of three trials of maximum exertion, measured by a force sensor.

Each subject was asked to perform isometric contractions for 15 seconds. This was repeated three times for each of the three contraction levels. Of the 15 s of recorded data, the 10 s with the most stable force level was extracted for analysis.

3 Results

Signal features that are frequently used to characterise the sEMG signal were calculated from both the experimental and the simulated data. The root mean square (RMS) is a measure of the amplitude of the signal and is known to increase with force during non-fatiguing contractions. From the results, it is observed that in both the simulated and experimental data sets obtained here, the RMS increased linearly with force in the range of 30% to 80% MVC. For the experimental results, the gradient of the %MVC/RMS trend lines for each of the three subjects are 0.0018, 0.0019 and 0.0024, all with r^2 values above 0.97. For the associated simulated results, the gradient of the %MVC/RMS trend lines for each of the three subjects is 0.18, with r^2 values above 0.93. Fig 3 and Fig 4 show the average RMS of the experimental and simulated data at each force level for subjects 1 and 2.

The spectral characteristics of the sEMG are represented by the signal features MPF and ZC. The MPF of both the experimental and simulated data show a slight increase with force, with a range of 6.9 Hz for the experimental data and 2.6 Hz for the simulated data. The MPF values of the experimental data were also slightly higher than of the simulated data.

Similarly, the ZC signal feature shows little variance with force, in both the simulated and experimental data sets.

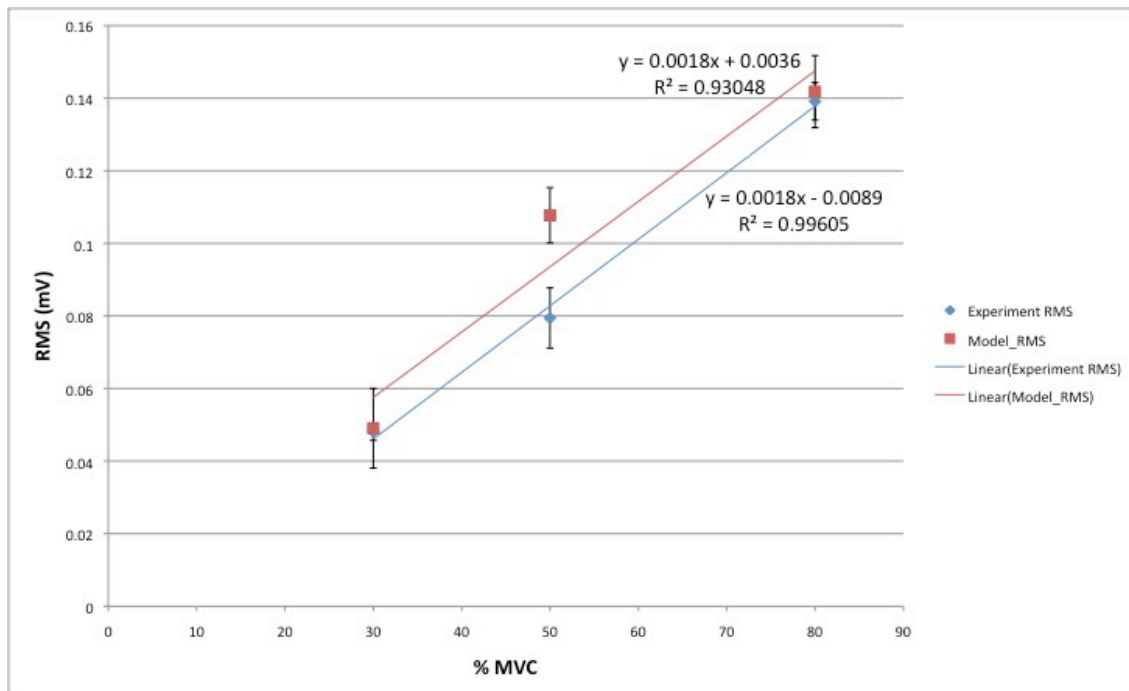


Fig 3. Subject 1: Average RMS values at each force level for experimental and simulated data

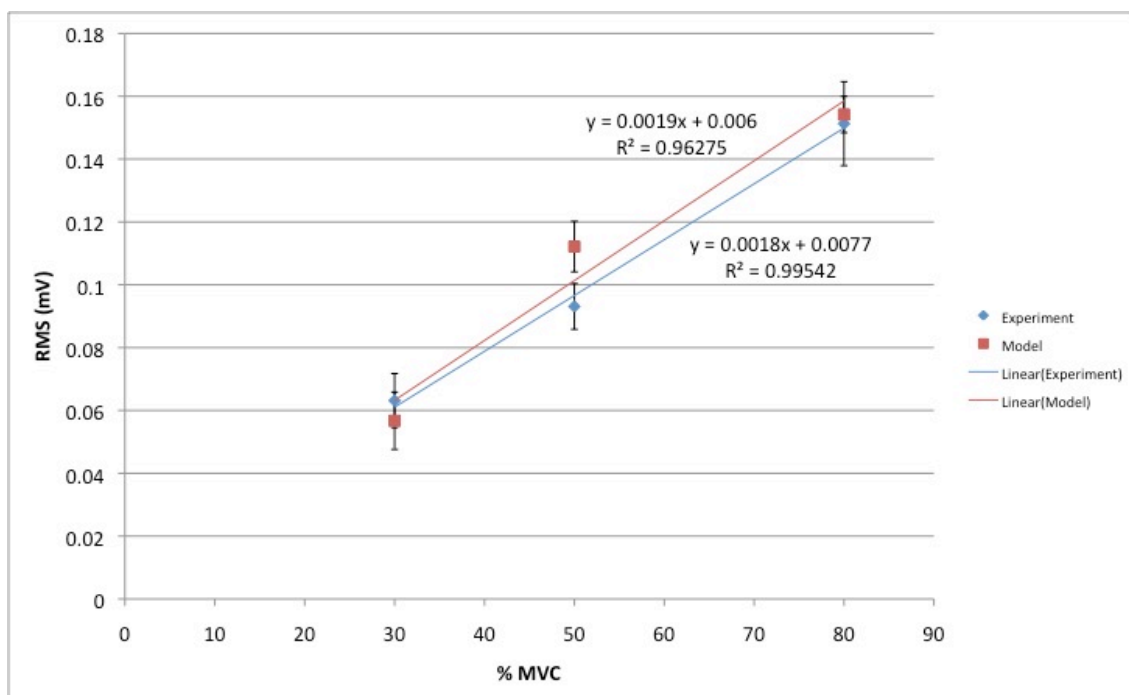


Fig 4. Subject 3: Average RMS values at each force level for experimental and simulated data

4 Discussion

The RMS values for both the simulated and experimental data sets increase linearly with force between 30-80% MVC. The rate of change of RMS is similar in both cases. The difference between experimental and simulated data are most likely due to the varying size of type I and type II motor unit types, which have not been implemented in this sEMG model. However, the results are similar enough to suggest that this recruitment threshold model is

accurate to experimentally acquired data. In particular, it is noted that a non-linear recruitment pattern and firing frequency variation produced a linear force/amplitude relationship in both cases.

The lack of variance of MPF and ZC for both the simulated and experimental data sets suggests that changes in firing frequency alone do not have a large impact on these signal features. Rather, it is likely that changes in the conduction velocity of the muscle fibres will alter the sEMG spectrum, a proposal supported by other researchers [9]. As this study is conducted under non-fatigue conditions, the conduction velocity is constant and the model is time-invariant. The ZC rate of the experimental data set is slightly higher than the simulated data, suggesting that the experimental data is noisier. In future work, system noise will be incorporated into the model to test this assumption.

To fully investigate the impact of the relationship between motor unit firing frequency and force on the sEMG spectrum, signal features other than the MPF could be considered. Most importantly, studies of the time-variant case (i.e. during muscle fatigue) may allow spectral changes in the sEMG signal to be studied.

5 Conclusion

The implementation of recruitment thresholds and firing frequency variation with force from needle EMG studies has been the basis for the development of a new sEMG model that avoids a number of assumptions made by earlier models. The results of experimental verification of the model reveals that amplitude characteristics predicted by this model are verified by the experimental data. The spectral properties of simulated signals have been shown to have only a small variation with force, which is similar to experimental results.

This sEMG model displays accuracy which may improve the usefulness of sEMG models for research and practical applications. A model that can accurately predict the signal features is useful for developing targeted signal processing techniques as well as identifying signal variations due to disease or disorder.

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