# TIME-VARIANT SPECTRAL ANALYSIS OF SURFACE EMG SIGNALS – EXEMPLARILY SHOWN FOR ARCHERY

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To analyse the spectral density of electromyographic (EMG) signals Fourier transforms are commonly used. The prerequisite of this transform is that the analysed signal is stationary. Generally, this can not be assumed for the electromyograms of muscle contractions of human movement. A new method to analyse non-stationary biological signals is the time-variant spectral analysis. The aim of this paper is to use the time-variant spectral analysis in a realistic sport application to show connections of the athlete's level and the spectral density of the EMG. Five top-level archers participated in the study. The results suggest, that a higher level of performance generally corresponds to lower median-frequencies and a smaller variability of the median-frequencies of the EMG-signals.

**KEY WORDS:** non-stationary signals, ARMA model, Fourier transform, frequency-time analysis

**INTRODUCTION:** Most spectral analyses of biological signals such as EMG or EEG base on Fourier transforms. But owing to the non-stationary behavior of real biological signals this method may not always be appropriate since Fourier transforms require stationary signals. Using two dimensional frequency-time analyses a second problem of Fourier transforms is the range of the sliding window: If the range is large the time resolution is poor, if the range is small the time resolution is high but the computed spectral density is poor.
A new method to do frequency-time analyses of non-stationary biological signals is the time-variant spectral analysis.
The aim of this paper is to demonstrate the use of the time-variant spectral analysis in serious sport and to show that there are connections of the athletes' levels and the spectral density of the EMG even in highly skilled athletes. This is exemplarily shown for archery. Archery is used, because it is a very precise movement that can be repeated very often without showing any fatigue and the performance can be quantified by the score.

**METHODS:** The time-variant spectral analysis is able to react on structure changes of the non-stationary signal. This condition is fulfilled by an autoregressive moving average model (ARMA model) with time variant parameters: The parameters are changed by an adaptive estimation procedure at every sample point in a manner minimizing the error of the model (see Schack et. al., 1995; Schack et al. 1996).
In archery immediately before the shot there are changes in the athlete's muscle activity of shoulder and back. From a biomechanical point of view, the archer has to cope with the release of the static balance of forces between the external tension and the muscular forces (see Fig. 1) at the time of shooting by means of his neuromuscular system.
The EMGs of eight muscles (on the pull side: m. extensor carpi radialis brevis, m. flexor carpi radialis, m. deltoideus, m. trapezius pars descendens-transversa, m. trapezius pars transversa and m. biceps brachii; on the bow side: m. pectoralis major and m. deltoideus) of each archer were acquired bipolary at a sampling rate of 2000 Hz. The muscles were selected according to the literature (Squadrone, & Rodano, 1994) and on reasons of plausibility. The moment of the release of the archer's hand from the bowstring and the contact-loss of the arrow with the bowstring were acquired using an accelerometer that was fixed to any position of the riser (see Edelmann-Nusser, & Gruber, 2000).
Five female archers of different performance levels of the German National Team participated in this study: One medalist in the Olympic Games 1996 and 2000 (level A), three participants of world championships but no medalists (level B) and one participant of national championships

(level C). Each archer shot with his own personal bow 20 times over a distance of 18m. The archers were instructed to aspire a maximum score.

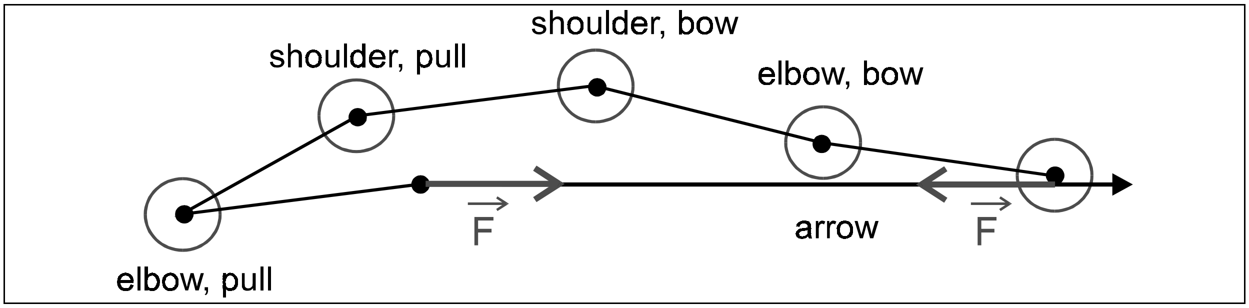


**Figure 1 - Schematic diagram of an archer's body segments shown from the top. The bow applies forces to the hand at the bow's side and the hand of the pull side. The archer's muscles produce equal and opposite forces resulting in a static balance of forces. Hence, there are torques in the joints (circles in the Figure). When the hand releases the bowstring, the force F as well as the torques decrease immediately to zero, the static balance of the forces breaks down. To anticipate this, neuromuscular activities are necessary immediately before the static balance breaks down.**

**RESULTS:** The eight muscles showed interindividually quite different activation patterns and changes in the activity with the exception of the m. trapezius pars transversa. Therefore only the EMGs of the m. trapezii partes transversae were researched: For all archers a decreasing activity of the m. trapezius pars transversa was observed immediately before the release of the hand from the bowstring (see Figure 2).

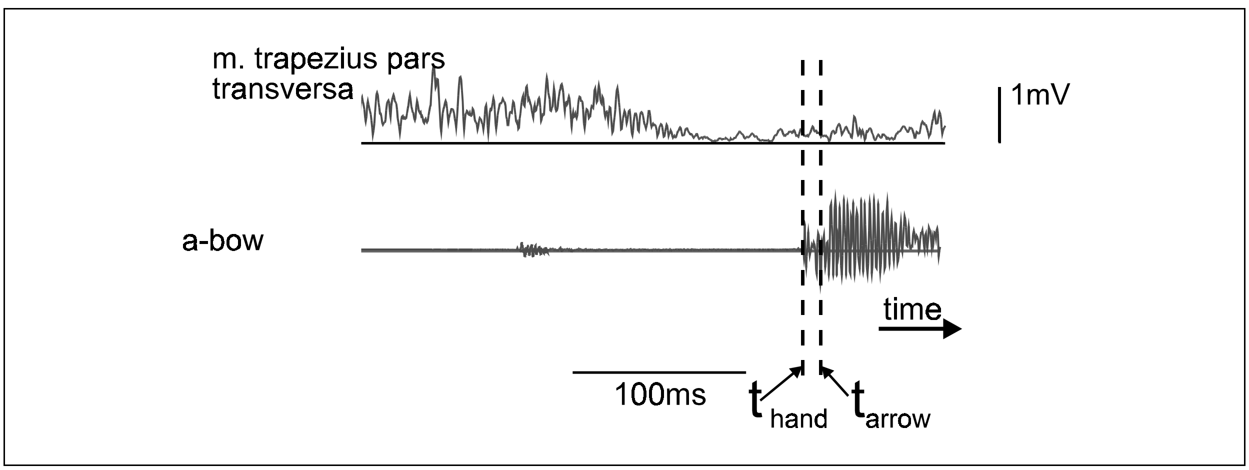


**Figure 2 - Typical rectified EMG of the m. trapezius pars transversa immediately before the shot. The moment of the release of the archer's hand from the bowstring ($t_{hand}$) and the contact-loss of the arrow with the bowstring are detected by an accelerometer (signal "a-bow").**

Table 1 shows the archers' mean scores. As expected the mean scores of the archers BA, SA, TI and NI correspond to their level. But although archer SB is level B she has the lowest score. This may be caused by an injury: she could not train for three months and resumed training only two weeks prior to the test.

**Table 1 The Archers' Mean Scores (The highest mean score that is possible is 10.)**

| Archer | BA, level A | SA, level B | TI, level B | NI, level C | SB, level B |
|---|---|---|---|---|---|
| Mean score | 9,43 | 9,29 | 9,13 | 8,73 | 7,90 |

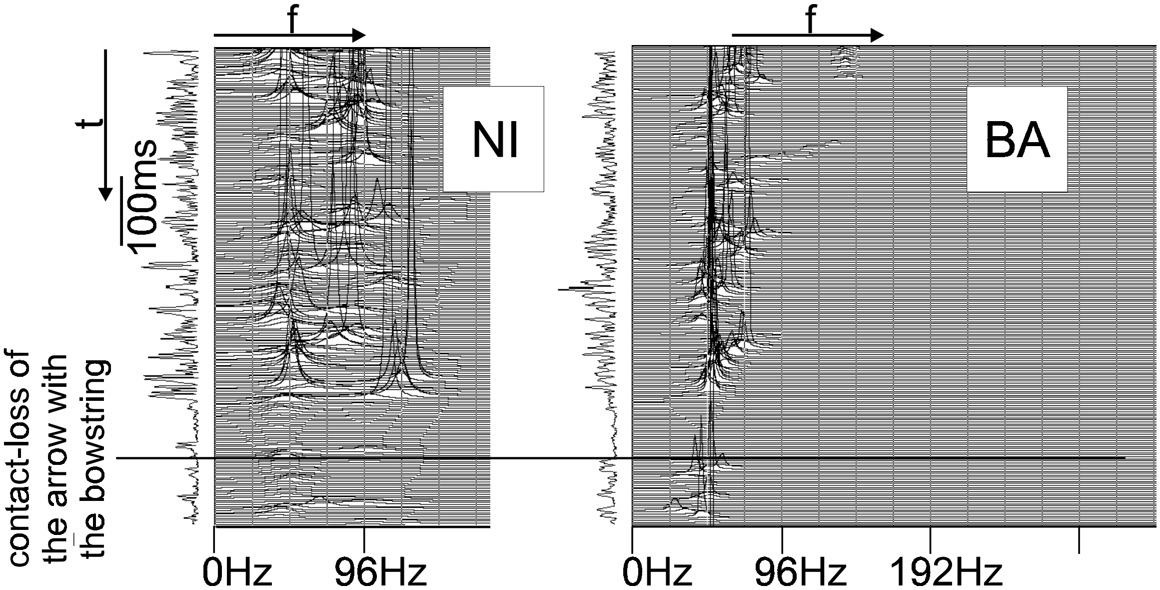


**Figure 3 - Time course of the frequency band of one shot of archer NI and one shot of archer BA. To the left of each frequency band the rectified EMG is drawn in. It is evident that the band width of NI is larger and that higher frequencies can be observed.**

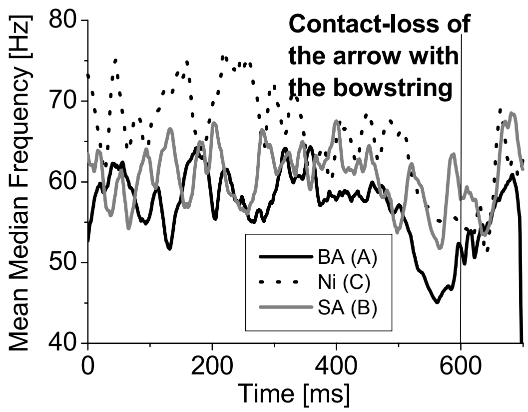


**Figure 4 - Mean of median frequencies of 3 archers.**

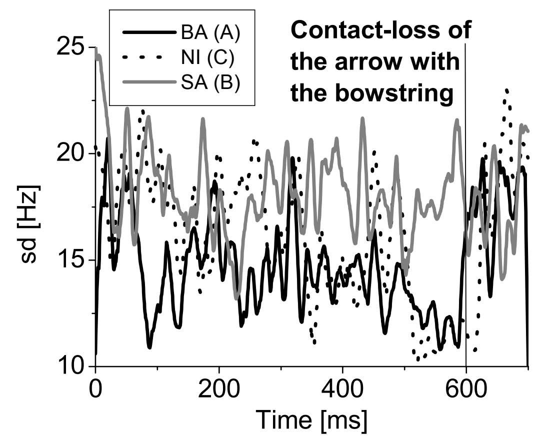


**Figure 5 - Standard deviation of median frequencies of 3 archers.**

For each archer and every shot the time course of the frequency band (see Figure 3) and the time course of the median frequency was computed using the time-variant spectral analysis. Figure 4 shows the mean median frequencies of every shot of three archers, Figure 5 shows the standard deviation of the median frequencies of every shot of three archers.

Table 2 shows the mean median frequencies of the level B and C archers in comparison to the level A archer. It is evident that the mean median frequency of the level A archer is lower than the mean median frequencies of the other archers. As Table 4 shows, it also evident that the standard deviation of the median frequency of the level A archer is smaller than the standard deviations of the median frequencies of the other archers. Vice versa Table 3 shows that the mean median frequency of the level C archer is higher than the mean median frequencies of the other archers with the exception of the injured archer SB and Table 5 shows that the standard deviation of the median frequency of the level C archer is larger than the standard deviations of the median frequencies of the other archers with the exception of the injured archer SB. Hence the results show clearly that in the researched highly skilled archers a higher level of performance corresponds to a lower median frequency of the EMG and a smaller variability of the median frequency of the EMG.

**Table 2 Percentages of Higher Mean Median Frequencies of Level B and C Archers (NI, SA, SB, TI) Compared to the Level A Archer (BA)**

| | NI-BA | SA-BA | SB-BA | TI-BA |
|---|---|---|---|---|
| Percentage | 100% | 94,7% | 100% | 70,8% |

**Table 3 Percentages of Lower Mean Median Frequencies of Level A and B Archers (BA, SA, SB, TI) Compared to the Level C Archer (NI)** Please note, that SB is level B but her score is lower than NI's score (compare Table 1).

| | NI-BA | NI-SA | NI-TI | NI-SB |
|---|---|---|---|---|
| Percentage | 100% | 63% | 91,7% | 6,75% |

**Table 4 Percentages of Higher Standard Deviations of the Median Frequencies of Level B and C Archers (NI, SA, SB, TI) Compared to the Level A Archer (BA)**

| | NI-BA | SA-BA | SB-BA | TI-BA |
|---|---|---|---|---|
| Percentage | 95,3% | 73,2% | 96,4% | 86,2% |

**Table 5: Percentages of Lower Standard Deviations of Median Frequencies of Level A and B Archers (BA, SA, SB, TI) Compared to the Level C Archer (NI)**

| | NI-BA | NI-SA | NI-TI | NI-SB |
|---|---|---|---|---|
| Percentage | 95,3% | 86,7% | 68,8% | 37,1% |

**CONCLUSION:** The results suggest that the time-variant spectral analysis is a useful method to analyze the spectral density of surface electromyograms in serious sport: For even in high skilled athletes differences in the performance level can be quantified in the spectral density of the surface-EMG signals, the time-variant spectral analysis could be used in training processes to quantify an in- or decrease of the performance level.
The poor score of archer SB can be interpreted in two alternative ways:
1. Less training leads to higher median frequencies which means that there is no long term stability of the EMG frequency pattern of high trained skills. Or:
2. The coordination of the athlete has changed because of her injury and she has to train this new coordination.
To decide this further research is necessary.

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