Analysis of Surface Electromyography Signals in Fatigue Conditions Under Dynamic Contractions Using Time Difference of Muscle Activations

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Muscle fatigue is a neuromuscular disease which occurs when the muscles fail to produce the necessary or expected potential, which is the cause for muscular forces. It could be either due to overexertion of the muscles or any excessive repetitive action [1]. It can occur to any subject - both normal as well as abnormal. The most common symptoms of this condition are localized pain, muscle twitching, trembling and muscle cramps. The detection of muscle fatigue can assist in the improvement of the performance in many fields such as clinical diagnosis and sports biomechanics and facilitates in the commercial development of various industries [2,3]. Analysis of fatigue conditions of a muscle also plays a major role in the rehabilitation processes and kinesiology [4]. The behaviour of sEMG signals is different under non-fatigue and fatigue conditions due to energetic, metabolic, and structural variations in the muscle [5]. Hence, in this work, the differences in the muscle activity under non-fatigue and fatigue conditions as determined from recorded multichannel sEMG signals of biceps brachii and triceps brachii during dynamic contractions are studied.

Twenty-Five untrained subjects with no history of neuromuscular or neurological disorders volunteered for this experiment. It was ensured that the participants did not experience any strenuous activity 12 hours before the exercise [6]. The experiment was well explained to the subjects, and their consents were taken. Two Ag-AgCl electrodes with an inter-electrode distance of 2 cm were placed over the Biceps Brachii Short Head (BBSH), Biceps Brachii Long Head (BBLH) and Triceps Brachii (TB). The differential electrode configuration was used, with the reference electrode being attached at the elbow joint [7]. The subjects were asked to sit upright on an isolated platform in order to avert electric shocks. The subjects were then told to carry out a continuous exercise (dynamic contraction) with a 3 kg dumbbell using their dominant hand until they experienced fatigue, or they were unable to continue with the exercise. The exercise, involving concentric and eccentric contractions, was performed in synchronization with the metronome, an online audio platform, where a sequence of beat sounds was played in the background to assist the participant. The subjects were directed to maintain their curl speed at their own comfortable pace. The rotation of their arm during dynamic contraction ranges from full extension to full flexion. Instructions were provided continuously during the exercise to ensure that there was no movement of the elbow, which would otherwise provide erroneous results.

Four-second sEMG signals were then extracted with the aid of the audio signal, corresponding to the non-fatigue and the fatigue curl for all the three muscles, namely, BBSH, BBLH and TB. The peaks of the fatigue and the non-fatigue curl and their corresponding time of occurrences were extracted, in both non-fatigue as well as fatigue curl. The time difference of the occurrence of peak amplitude between biceps and triceps brachii was then noted and compared in both non-fatigue and fatigue conditions.

$$t_{max} = \arg\{\max_t s(t)\} \quad (1)$$

Here, $s(t)$ corresponds to the sEMG signals of BBSH, BBLH and TB in both non-fatigue and fatigue conditions. t_{max} in equation (1) is the time index that corresponds to the maximum amplitude in $s(t)$.

$$\Delta t_{max} = t_{maxb} - t_{maxt} \quad (2)$$

where Δt_{max} is the time difference between the instances of occurrence of maximum amplitude in biceps brachii (BB) and triceps brachii, in both the non-fatigue and fatigue conditions, t_{maxb} corresponds to the time of occurrence of maximum amplitude in BB and t_{maxt} corresponds to the time of occurrence of maximum amplitude in TB.

sEMG signals were recorded from biceps brachii and triceps brachii from 25 subjects, but five signals were rejected due to poor SNR. Fig. 1 and fig. 2 are representations of BBSH, BBLH and TB under non-fatigue and fatigue conditions, respectively. It may be observed from the figure that the activations of biceps brachii and triceps brachii follow a cyclic pattern, during flexion and contraction. It may also be observed that the strength of triceps brachii is lower in this exercise.

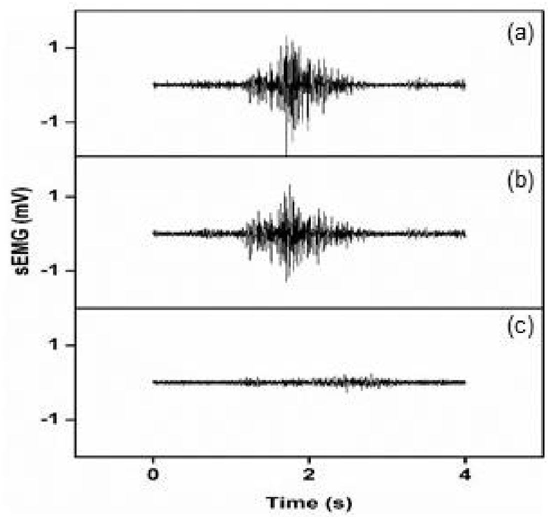

Figure 1: Representative sEMG signals of (a) BBSH, (b) BBLH and (c) TB under non-fatigue conditions.

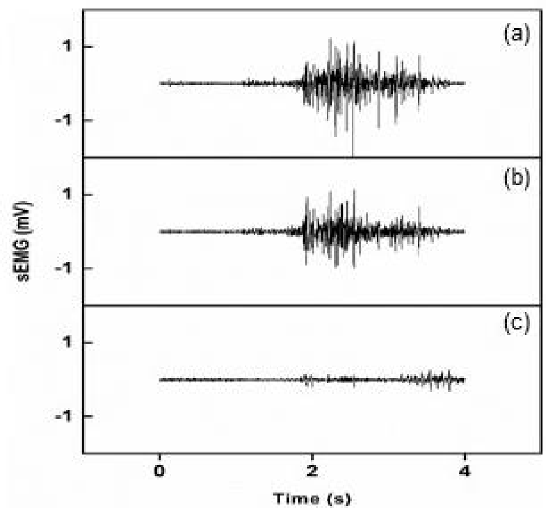

Figure 2: Representative sEMG signals of (a) BBSH, (b) BBLH and (c) TB under fatigue conditions

The scatter plots in fig. 3 and fig. 4 corresponds to the difference in time between the maximum amplitudes of BBSH, BBLH and TB respectively and are found to be statistically significant ($P<0.05$). This shift in maximum amplitude is found to be more under non-fatigue conditions in comparison with fatigue conditions. This may be because, the 'slow-twitch' muscles tend to wear out during periods of extreme exertion and the 'fast-twitch' muscles, offering maximum contraction within minimum time, get activated. Since the endurance reduces during periods of maximum exertion, the time difference between the activations consequently reduces.

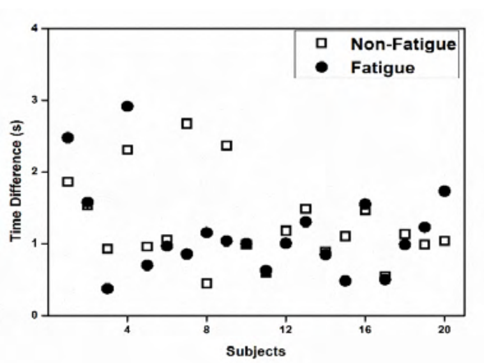

Figure 3: Difference in time corresponding to the maximum amplitudes of BBSH and TB under non-fatigue and fatigue conditions. (i.e Δt_{max} with respect to subjects)

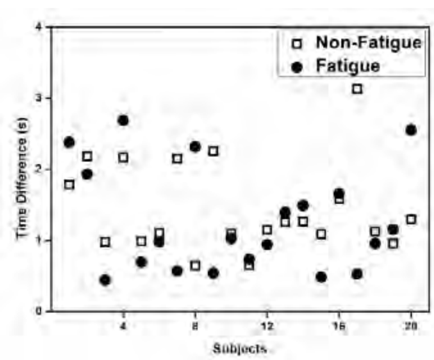

Figure 4: Difference in time corresponding to the maximum amplitudes of BBLH and TB under non-fatigue and fatigue conditions. (i.e Δt_{max} with respect to subjects)

The recorded electrical activity corresponds to the motor neurons' conduction velocity. As suggested by fig. 5, there appears to be a shift in time in the maximum amplitude of muscle activity in BB and TB in non-fatigue and fatigue conditions and was also found to be statistically significant ($P<0.05$ and $P<0.01$ respectively). This may be attributed to the fact that nerve conduction velocity reduces due to the prolonged period of muscle activity, and hence a delay in the action potential curve.

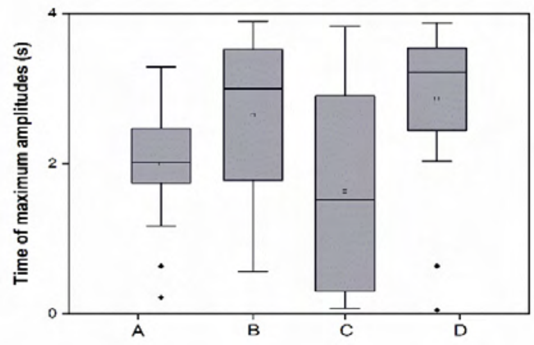

Figure 5: The recorded time corresponding to the maximum amplitudes of BBSH under (A) non-fatigue conditions and (B) fatigue conditions ($P<0.05$) and TB under (C) non-fatigue conditions and (D) fatigue conditions ($P<0.01$) (i.e t_{max} on the y-axis)

The multichannel sEMG recordings indicate that the time differences between the channels are higher in the non-fatigue condition and during fatigue, the coordination between these muscles increase and are found to contract simultaneously. The results of this work indicate that the use of multichannel sEMG recordings with simple time features can reliably detect fatigue, and the results might be extended to fields such as sports sciences and rehabilitation.

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Introduction

- ✓ Muscle fatigue is a neuromuscular disease which occurs when the muscles fail to produce the necessary or expected potential, which is the cause for muscular forces
- ✓ Muscle fatigue could be either due to overexertion of the muscles or any excessive repetitive action[1]
- ✓ Detection of muscle fatigue can assist in the improvement of the performance in many fields such as clinical diagnosis and sports biomechanics and facilitates in the commercial development of various industries[2]
- ✓ Analysis of fatigue conditions of a muscle also plays a major role in the rehabilitation processes and kinesiology[3]
- ✓ Behaviour of sEMG signals are different under non-fatigue and fatigue conditions due to energetic, metabolic, and structural variations in the muscle[4]

Objectives

- ✓ To record sEMG signals during biceps curl experiment using the prescribed SENIAM protocol
- ✓ To analyze the time difference in the peak muscle activity under non-fatigue and fatigue conditions during dynamic contractions

Methodology

Signal Acquisition

- Biopac MP36 Sampling rate 10 kHz
- Ag-AgCl electrodes with inter electrode distance 2 cm.
- Biceps curl exercise - 3 kg - until fatigue

Preprocessing

- first and the last segments
- IIR BPF 10-450 Hz, notch 50 Hz

Feature Extraction and Analysis

- $t_{max} = \arg\{\max_t s(t)\}$

$s(t)$ - sEMG signals of BBSH, BBLH and TB

t_{max} - time index at maximum amplitude in $s(t)$.

- $\Delta t_{max} = t_{maxb} - t_{maxt}$

Δt_{max} - time difference between occurrence of maximum amplitude in BB and TB

t_{maxb} -time of peak BB activity

t_{maxt} -time of peak TB activity

Results

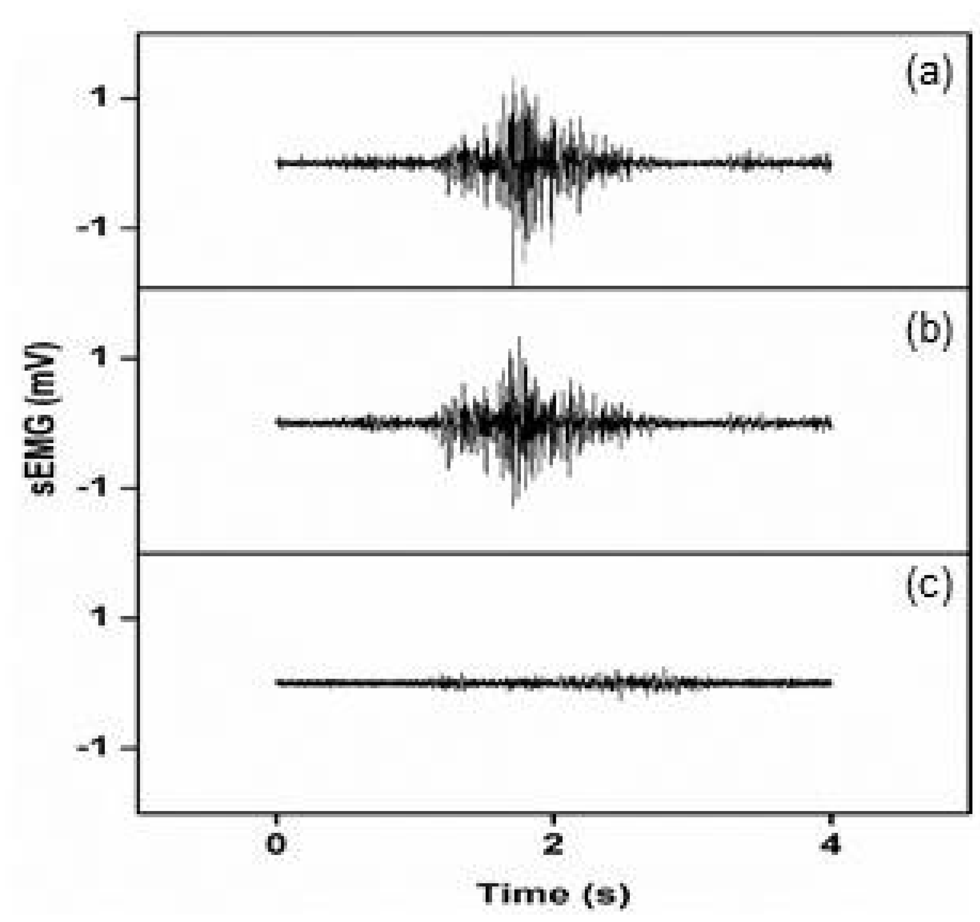

Figure 1: Representative sEMG signals of (a) BBSH, (b) BBLH and (c) TB under non-fatigue conditions

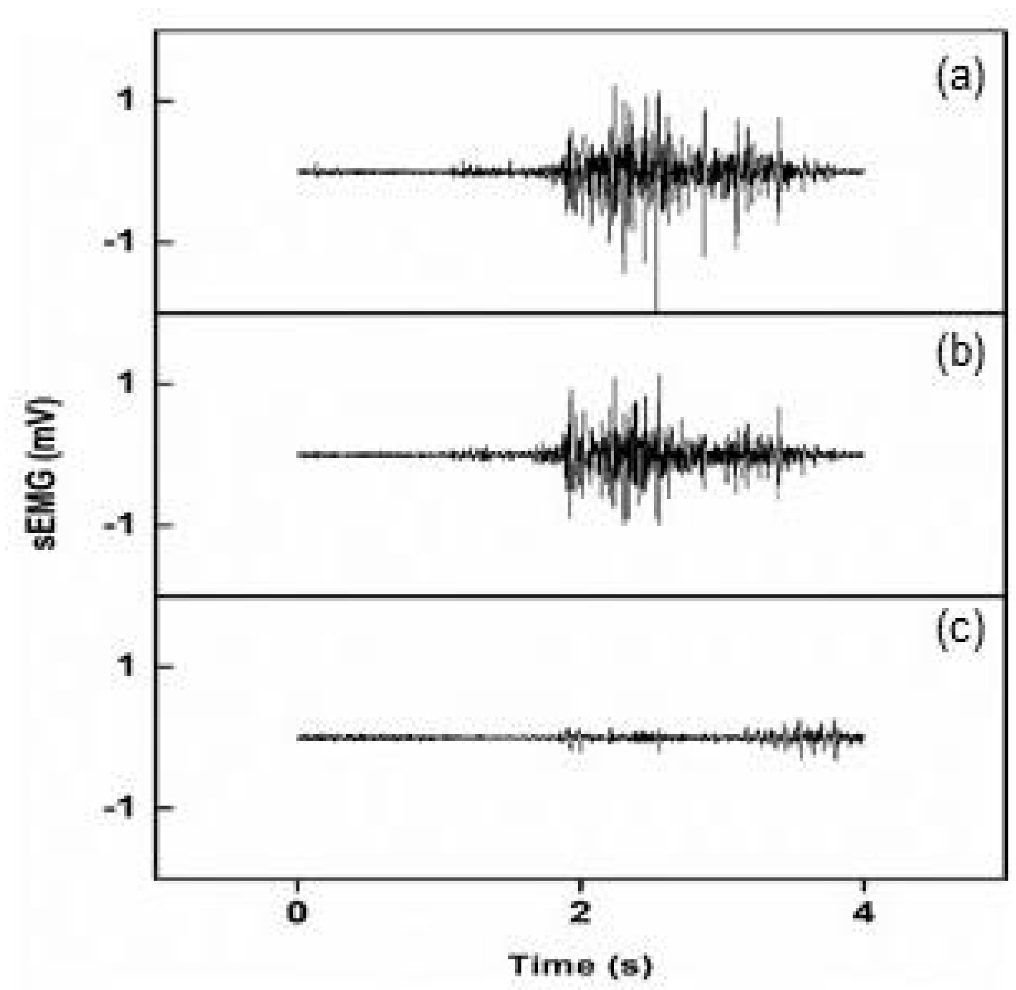

Figure 2: Representative sEMG signals of (a) BBSH, (b) BBLH and (c) TB under fatigue conditions

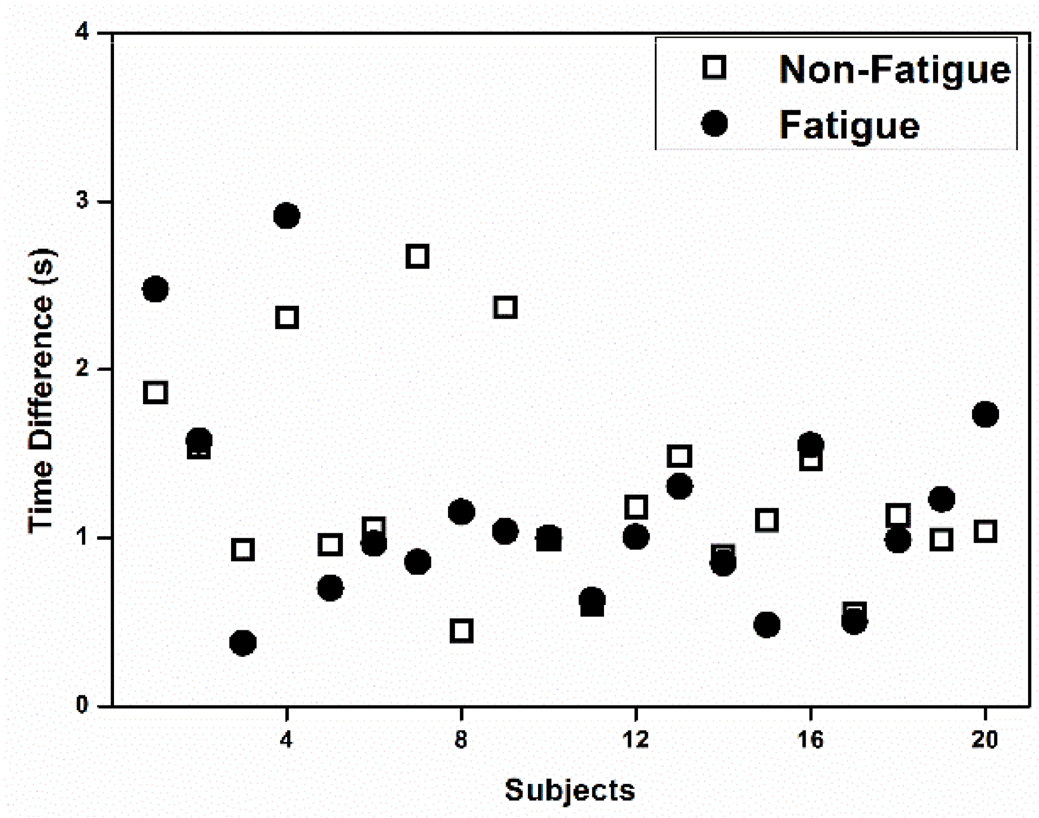

Figure 3: Difference in time corresponding to the maximum amplitudes of BBSH and TB under non-fatigue and fatigue conditions. (i.e Δt_{max} with respect to subjects) (P<0.05)

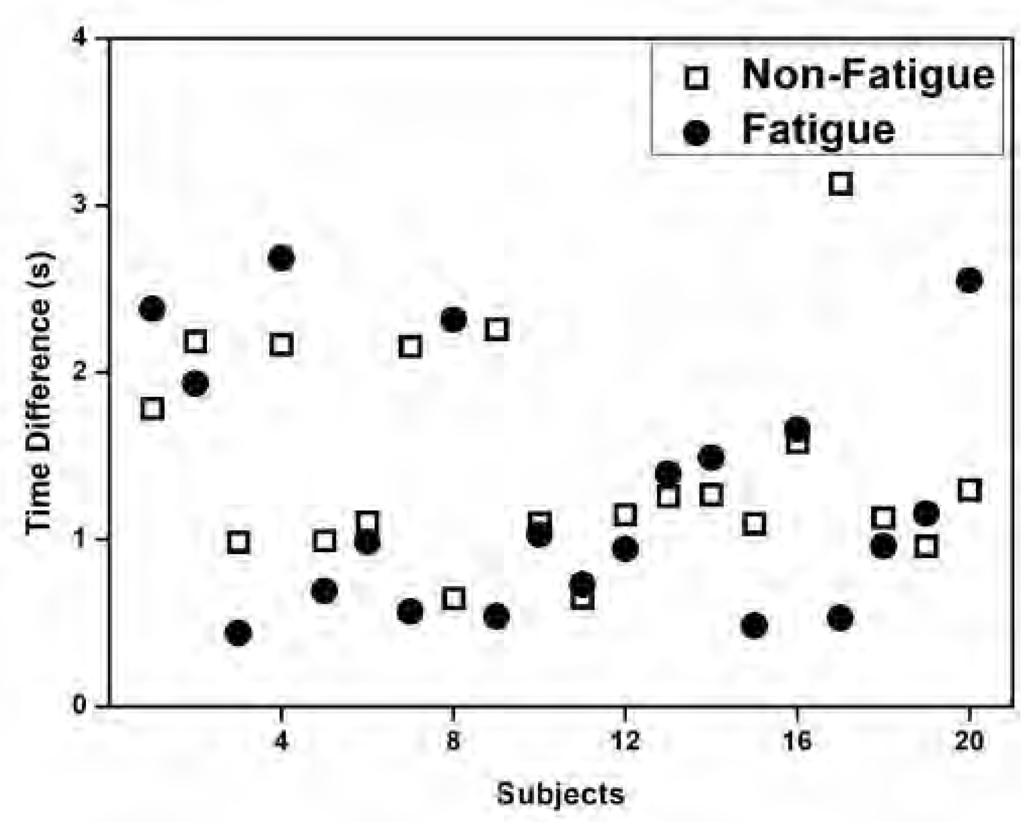

Figure 4: Difference in time corresponding to the maximum amplitudes of BBLH and TB under non-fatigue and fatigue conditions. (i.e Δt_{max} with respect to subjects) (P<0.05)

Results

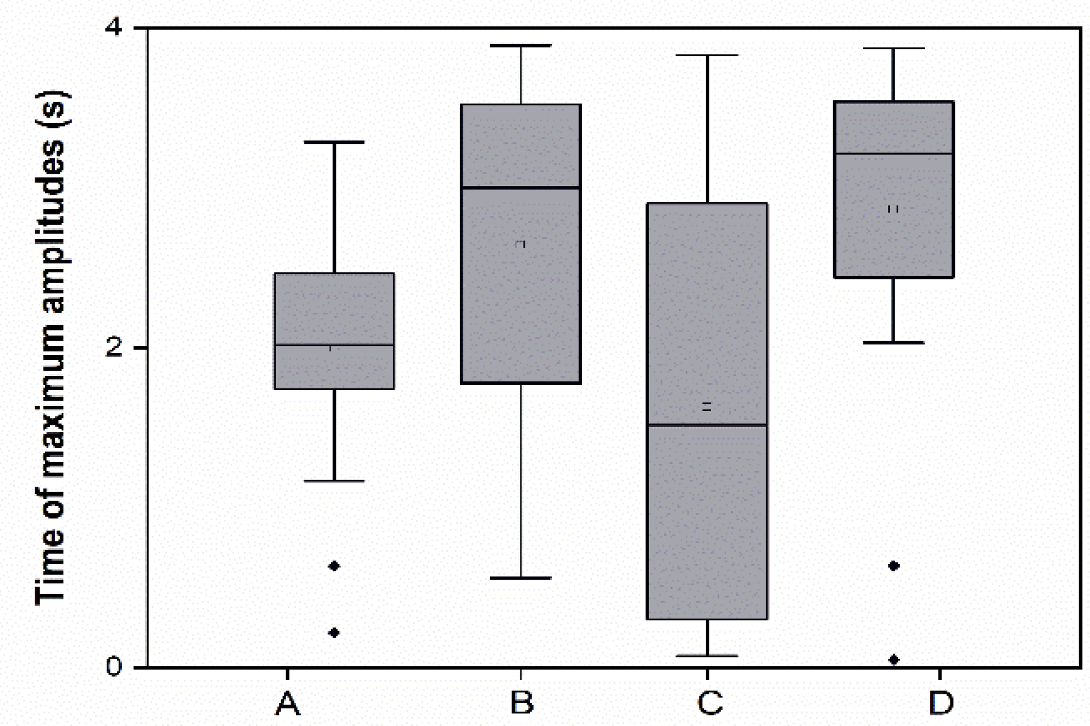

Figure 5: The recorded time corresponding to the maximum amplitudes of BBSH (A) under non-fatigue conditions and (B) fatigue conditions (P<0.05) and TB (C) under non-fatigue conditions and (D) fatigue conditions (P<0.01) (i.e t_{max} on the y-axis)

- ✓ In Fig. 2, it is observed that the peak muscle activity is shifted towards the end of the curl, when compared to Fig. 1.
- ✓ From Fig. 5, the time of maximum activation is more in fatigue conditions owing to a delay in the action potential curve.
- ✓ From Figs. 3 and 4, it is found that the shift in time corresponding to maximum amplitude in non-fatigue conditions is greater than that of its fatigue counterpart.

Conclusion

- Significant difference is observed in the time of occurrence of peak amplitude between BBSH and TB under non-fatigue and fatigue conditions p<0.05
- Time of maximum amplitude in BBSH, BBLH and TB, under non-fatigue and fatigue conditions show statistically significant difference (p<0.05)
- It appears that this method is useful for the identification of fatigue in sports biomechanics.
- This work has only presented a preliminary study and it is expected that the results will be more enhanced for a larger population.

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