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

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Purpose:

In recent years, the pedaling force vector can now be accurately measured using pedaling analyzer systems (Bikefitting.com, Sittard, Netherlands). Using this device, we showed that the pedaling force vector components in the tangential and radial directions can be represented by the sum of two or three elemental waveform components, respectively (Kitawaki et al 2018). Besides, a previous study that analyzed the electromyogram (EMG) signals of the lower limb muscles demonstrated that pedaling is accomplished by combining three similar muscle synergies (Hug et al. 2010).

Therefore, this study aims to clarify the relationship between the elemental components of the force vector and EMG synergies. We performed synergy analysis of the EMG waveform, which was measured simultaneously with the force vector.

Methods:

Two participants (a former professional and a top-level amateur cyclist) performed pedaling under a variety of conditions (load: 100 W, 200 W, 300 W; cadence: 70 rpm, 90 rpm, 110 rpm; saddle position: back (5 mm), forward (10 mm), up (3 mm), and down (5 mm, 10 mm); pedaling action type: normal, spinning, pulling, and pushing and pulling). Pedaling force vector data was obtained every 15° using a pedaling analyzer system (Bikefitting.com). The surface EMG was simultaneously measured on the right leg at eight locations (anterior tibialis: TA, gastrocnemius medialis: GM, soleus: SOL, rectus femoris: RF, vastus medialis: VM, biceps femoris: BF, gluteus maximus (upside: GM1, downside: GM2)).

Pedaling vector data were expressed as the sum of elemental vectors, as demonstrated in our previous study (Kitawaki et al 2018). After the EMG waveforms have been rectified and integrated, iEMG waveforms were obtained every 5° using crank position data. A non-negative matrix factorization (NNMF) algorithm was applied to the iEMG waveforms of the pedaling cycles to differentiate muscle synergies. The number of synergies was set to five to accurately express the muscle output exerted according to the variety of pedaling conditions.

Results & Discussion:

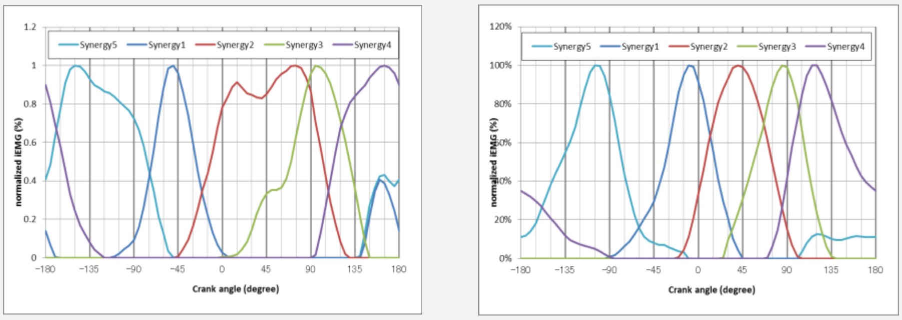
The iEMG waveform can be represented by the sum of five synergies, as shown in Figure 1. The amplitude of the synergy varies with the pedaling conditions. The analysis of NNMF does not include change in phase, whereas the force vector waveform analysis includes change in phase angle. Moreover, the change in phase angle was not included in the EMG analysis as it was approximately 5°.

Table 1 lists the correlation coefficient between the amplitude of EMG synergy by muscle and the force vector amplitude (A1, A2, A3) of elemental vector waveforms. A few muscles with less muscular amplitude were removed from the table. The following can be observed from the results:

Subject ID1: In the pushing phase of Synergy 2-3, the magnitude of A1 that means to pedaling power has a positive correlation with most muscular strength. On the other hand, in the recovery phases of Synergy 1 & 5, most muscular strengths have negative correlation with the magnitude of A1. Thus, it seems that subject ID1 is performing more integrated pedaling.
Subject ID2: By contrast, in the early pushing phase of Synergy 2-3, certain muscle (RF, VM GM) strengths increase due to the difference in pedaling, whereas some muscular (GC, SOL,BF) strengths decrease. In the case of subject ID 2, the combination of various muscles changes and the pedaling action seems to be changing.
These results indicate that the change in the force vector is caused by the difference in pedaling due to the difference in the muscle force strength. In the future, we will continue to investigate the difference between change in the element waveform and muscle force assessment by increasing the number of participants and we will study the corresponding muscle force strength and pedaling action.

Conclusion:
The change in the amplitude of elemental waveform components of the force vector and the amplitude of EMG synergy are interrelated; we clarified that the force vector and the EMG waveform change at the same time due to a variety of pedaling conditions.

References:
T. Kitawaki et. al. (2018), A pedaling force vector can be represented by the sum of three elemental force vector waveforms. J Science & Cycling, 7(2) 1-2.
F Hug, et. al. (2010), Is interindividual variability of EMG patterns in trained cyclists related to different muscle synergies? J Appl Physiol, 108(6) 1727-36.



(a) ID1 (b) ID2

Figure 1. Five iEMG synergies of each participant (TDC: 0 degree, BDC: 180 degree).

Table 1. Correlation coefficient between change of EMG synergy and force vector amplitude of elemental vector waveforms. (Exclude muscles with less power)

(a) ID1

		A1	A2	A3
Synergy1	TA	−0.847	−0.658	0.377
	SOL	0.006	0.056	0.377
	RF	−0.795	−0.437	0.268
	VM	−0.417	−0.298	−0.045
	BF	−0.540	−0.984	0.716
	GM1	−0.408	0.250	−0.259
	GM2	−0.344	0.530	−0.619
Synergy2	GC	0.568	0.260	−0.151
	SOL	0.680	0.396	−0.345
	RF	0.506	−0.089	−0.047
	VM	0.600	0.051	−0.096
	BF	−0.405	0.040	0.113
	GM1	0.602	0.444	−0.377
	GM2	0.723	0.600	−0.434
Synergy3	TA	0.605	0.257	−0.081
	GC	0.339	0.108	−0.267
	SOL	0.374	−0.076	−0.052
	RF	0.428	0.225	−0.043
	VM	−0.604	−0.723	0.545
	BF	−0.512	−0.742	0.277
	GM1	0.183	−0.107	0.023
	GM2	0.112	−0.053	−0.128
Synergy4	TA	−0.760	−0.595	0.424
	GC	−0.679	−0.283	0.265
	RF	0.635	0.252	−0.084
	VM	0.497	−0.140	0.151
	BF	−0.724	−0.444	0.330
	GM1	0.568	0.260	−0.151
	GM2	0.550	0.275	0.021
Synergy5	TA	−0.322	0.229	−0.089
	GC	−0.247	0.348	−0.203
	SOL	−0.408	0.123	−0.022
	RF	−0.367	0.196	−0.059
	VM	−0.145	0.493	−0.464
	BF	−0.330	0.223	−0.079
	GM1	−0.403	0.090	0.005
	GM2	−0.446	0.206	−0.122

(b) ID2

		A1	A2	A3
Synergy1	TA	−0.071	0.046	0.218
	GC	0.032	0.334	−0.313
	RF	−0.903	−0.696	0.431
	VM	−0.417	−0.949	0.748
	BF	0.755	0.693	−0.298
	GM1	−0.537	−0.945	0.678
	GM2	0.563	0.287	−0.020
Synergy2	TA	0.512	0.862	−0.756
	GC	−0.309	−0.942	0.822
	SOL	−0.292	−0.857	0.731
	RF	0.766	0.916	−0.733
	VM	0.658	0.864	−0.734
	BF	−0.449	−0.898	0.687
	GM1	0.551	0.935	−0.751
	GM2	0.504	0.950	−0.785
Synergy3	TA	0.277	−0.547	0.577
	GC	0.186	0.680	−0.668
	SOL	0.853	0.707	−0.500
	RF	−0.107	−0.461	0.418
	VM	−0.201	−0.688	0.622
	BF	0.645	0.694	−0.624
	GM1	0.684	0.650	−0.434
	GM2	0.291	0.436	−0.265
Synergy4	TA	−0.194	0.416	−0.429
	GC	0.062	0.739	−0.696
	SOL	−0.096	−0.859	0.761
	VM	−0.012	0.188	−0.253
	BF	−0.719	−0.905	0.579
	GM2	−0.490	−0.942	0.700
Synergy5	TA	−0.681	−0.308	0.027
	GC	0.533	0.934	−0.739
	SOL	0.581	0.824	−0.701
	RF	−0.852	−0.775	0.398
	VM	−0.051	0.630	−0.388
	BF	−0.516	0.119	−0.216
	GM1	−0.228	0.622	−0.759
	GM2	0.200	0.188	−0.017

Keywords: pedaling force, biomechanics, pedaling technique, mathematical analysis.