Spectral Analysis on Vibroartrographic Signal of Total Knee Arthroplasty

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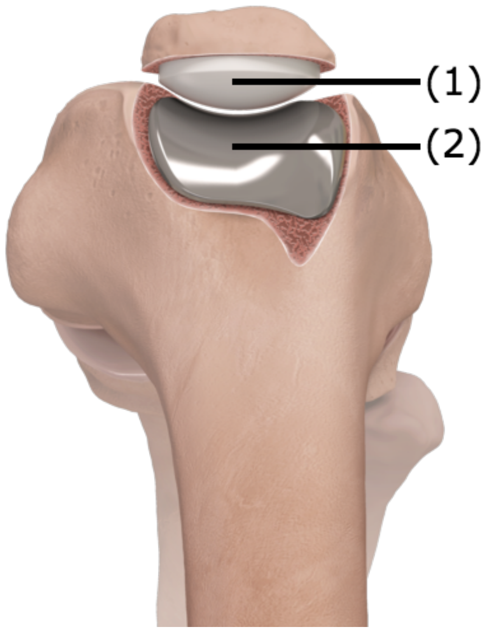
Outline

- VAG signals
- Signal processing pipeline
- Ensemble Empirical Mode Decomposition (EEMD)
- Detrended Fluctuation Analysis (DFA)
- STFT analysis
- Conclusion

Background

- Total Knee Arthroplasty (TKA) is usually done when articular cartilage of the knee joint is degenerated
- Patellar resurfacing in TKA is up to surgeons



- resurface: replaced by polyethylene patella prosthesis
- non-resurface: natural patella is kept

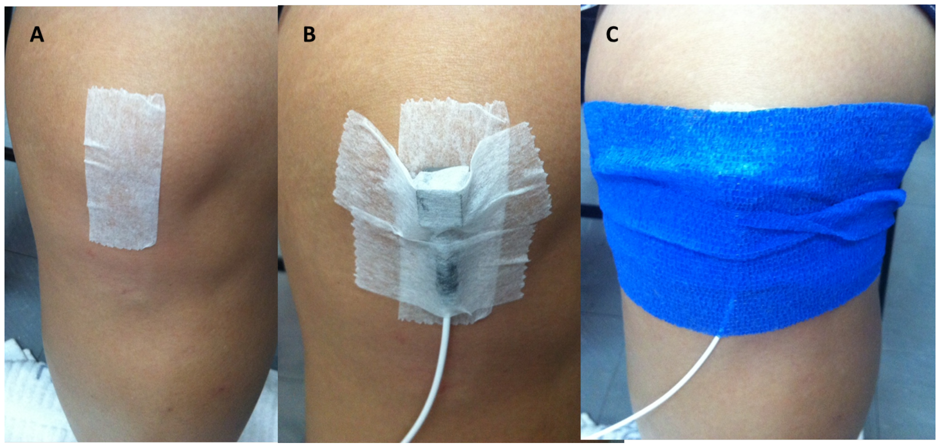
Vibroarthrographic Signal (VAG)

- VAG signal is the vibration signal of the joint
- Different rubbing surfaces cause different vibration signal
- Crepitus, or the joint sound, is often heard and associated with different rubbing surfaces
- Anecdotal evidence: different crepitus is heard in resurface and non-resurface cases

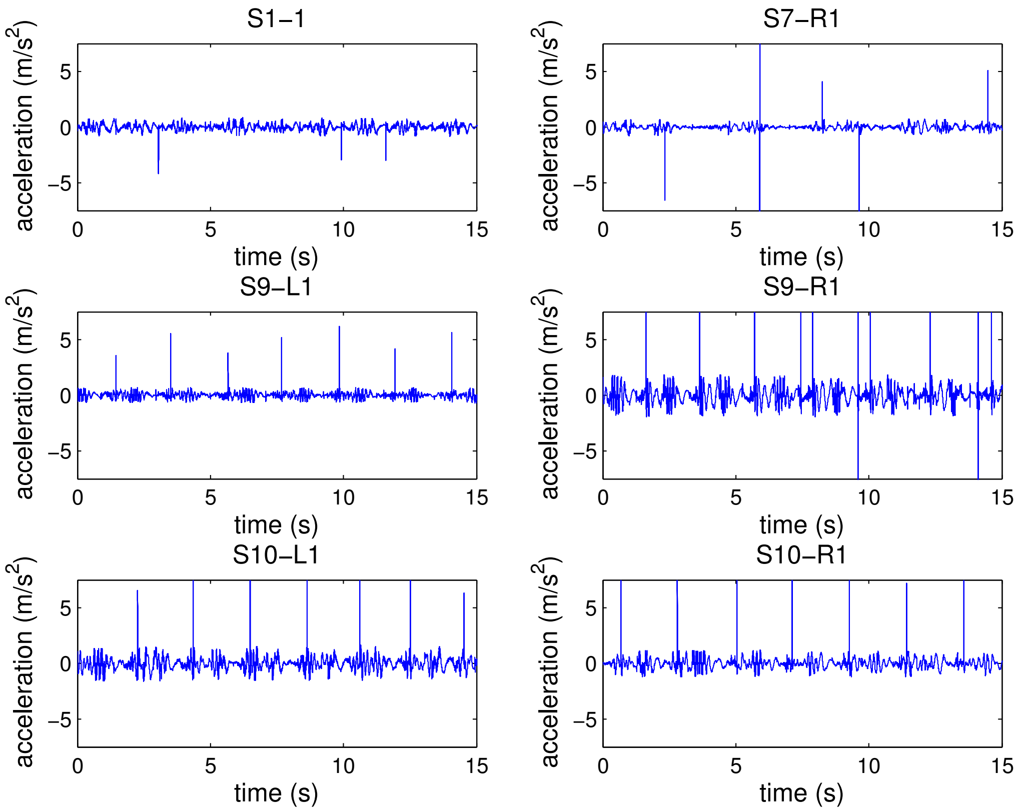
Aim: to see if VAG signal can identify those differences

Materials and methods

- Vibration sensor (accelerometer) attached on the mid-patella position to get the signal
- 8 subjects with TKA
- Subjects were asked to swing their legs from 90 degrees to full extension and back to the 90-degree posture

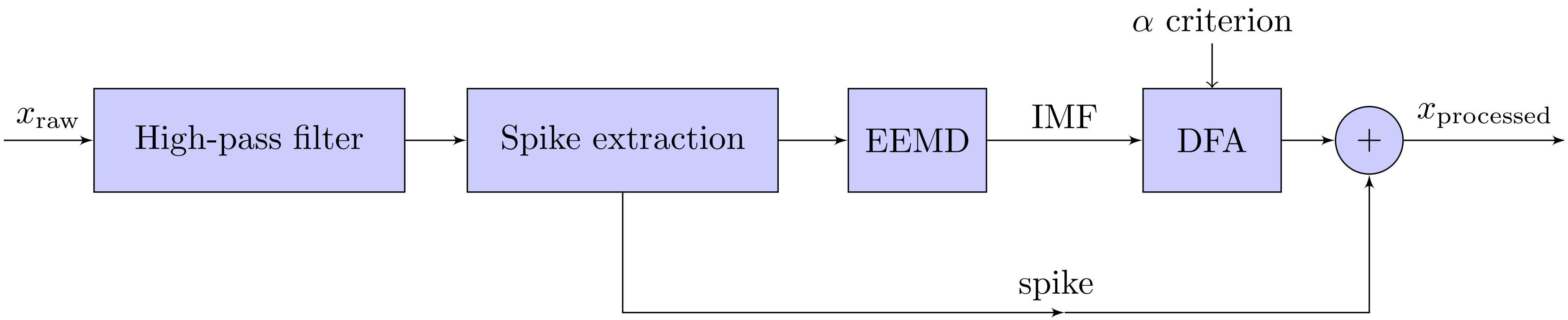


VAG signals in time-domain



- periodic spikes from tendon click
- signals contain many different frequency modes

VAG signal processing pipeline



- high-pass filtering for removing a trend
- remove spikes occurred from moving the joint
- perform EEMD to decompose signals into IMFs
- perform DFA to analyze the randomness of each IMF
- the processed signals are further analyzed through STFT

Empirical Mode Decomposition (EMD)

commonly applied to nonstationary signals, e.g. EEG

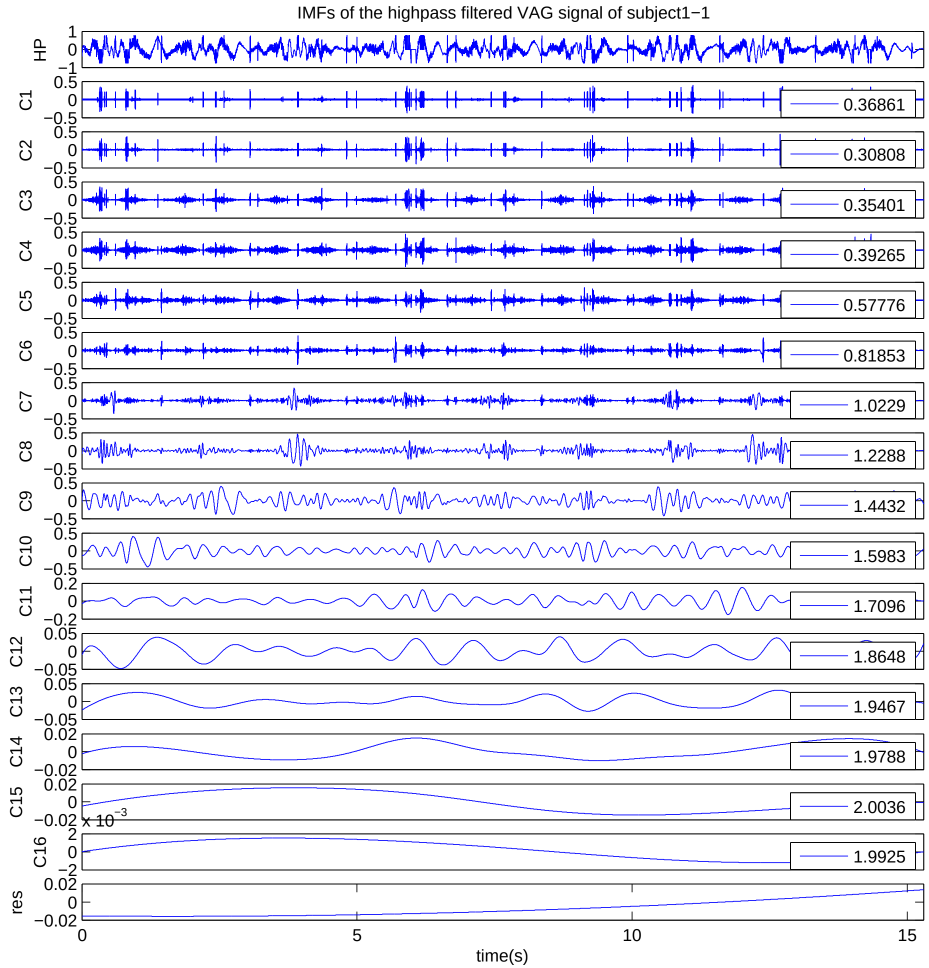
$$x(t) = \sum_{k=1}^{n} c_k(t) + r_n$$

- assumption: a signal may contain many oscillatory modes of different freq
- decomposes into n modes of Intrinsic Mode Functions with residual r_n

to obtain IMFs:

- **sifting process:** Interpolated upper and lower envelope and evaluate its mean
- subtract this signal by this mean
- repeat until reach (i) no. of iteration or (ii) signal has a certain number of zero crossing

Ensemble Empirical Mode Decomposition (EEMD)



plots of IMFs show that randomness must be discarded using DFA

Detrended Fluctuation Analysis (DFA)

used to explain if signal fluctuations are associated with the intrinsic correlation

$$C(s) = \mathbf{E}[x(t)x(t+s)] \approx \frac{1}{N-s}\sum_{t=1}^{N-s} x(t)x(t+s)$$

- correlation should obey the power law as $C(s) \propto s^{-\gamma}$
- parameter γ can be indirectly estimated by **fluctuation function**

$$F(s) = s^{1-\gamma/2} = s^{\alpha},$$

where s is a segmentation length of the signal

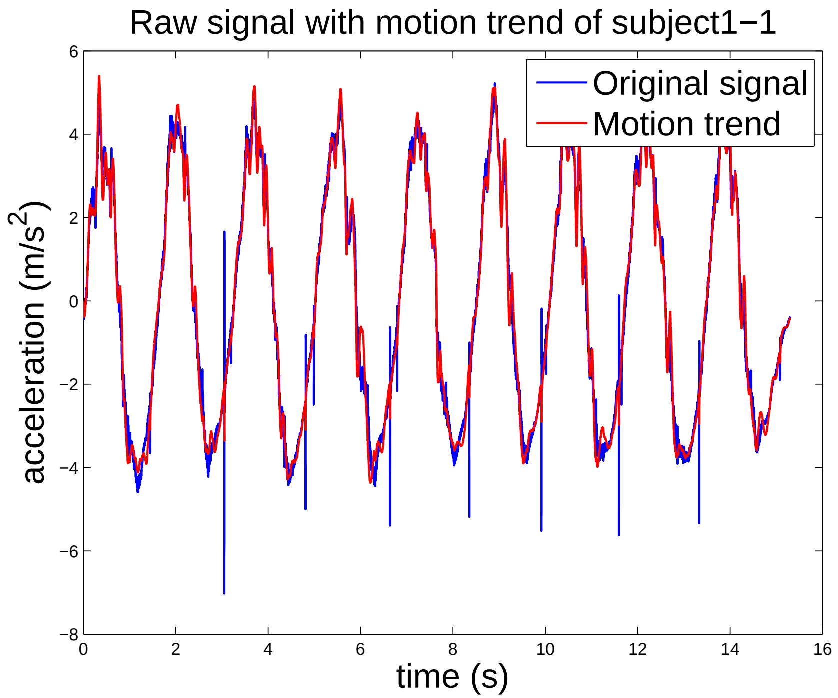
Fractal scaling index (α) from DFA

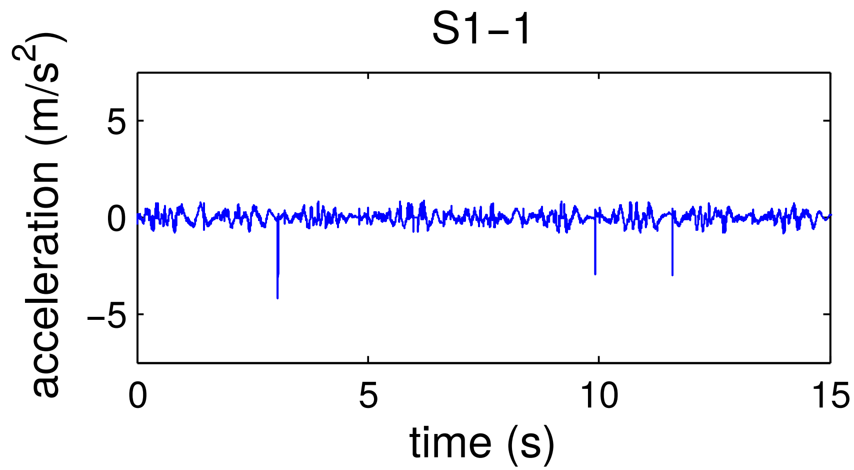
some important range of are as follows

- $0.5 < \alpha < 1$: long-range power law correlation
- $0 < \alpha < 0.5$: short-range power law correlation
- $\alpha = 0.5$: white noise

in this paper, IMFs with $\alpha \leq 0.5$ are discarded

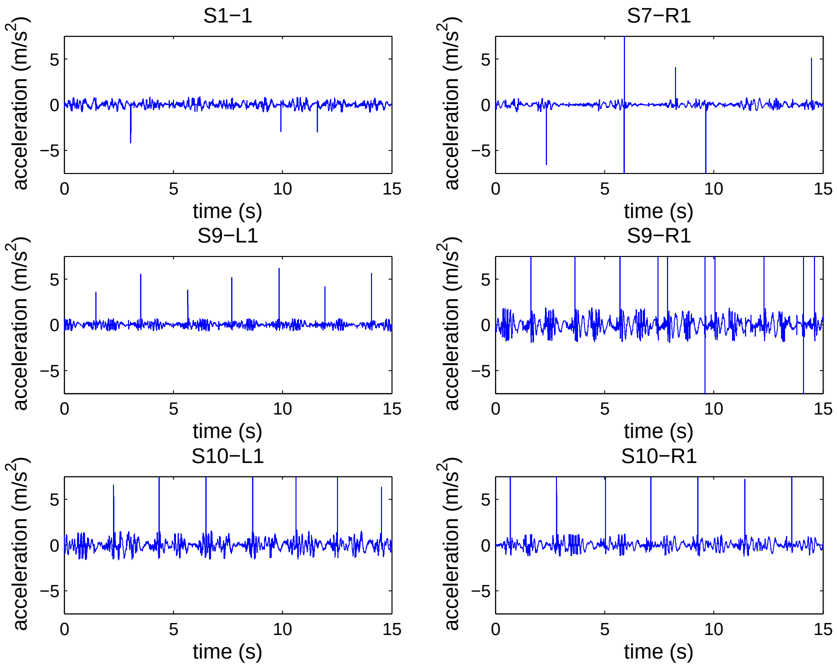
Processed signal

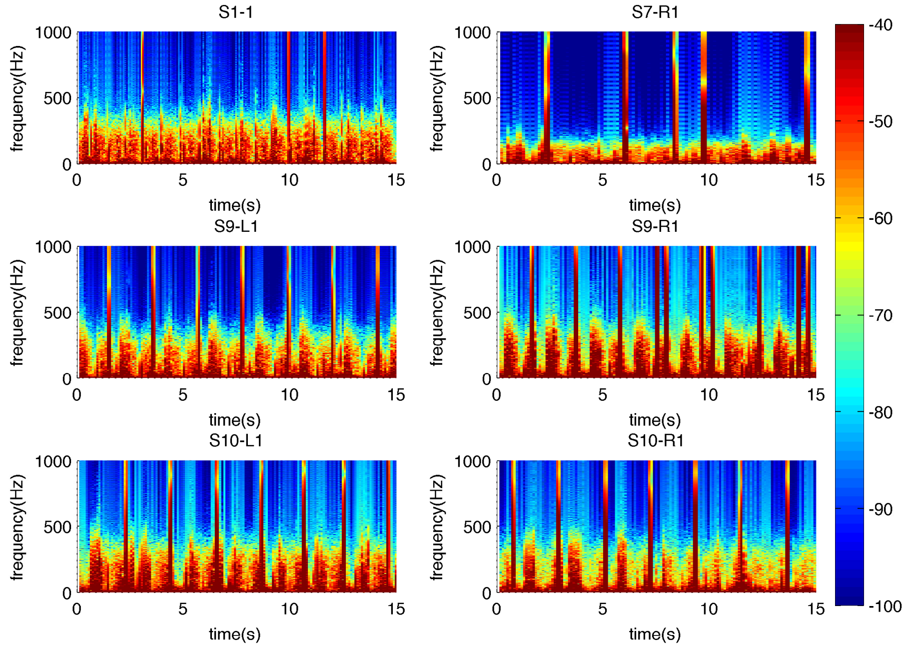




- *Left:* raw VAG signal with motion trend
- *Right:* processed signal after performing EEMD and DFA

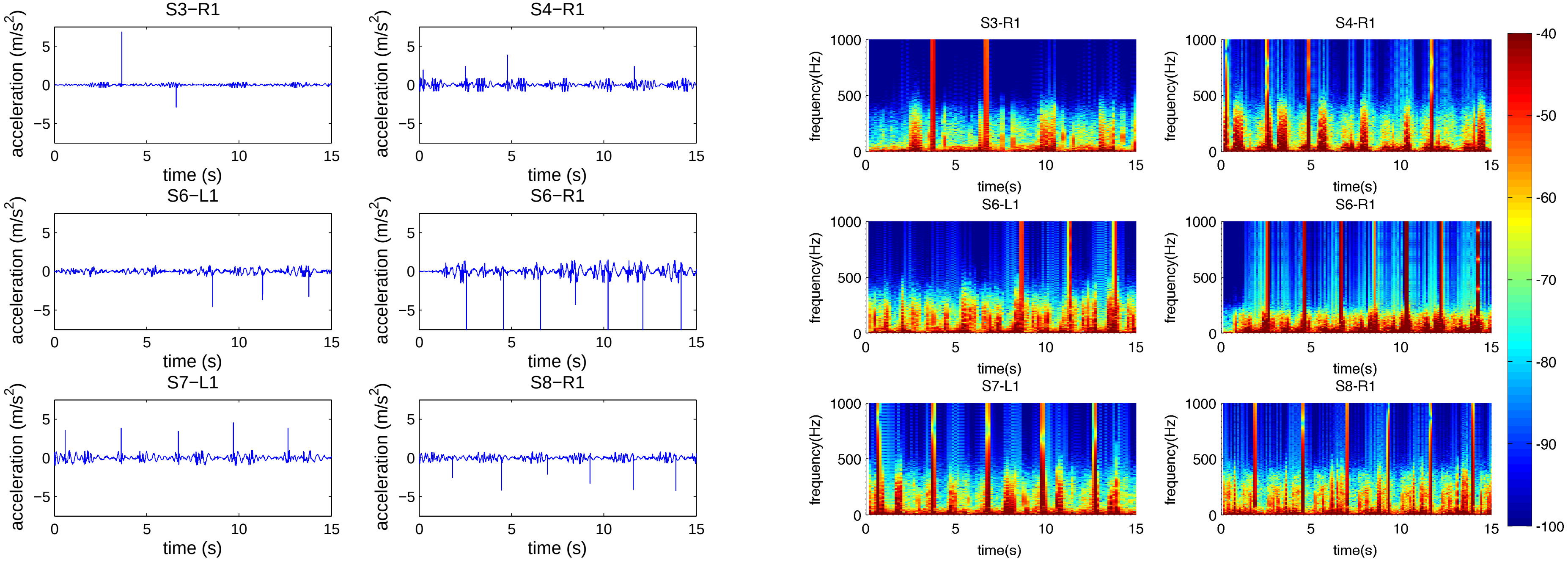
STFT analysis of VAG signals: resurfaced





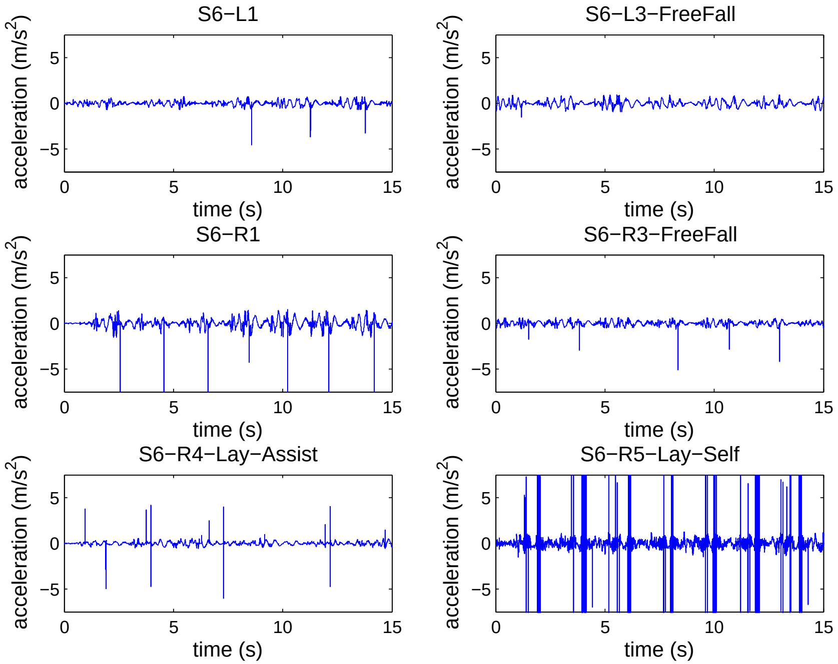
spikes and high frequency components up to about 500 Hz

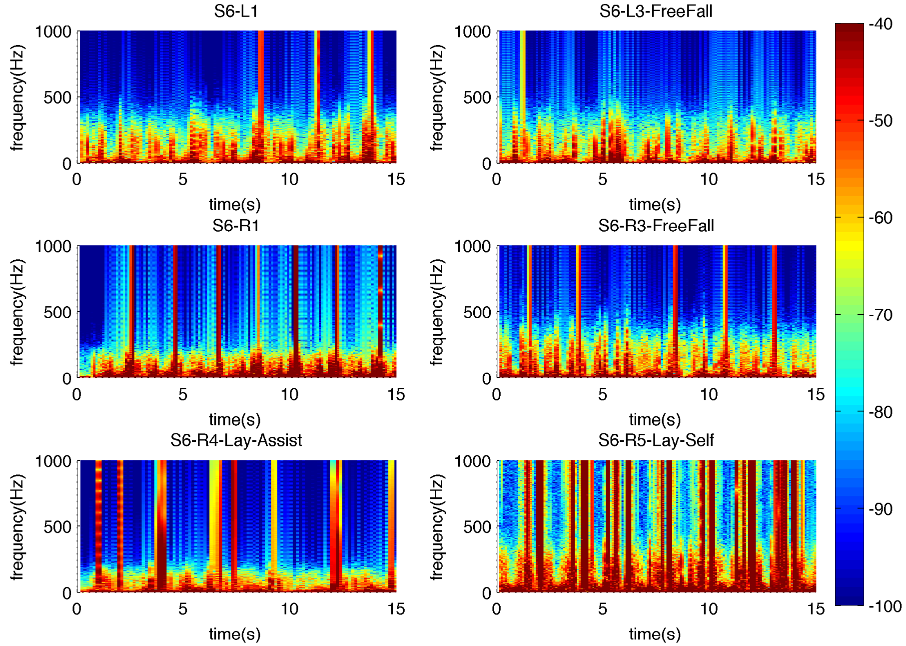
STFT analysis of VAG signals: non-resurfaced



- spikes and high frequency components up to about 500 Hz
- results look similar to resurface cases

STFT analysis of VAG signals: subject 6

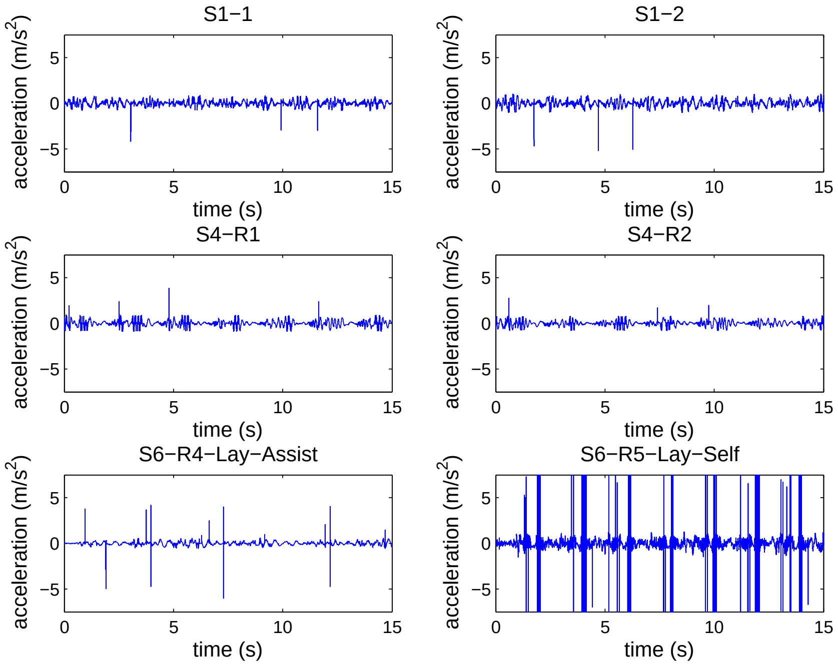


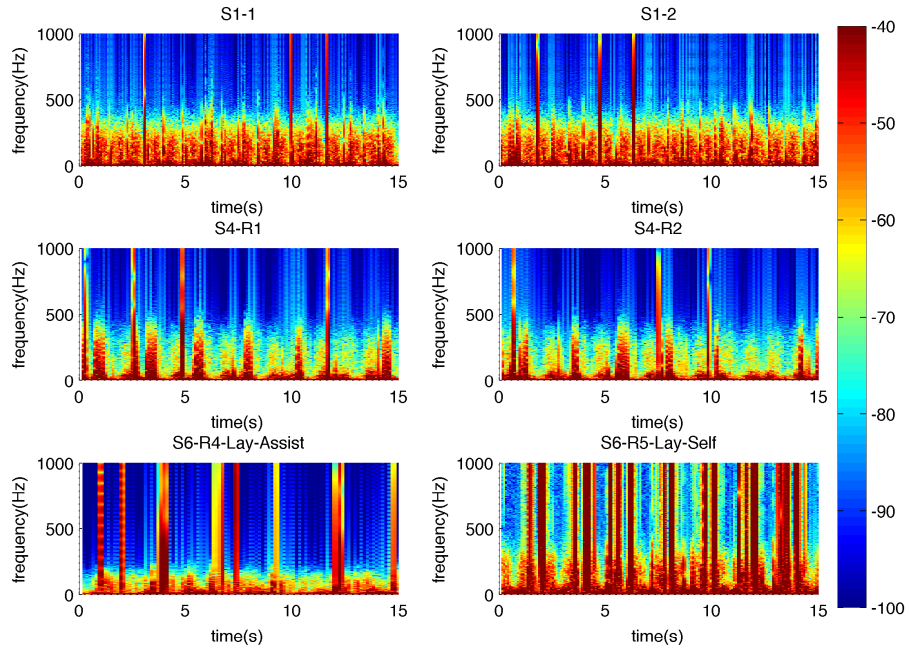


different postures and conditions affect muscle force acting on the patella

- affecting the surface contact of the patella
- resulting in different gliding mechanisms
- larger amplitudes of high frequency components were observed

STFT analysis of VAG signals: with Crepitus (joint sound)

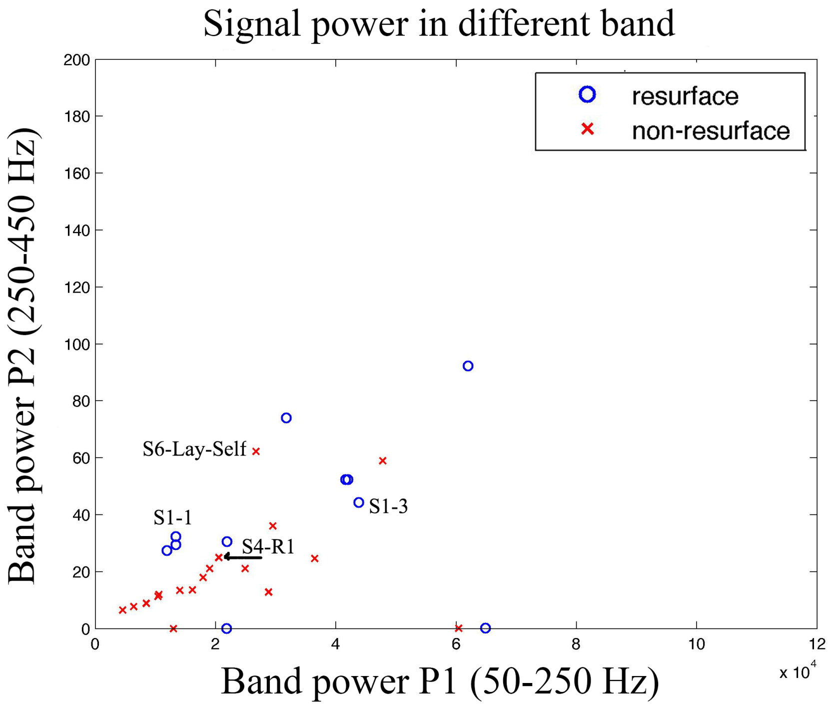




- different frequency components indicated different sounds that were heard
- consistency of the measurement: similar characteristics of the same knee at different times

Frequency band power

	P1 (50-250 Hz) (W)	P2 (250-450 Hz) (W)
resurface	$(3.92 \pm 2.69) \times 10^4$	52.25 ± 51.27
non-resurface	$(2.20 \pm 1.47) \times 10^4$	19.65 ± 17.38



no cluster of the data

Conclusion

- no significant difference was observed in the VAG signals between the resurface and non-resurface classes
- knee and measurement conditions affect the characteristics of the signals
- more features should be explored in further studies

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