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

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Background & 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

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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.

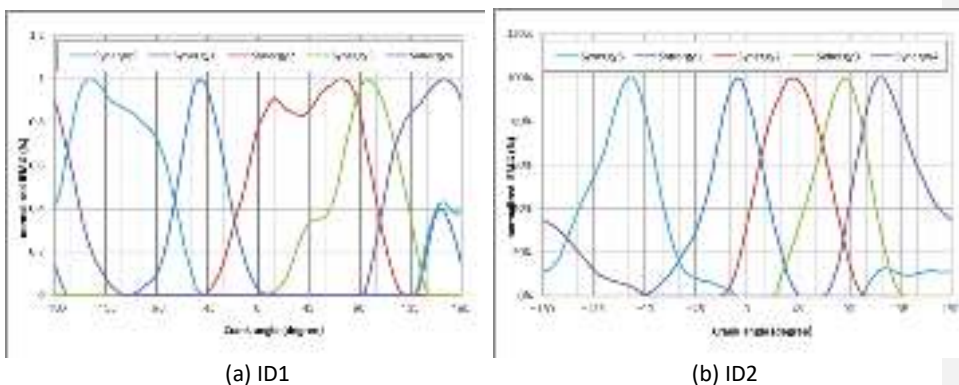


Figure 1: Five iEMG synergies of each participant (TDC: 0 degree, BDC: 180 degree).

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

(a) ID1				(b) ID2					
	A1	A2	A3		A1	A2	A3		
Synergy1	TA	-0.847	-0.658	0.377	Synergy1	TA	-0.071	0.046	0.218
	SOL	0.006	0.056	0.377		GC	0.032	0.334	-0.313
	RF	-0.795	-0.437	0.268		RF	-0.903	-0.696	0.431
	VM	-0.417	-0.298	-0.045		VM	-0.417	-0.949	0.748
	BF	-0.540	-0.984	0.716		BF	0.755	0.693	-0.298
	GM1	-0.408	0.250	-0.259		GM1	-0.537	-0.945	0.678
	GM2	-0.344	0.530	-0.619		GM2	0.563	0.287	-0.020
Synergy2	GC	0.568	0.260	-0.151	Synergy2	TA	0.512	0.862	-0.756
	SOL	0.680	0.396	-0.345		GC	-0.309	-0.942	0.822
	RF	0.506	-0.089	-0.047		SOL	-0.292	-0.857	0.731
	VM	0.600	0.051	-0.096		RF	0.766	0.916	-0.733
	BF	-0.405	0.040	0.113		VM	0.658	0.864	-0.734
	GM1	0.602	0.444	-0.377		BF	-0.449	-0.898	0.687
	GM2	0.723	0.600	-0.434		GM1	0.551	0.935	-0.751
Synergy3	TA	0.605	0.257	-0.081	Synergy3	GM2	0.504	0.950	-0.785
	GC	0.339	0.108	-0.267		TA	0.277	-0.547	0.577
	SOL	0.374	-0.076	-0.052		GC	0.186	0.680	-0.668
	RF	0.428	0.225	-0.043		SOL	0.853	0.707	-0.500
	VM	-0.604	-0.723	0.545		RF	-0.107	-0.461	0.418
	BF	-0.512	-0.742	0.277		VM	-0.201	-0.688	0.622
	GM1	0.183	-0.107	0.023		BF	0.645	0.694	-0.624
GM2	0.112	-0.053	-0.128	GM1	0.684	0.650	-0.434		
Synergy4	TA	-0.760	-0.595	0.424	Synergy4	GM2	0.291	0.436	-0.265
	GC	-0.679	-0.283	0.265		TA	-0.194	0.416	-0.429
	RF	0.635	0.252	-0.084		GC	0.062	0.739	-0.696
	VM	0.497	-0.140	0.151		SOL	-0.096	-0.859	0.761
	BF	-0.724	-0.444	0.330		VM	-0.012	0.188	-0.253
	GM1	0.568	0.260	-0.151		BF	-0.719	-0.905	0.579
	GM2	0.550	0.275	0.021		GM2	-0.490	-0.942	0.700
Synergy5	TA	-0.322	0.229	-0.089	Synergy5	TA	-0.681	-0.308	0.027
	GC	-0.247	0.348	-0.203		GC	0.533	0.934	-0.739
	SOL	-0.408	0.123	-0.022		SOL	0.581	0.824	-0.701
	RF	-0.367	0.196	-0.059		RF	-0.852	-0.775	0.398
	VM	-0.145	0.493	-0.464		VM	-0.051	0.630	-0.388
	BF	-0.330	0.223	-0.079		BF	-0.516	0.119	-0.216
	GM1	-0.403	0.090	0.005		GM1	-0.228	0.622	-0.759
GM2	-0.446	0.206	-0.122	GM2	0.200	0.188	-0.017		