



SUPPLEMENTARY MATERIAL OPEN ACCESS

Myoelectric Manifestations of Fatigue in Sport: Evidence from Repeated Maximal Shooting in Professional Water Polo

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Analysis component	Possible	Included	Completeness (%)	Notes
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Supplementary Tables

Supplementary Table S1. Data quality.

Analysis component	Possible	Included	Completeness (%)	Notes
14-muscle late-cocking spectral windows	3,108	2,957	95.1	No imputation
14-muscle × four-phase observations	12,432	11,876	95.5	Amplitude and timing atlas
Recruitment-fatigue-velocity shots	219 velocity-matched	211	96.3	All 14 athletes represented

Supplementary Table S2. FDR-significant amplitude phase-selectivity contrasts.

Throwing-side muscle	Peak phase	Peak vs other phases	95% CI	FDR q
Flexor carpi radialis	Acceleration	+59.79 pp	+51.67 to +67.45	0.0012
Clavicular pectoralis	Acceleration	+37.27 pp	+25.88 to +48.44	0.0012
Latissimus dorsi	Acceleration	+36.40 pp	+24.73 to +47.51	0.0014
Lateral triceps	Acceleration	+31.92 pp	+21.89 to +42.14	0.0012
Pectoralis major	Acceleration	+31.47 pp	+25.69 to +37.39	0.0012
Lower rectus abdominis	Acceleration	+29.99 pp	+20.42 to +38.61	0.0012
Teres major	Acceleration	+20.91 pp	+7.46 to +34.76	0.0248
Middle deltoid	Preparation	+18.89 pp	+9.02 to +29.03	0.0056
Middle trapezius	Preparation	+14.74 pp	+4.53 to +23.34	0.0248
Infraspinatus	Deceleration	+15.44 pp	+4.06 to +26.39	0.0296
Thoracic erector spinae	Deceleration	+13.24 pp	+2.56 to +23.62	0.0492

Note. Peak phases were identified from the observed phase atlas; these FDR-corrected contrasts are therefore treated as secondary/exploratory phase-selectivity summaries.

Supplementary Table S3. Complete-montage muscle-specific spectral models.

Throwing-side muscle	Adjusted endpoint change (Hz)	95% CI	FDR q
Teres major	-14.62	-22.71 to -5.89	0.0042
Clavicular pectoralis	-10.08	-17.18 to -4.93	0.0028
Infraspinatus	-8.32	-23.51 to +7.55	0.624
Pectoralis major	-6.20	-12.26 to +0.04	0.243
Lower rectus abdominis	-4.78	-10.72 to +0.94	0.331
Latissimus dorsi	-2.46	-6.51 to +2.02	0.612
Biceps brachii	-1.30	-5.26 to +2.66	0.812
Lateral triceps	-1.05	-9.42 to +9.02	0.912
Posterior deltoid	-0.71	-5.72 to +2.54	0.899
Middle deltoid	-0.69	-7.05 to +3.22	0.912
Anterior deltoid	+0.05	-10.18 to +9.15	0.958
Flexor carpi radialis	+1.25	-5.96 to +9.02	0.899
Middle trapezius	+1.87	-3.59 to +8.44	0.812
Thoracic erector spinae	+4.81	-1.07 to +11.30	0.331

Supplementary Table S4. Integrated all-muscle and localized fatigue models.

Model family	Outcome	Predictor	β	95% CI	FDR q
All-muscle fatigue sequence	Fatigue burden	Sequence	+0.415	-1.362 to +2.058	0.946
All-muscle fatigue sequence	Fatigue burden	Amplitude-pattern distance	-0.126	-0.364 to +0.123	0.946
All-muscle fatigue sequence	Fatigue burden	Timing-pattern distance	-0.010	-0.223 to +0.164	0.946
All-muscle velocity	Ball velocity	All-muscle fatigue burden	+0.263	-0.588 to +1.148	0.846
All-muscle velocity	Ball velocity	Amplitude-pattern distance	+0.593	-0.732 to +1.844	0.846
All-muscle velocity	Ball velocity	Timing-pattern distance	+0.033	-1.105 to +1.005	0.944
All-muscle velocity	Ball velocity	Fatigue $\times$ amplitude reorganization	-0.322	-1.583 to +0.660	0.846
All-muscle velocity	Ball velocity	Fatigue $\times$ timing reorganization	+0.133	-1.173 to +1.278	0.944
Localized fatigue sequence (post-identification)	Fatigue burden	Sequence	+1.779	+0.428 to +2.973	0.030
Localized velocity (post-identification)	Ball velocity	Localized fatigue burden	-0.012	-0.667 to +0.594	0.997
Localized velocity (post-identification)	Ball velocity	Amplitude-pattern distance	+0.412	-0.889 to +1.764	0.817
Localized velocity (post-identification)	Ball velocity	Timing-pattern distance	-0.004	-0.919 to +0.886	0.997
Localized velocity (post-identification)	Ball velocity	Fatigue $\times$ amplitude reorganization	+0.497	-0.941 to +1.643	0.761
Localized velocity (post-identification)	Ball velocity	Fatigue $\times$ timing reorganization	-1.068	-2.455 to +0.280	0.277

Supplementary Table S5. Complete-montage spectral sensitivity analyses.

Variant	Amplitude adjusted	Standardized endpoint contrast	95% CI	FDR q
CWT 20 Hz	No	-0.422	-0.704 to -0.161	0.0014
CWT 20 Hz	Yes	-0.405	-0.644 to -0.174	0.0007
CWT 30 Hz	No	-0.388	-0.671 to -0.143	0.0010
CWT 30 Hz	Yes	-0.368	-0.588 to -0.162	0.0003
CWT 40 Hz	No	-0.376	-0.647 to -0.156	0.0008
CWT 40 Hz	Yes	-0.357	-0.574 to -0.167	0.0003
FFT 20 Hz	No	-0.311	-0.471 to -0.156	0.0005
FFT 20 Hz	Yes	-0.307	-0.480 to -0.148	0.0003
FFT 30 Hz	No	-0.292	-0.483 to -0.109	0.0013
FFT 30 Hz	Yes	-0.282	-0.484 to -0.105	0.0012
FFT 40 Hz	No	-0.317	-0.504 to -0.145	0.0005
FFT 40 Hz	Yes	-0.305	-0.489 to -0.147	0.0003
CWT active window	No	-0.454	-0.715 to -0.218	0.0005
CWT active window	Yes	-0.436	-0.642 to -0.233	0.0003
CWT low-band trim	No	-0.400	-0.698 to -0.125	0.0022
CWT low-band trim	Yes	-0.378	-0.595 to -0.163	0.0003

Note. Standardized endpoint contrasts are complete-montage sensitivity summaries. Negative values indicate a downward spectral shift across the sequence. FDR q values are calculated within the corresponding adjustment set.

Supplementary Figure

Figure S1. Observed peak-phase amplitude contrasts across the 14-muscle montage. Points indicate the difference between the observed peak-amplitude phase and the mean of the remaining phases; error bars represent 95% confidence intervals. Colors indicate the observed peak-amplitude phase.

