The synergy of EMG waveform during bicycle pedaling is related to elemental force vector waveform

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Conflict of Interest (COI) Disclosure

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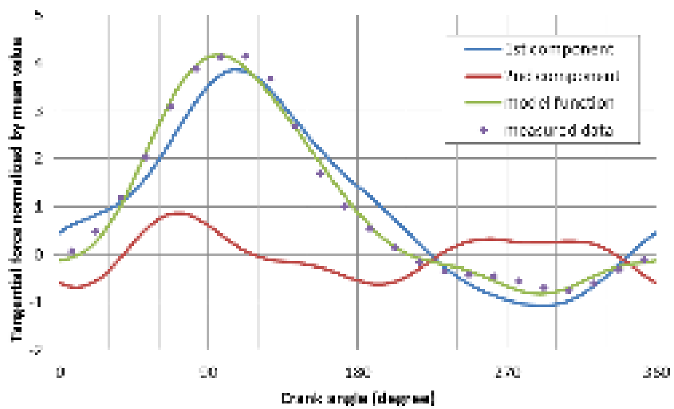
Introduction (1): Background

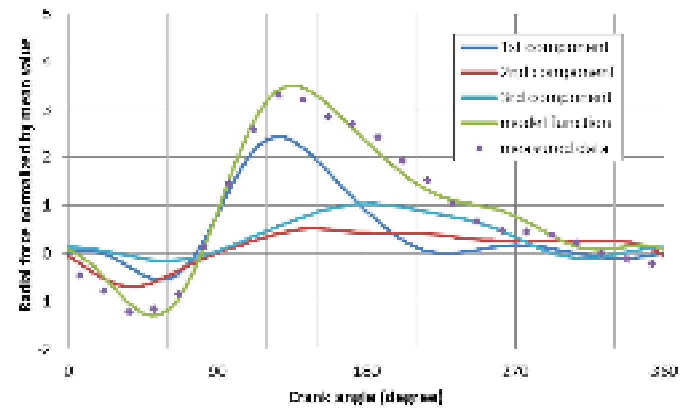
- Measurement of the pedaling force vectors

Cycle trainer
pedaling analyzer
(bikefitting.com)

Accurately measured pedaling force vector

Tangential direction **Radial direction**





$$Tan(\theta) = T_0\left\{1 + A_1 f_1(\theta-\theta_1) + A_2 f_2(\theta-\theta_2)\right\}$$

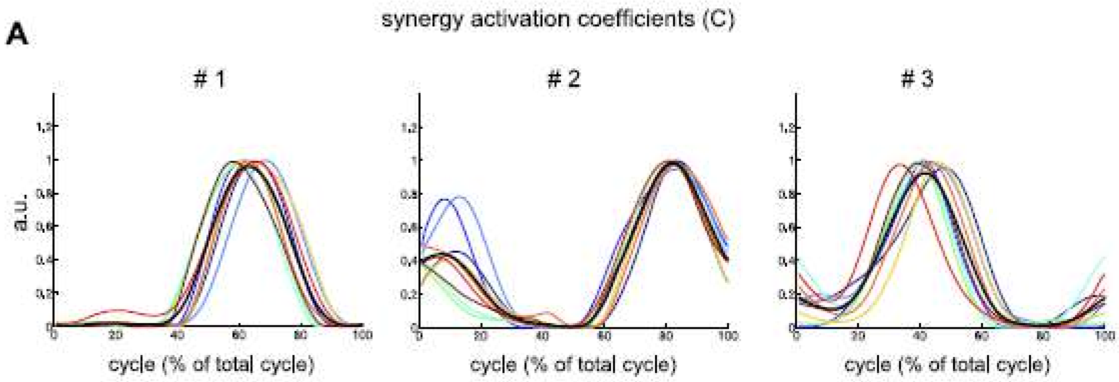
(Kitawaki et al 2018)

$$Rad(\theta) = T_0\left\{B_0 + B_1 g_1(\theta-\varphi_1) + B_2 g_2(\theta-\varphi_2) + B_3 g_3(\theta-\varphi_3)\right\}$$

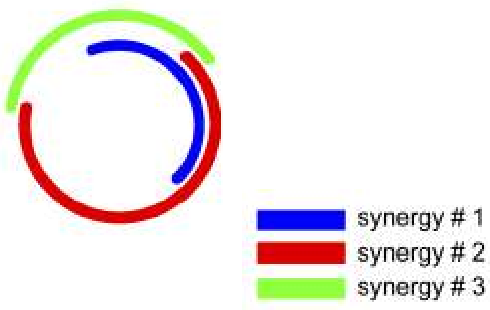
- **Tangential : sum of the two waveform components**
- **Radial : sum of the three waveforms**

Introduction (2): EMG synergies and purpose

A previous study:



Schematic representation of the 3 muscle synergies



EMG signals from the lower limb muscles indicated that pedaling is accomplished by combining <u>three similar muscle synergies</u>.

(Hug F., Turpin N., Guével A. and Dorel S., J Appl Physiol, 108(6) 1727-36. 2010)

Purpose:

- We performed synergy analysis of the EMG waveform, which was measured simultaneously with the force vector.
- To clarify the relationship between the elemental components of the force vector and EMG synergies.

Methods (1): Force vector measuring system

Pedaling analyzer system (bikefitting.com)

Pedaling analyzer sensor unit

Load device control by cycle computer

Pedaling force vector data was obtained every 15°

Pedaling force can be obtain using the tangential and radial directions

Methods (1): Procedure and data analysis

Procedure

- Two subjects (no. 1: top-level amateur cyclist and no. 2: former professional)
- Load power: 100, 200, 300 W
- Cadence : 70, 90, 110 rpm

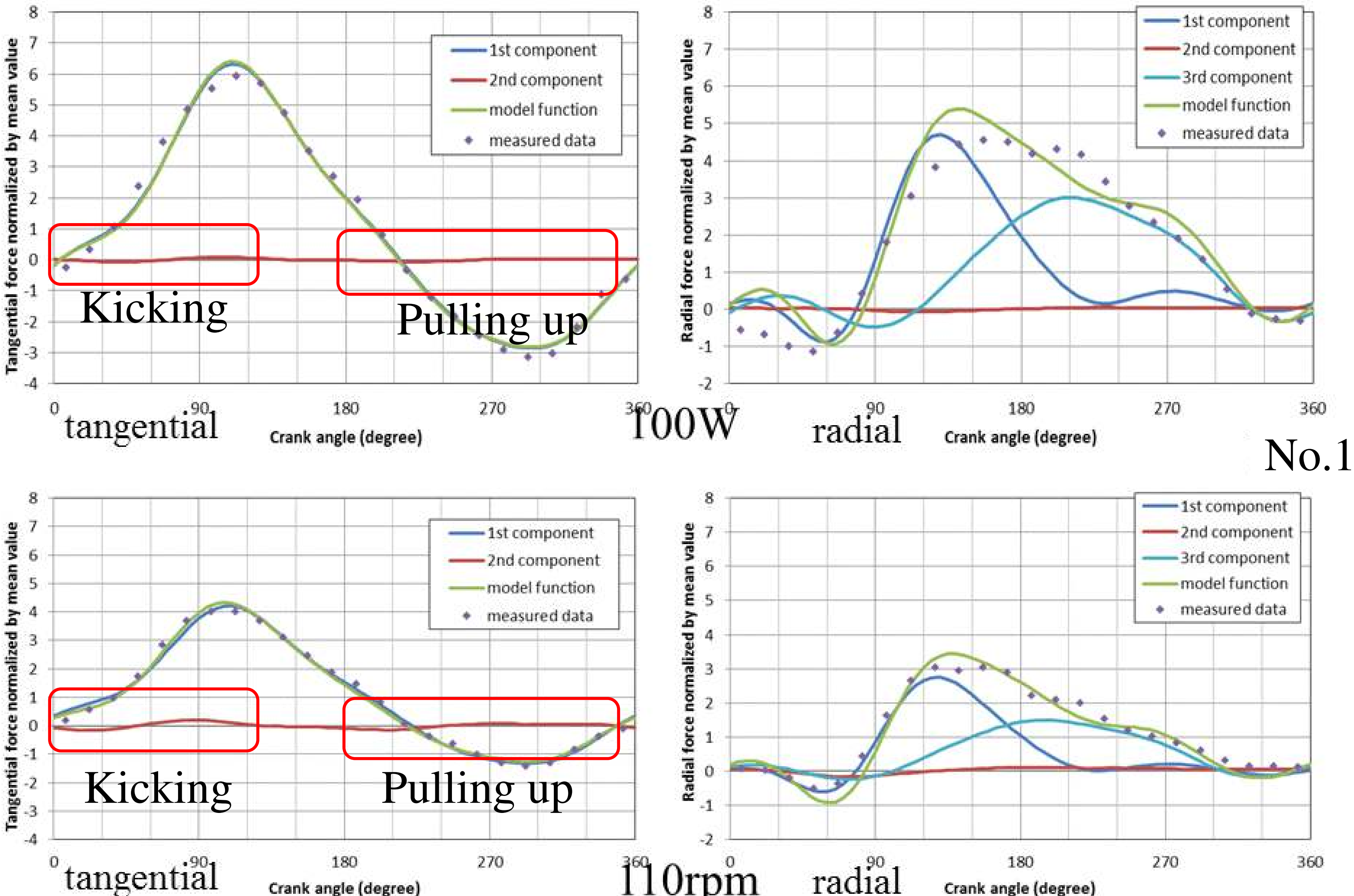
} 200 W and 90 rpm set as the reference values

- Pedaling action: pushing, spinning, pulling, and pushing and pulling
- Saddle position: back (5 mm), forward (10 mm), up (3 mm), and down (5 or 10 mm)

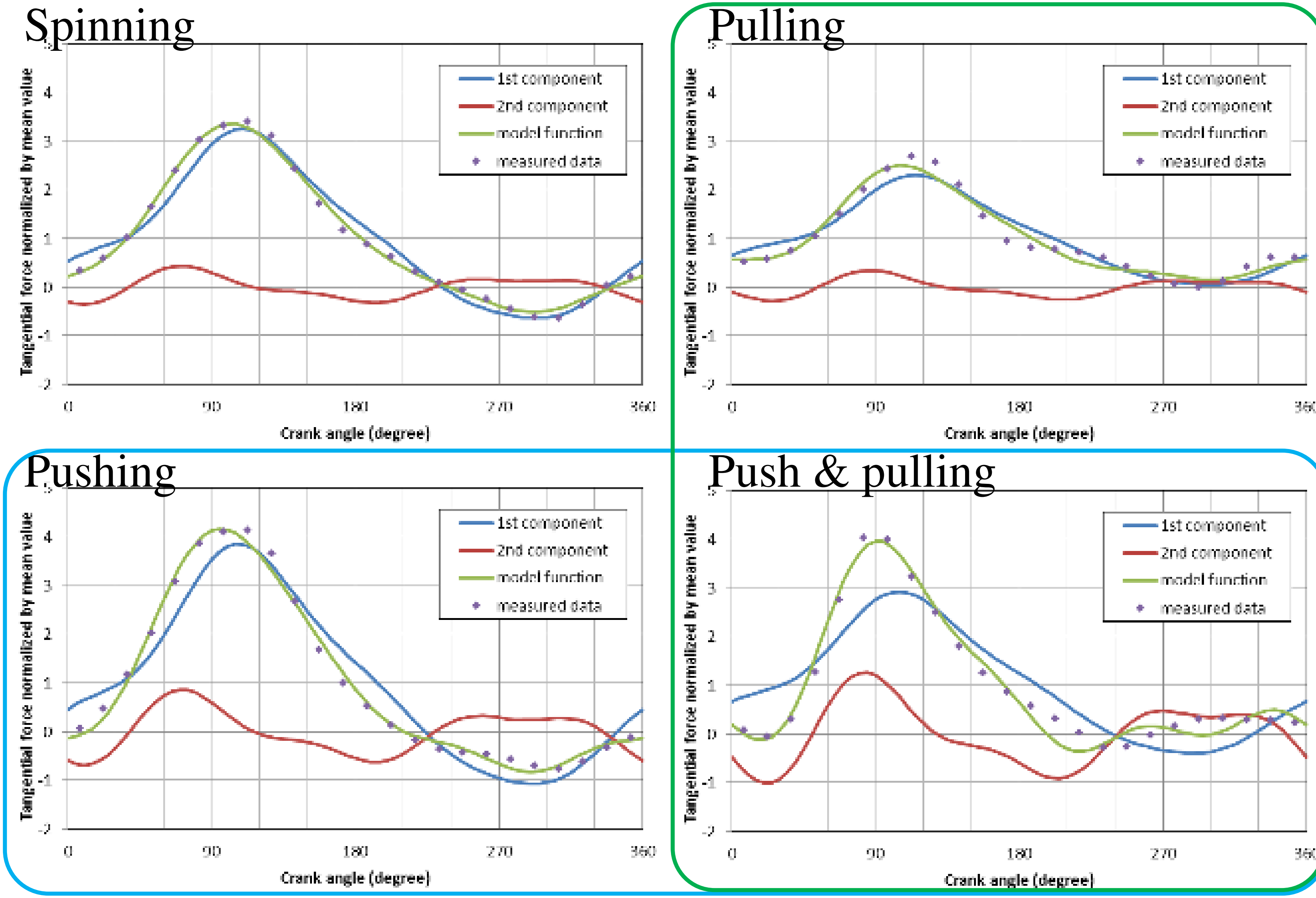
Data analysis of the force vector

- The mean pedaling force vector was calculated at each pedaling condition for 60 s.
- The pedaling vector data were expressed as the sum of 2 or 3 elemental vectors.
  - The common elemental vector waveforms and parameters were determined.
  - The RMS error between the sum of the elemental vector waveforms and the original vector data was minimized.
  - The amplitude and phase angle differences were changed.
  - The pedaling vector data and parameters were plotted.

Results (1): Force vector resolution (example)



Results (1): Force vector resolution by pedaling action

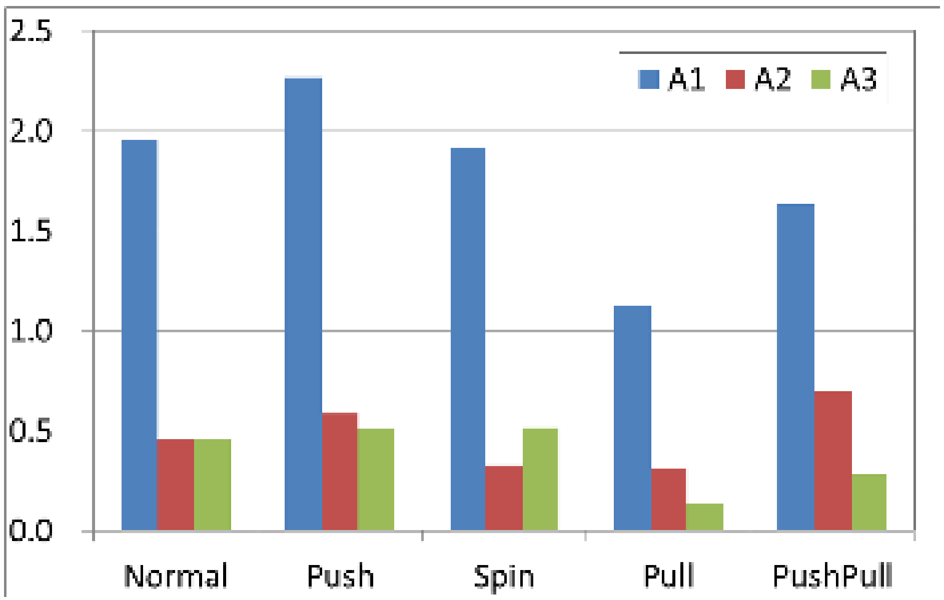


tangential components: No.1 (200W 90rpm)

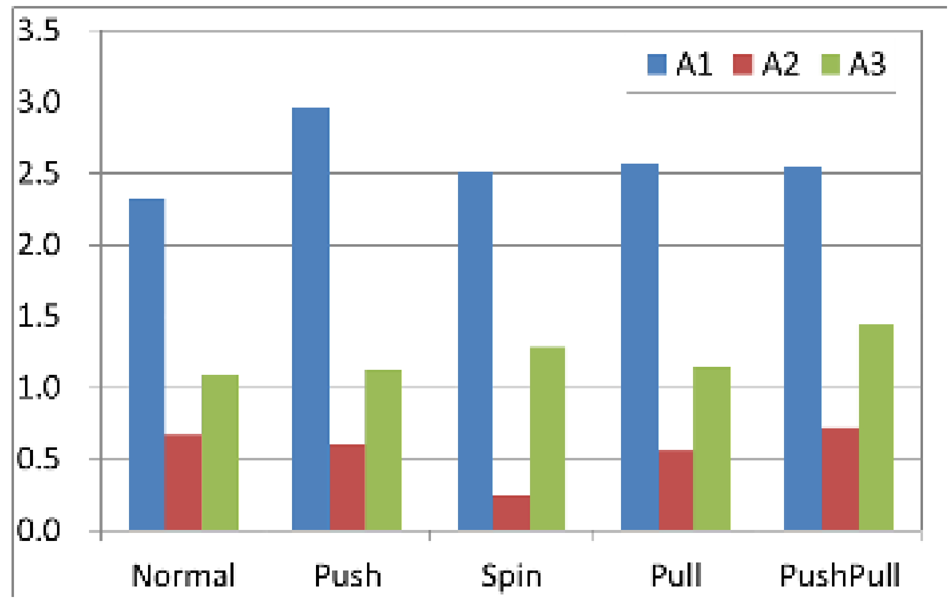
Results (1): Force vector resolution (pedaling action)

200W, 90rpm

No. 1



No. 2



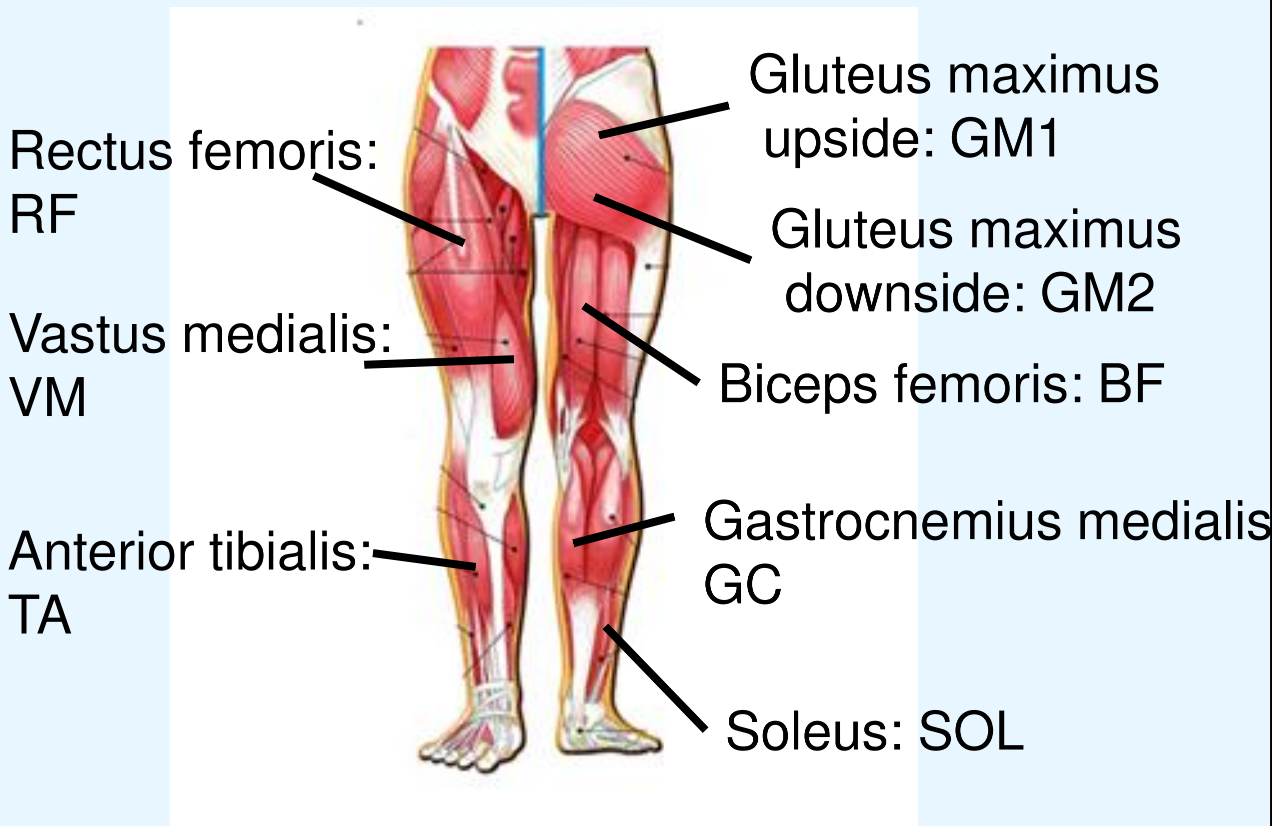
- Although the appearance of pedaling actions seem similar, the amplitudes of the components are different.
- The pedaling strategies of the subjects were different.

Change in the amplitude of force component ⟺ relationship ⟺ Change in muscle activity using EMG

Methods (2): EMG measurement

Surface EMG was recorded on the dominant leg

Electrode attachment



- Surface EMG was synchronously recorded at eight locations with force vector.
- Motion Capture System measured simultaneously, and each crank angle were calculated.

Methods (2): Procedure & data analysis

Procedure (same as force measurement)

- Two subjects (no. 1: former professional, and no. 2: top-level amateur cyclist)
- Load power: 100, 200, 300 W
- Cadence: 70, 90, 110 rpm
- Pedaling action: normal, spinning, pulling, and pushing and pulling

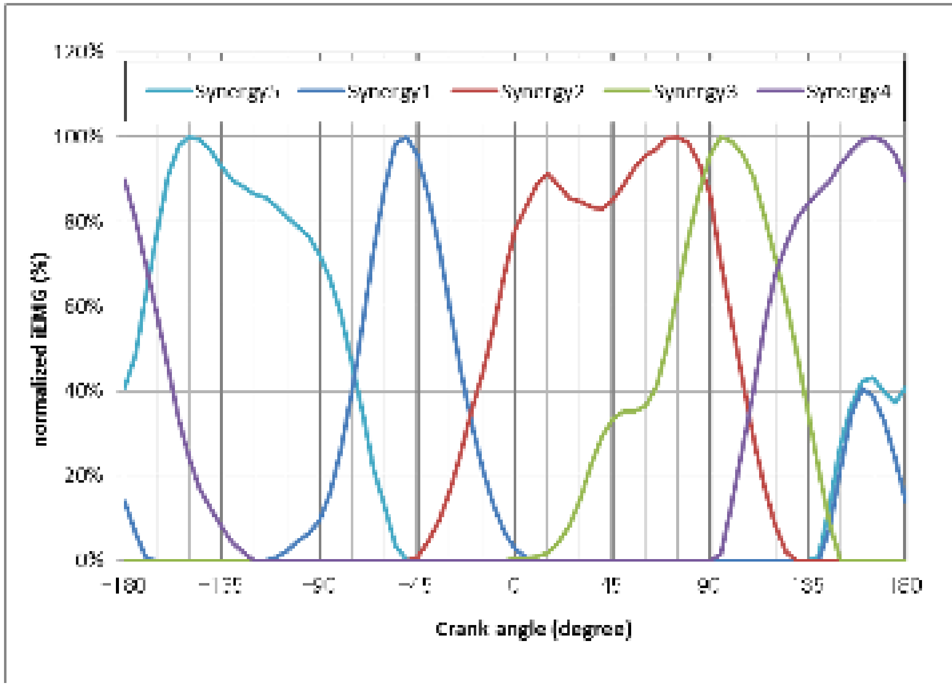
} 200 W and 90 rpm set as the reference values

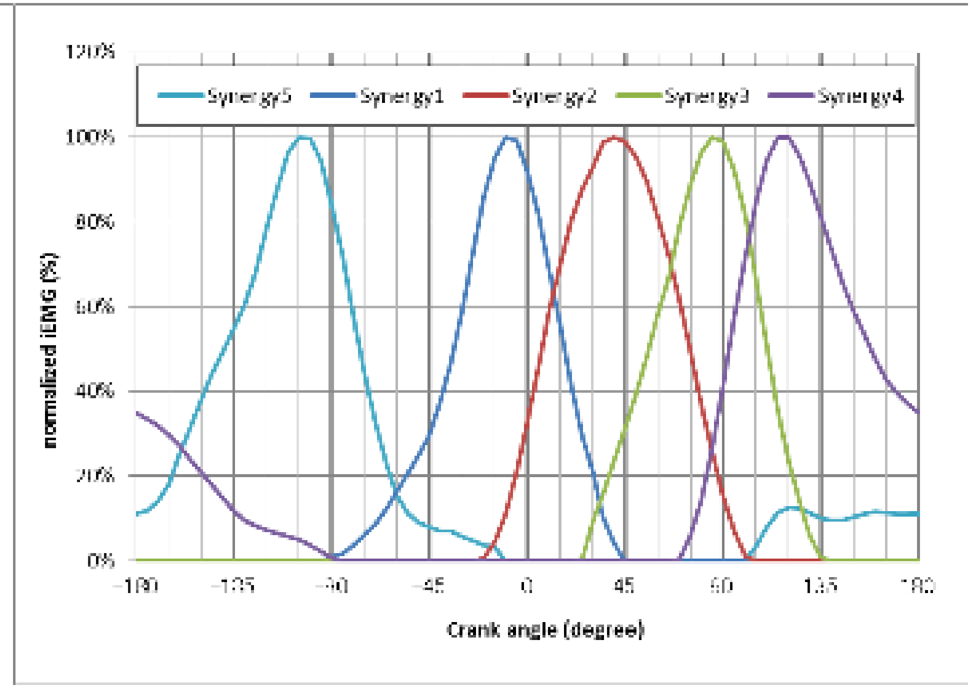
Data analysis of the EMG

- We acquired the EMG signal at the same time as the pedaling data measurement.
- The synergy factor was determined from the EMG signal per the following procedure:
  - The EMG waveforms were rectified and integrated (iEMG).
  - The un-normalized iEMG waveforms were obtained every 5° using the crank position
  - A non-negative matrix factorization (NNMF) algorithm was applied to the iEMG waveforms of the pedaling cycles to differentiate the muscle synergies.
  - The number of synergies was set to five to accurately express the muscle output according to the variety of the pedaling conditions.

Results: Individual iEMG synergies

ID 1 ID 2

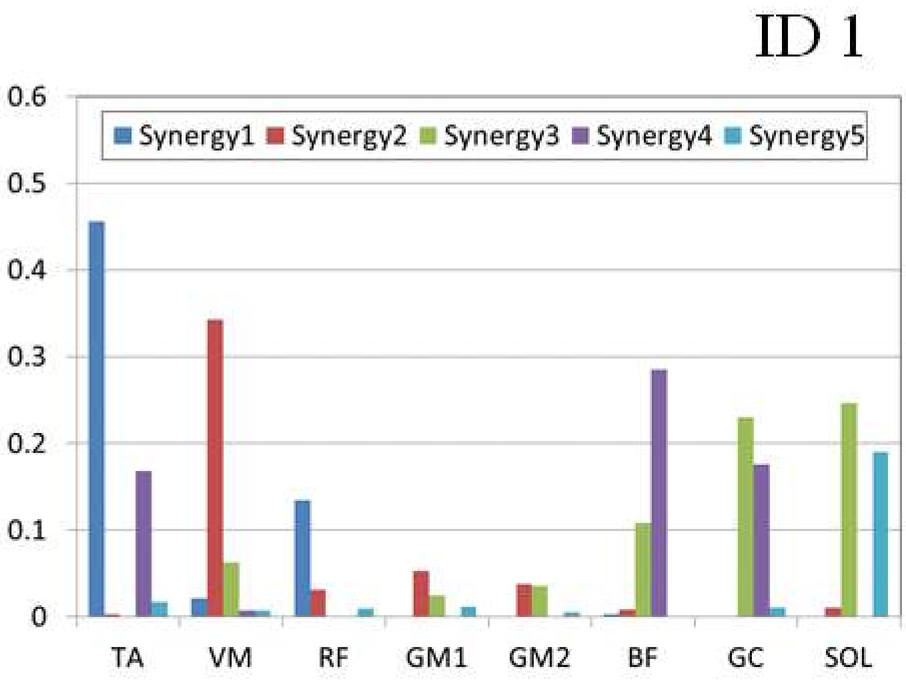


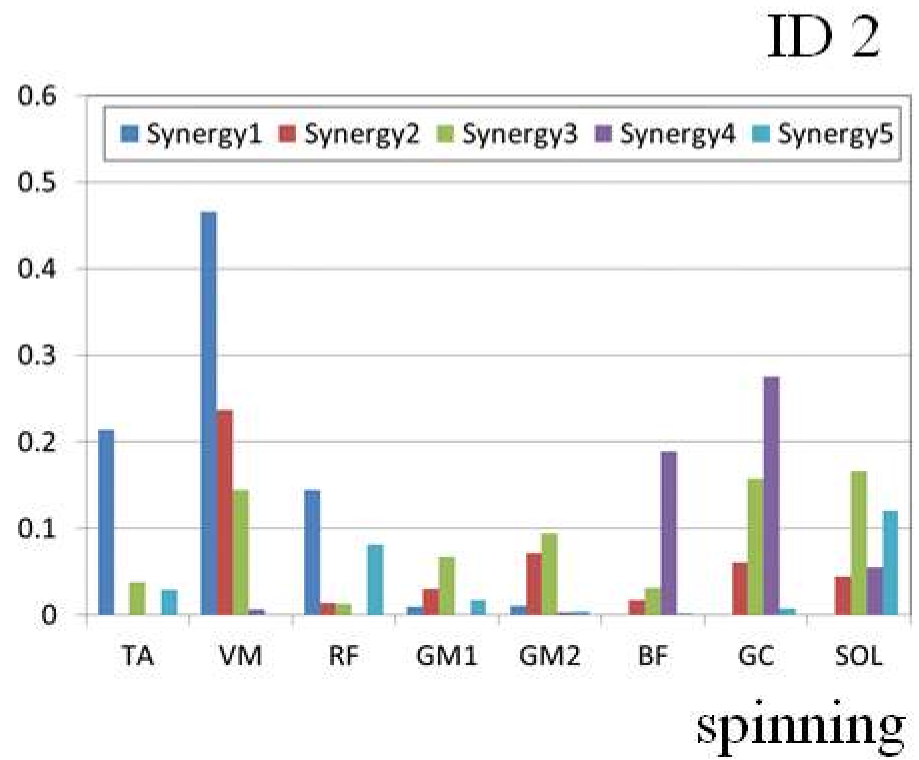


Five iEMG synergies of each subject (TDC: 0, BDC: ±180°)

- Five iEMG synergies: to analyze the various pedaling conditions.
- Peculiar changes appeared when the pedaling actions were varied.

Results: Amplitudes of the synergy components

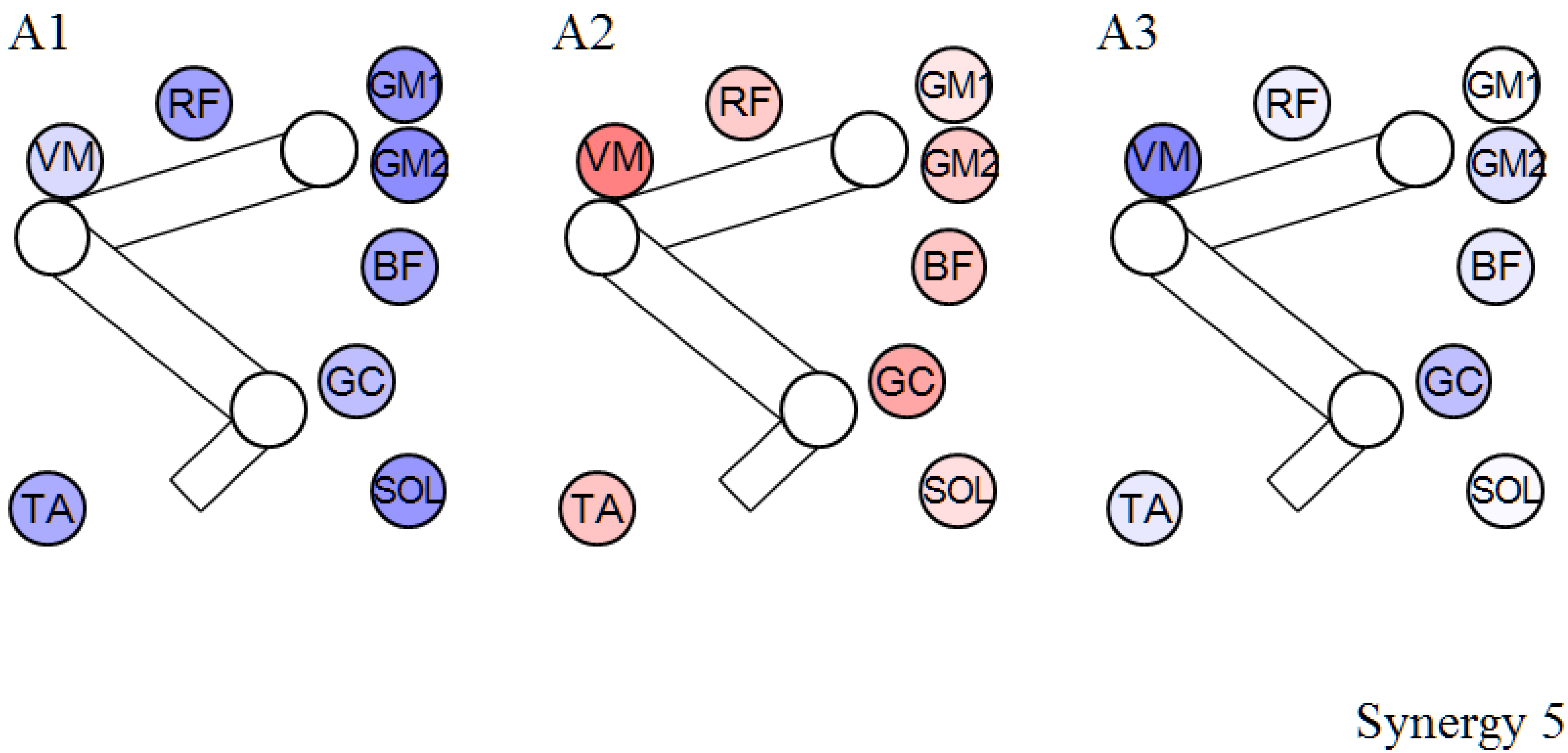




- Overall, the muscles were active at similar times.
- Due to the differences in the pedaling actions changed according to the activities of the muscles.
- Small muscles with a large amount of activity -> favorite action

Results: Correlation coefficient between the change in EMG synergy and force vector amplitude

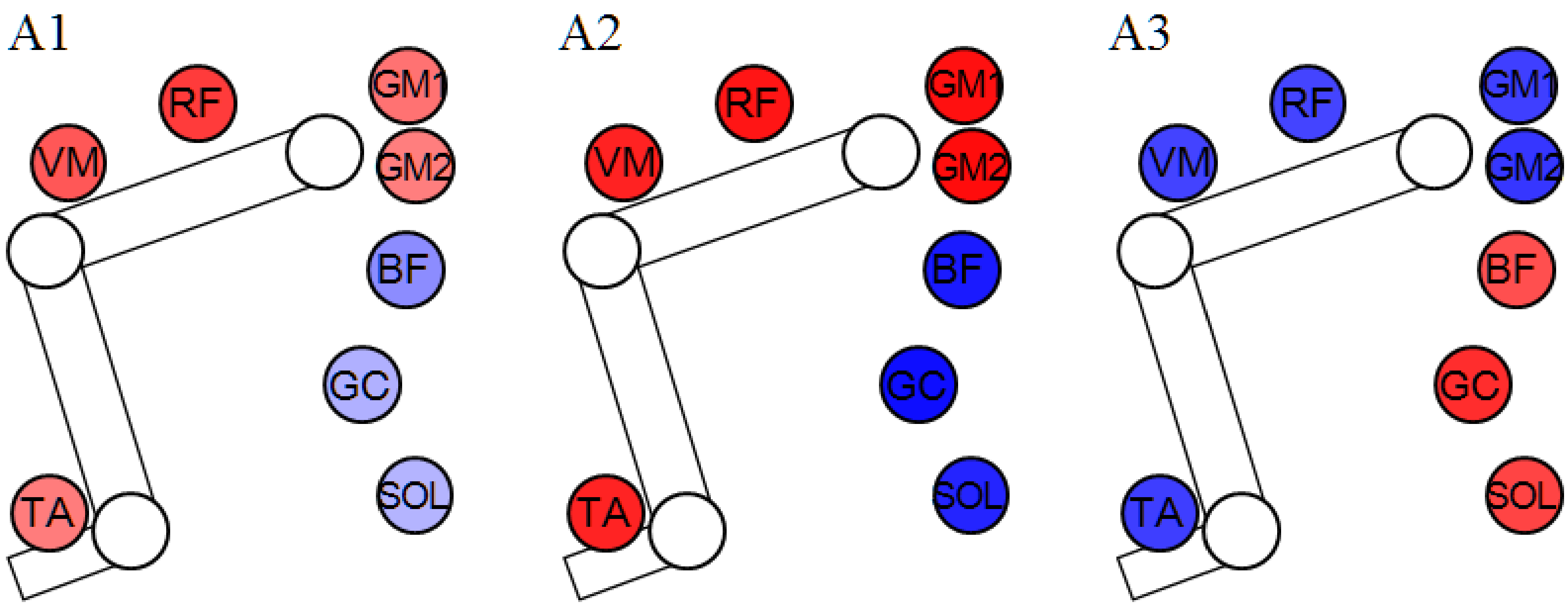
ID 1



- Pushing phase: positive correlation with most muscular activity.
- Recovery phases: negative correlation with the magnitude of A1.

Results: Correlation coefficient between the change in EMG synergy and force vector amplitude

ID 2



Synergy 2

- In Synergy 2, the upside muscular (VM, RF, and GM) activities increased and backside muscular (BF, GC, and SOL) activities decrease.
- The combination of various muscles changed, and the pedaling action also seemed to change.

Conclusion

In this study,

- We performed synergy analysis of the EMG waveform, which was measured simultaneously with the force vector.
- This was performed to reveal the relationship between the elemental components of the force vector and the EMG synergies.

As a result, the following findings were revealed:

- The changes in the amplitude of the elemental waveform components of the force vector and the amplitude of the EMG synergy were interrelated.
- The changes in the force vector were caused by the difference in pedaling due to the differences in the muscle force activity.

Future directions:

- Investigate the differences between the changes in the element waveform and muscle force assessment by increasing the number of subjects
- Study the corresponding muscle force activity and the pedaling action

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Thank you for your kind attention