

SUPPLEMENTARY RESULTS

Tables

Table S1. Data quality comparison of sports cohorts: the Norwegian elite U-19 football data (55% male, age; mean \pm standard deviation (SD) = 17 \pm 1 years), Norwegian Premier League football data (all male, age 26 \pm 4 years) and elite youth handball data (36% male, age 17 \pm 0.9 years).

		Football U-19	Football Elite	Handball
Sample Size	Number of athletes	81	36	205
	Number of sRPE values before imputation	6 424	6 061	17 268
	Number of sRPE values after imputation	8 495	10 232	47 651
	Number of injuries	81	38	472
	Number of injuries per athlete, mean (SD)	1 (1.2)	1 (1.5)	2.3 (2.9)
Missing data	Missing load values, n (%)	2 071 (24%)	4 171 (41%)	30 383 (64%)
	Missing load values per athlete, mean (SD)	26 (32)	116 (62)	148 (71)
Timelines	Mean (SD) answering time, days	0.3 (0.7)	0.01 (0.2)	0.7 (1.6)
	Percentage of forms answered the same day	72%	99%	53%
	Max answering time, days	9	4	119

Abbreviations: Football Elite, Norwegian Premier League; sRPE, session Rating of Perceived Exertion

Table S2. Overview of injury definition and models run on each sport population, with the number of load values and the number of injuries used in each model.

Population	Injury Definition ¹	Load Definition ²	Load Values (n) ³	Injuries (n) ³
Football U-19 (n = 81)	Same day	sRPE	8495	81
		Daily ACWR 7:21-period	6308	43
	Next 4 days	sRPE	8495	210
		Daily ACWR 7:21-period	6308	129
Football Elite (n = 36)	Next micro-cycle	Micro-cycle ACWR 1:3-period	793	26
		Same day	sRPE	10 232
	Next 4 days	Daily ACWR 7:21-period	9 260	32
		sRPE	10 232	44
Handball (n = 205)	Next micro-cycle	Daily ACWR 7:21-period	9 260	34
		Micro-cycle ACWR 1:3-period	553	26
	Same day	sRPE	47 651	472
		Daily ACWR 7:21-period	42 116	320
Next 4 days	sRPE	47 651	1 136	
	Daily ACWR 7:21-period	42 116	714	
	Next micro-cycle	Micro-cycle ACWR 1:3-period	1 897	242

Abbreviations: ACWR, Acute: Chronic Workload Ratio; Football Elite, Norwegian Premier League; sRPE = daily session Rating of Perceived Exertion; TL, Training Load.

¹Same day was injury same day as the measured load value; Next 4 days was one or more injuries during the four days after the measured load value; Next micro-cycle was one or more injuries during the micro-cycle after the micro-cycle of the measured load values.

²Daily ACWR 7:21-period was the 7-day acute sRPE divided by previous 21-day chronic sRPE per day; Micro-cycle ACWR 1:3-period was the 1-micro-cycle acute sRPE divided by previous 3-micro-cycle chronic sRPE per micro-cycle. A micro-cycle was defined as all recovery days after the previous match as well as the training days before the next match.

³Due to aggregations, ACWR calculations and injury time-windows, the number of load values and injury events varied between models.

Table S3. Odds ratio with 95% confidence intervals, standard error, degrees of freedom and p-values from modelling the relationship between training load and injury risk using mixed effect models with restricted cubic splines.

Population	Load Definition ¹	Injury Definition ²	Variable	OR ³	CI 2.5%	CI 97.5%	SE	df	p		
Football U-19	sRPE	Same day	Intercept	0.004	<0.001	0.939	2.808	941	0.047		
			Load	1.000	0.997	1.003	0.002	3331	0.837		
			Load'	1.001	0.997	1.004	0.002	3337	0.746		
			Sex Female (Ref)	-	-	-	-	-	-		
			Sex Male	1.163	0.628	2.155	0.314	3286	0.631		
			Age (Years)	1.088	0.800	1.479	0.157	921	0.592		
			Intercept	0.031	<0.001	13.614	3.094	273	0.262		
		Next 4 days	Load	1.001	1.000	1.002	0.001	4253	0.179		
			Load'	0.999	0.998	1.001	0.001	3386	0.502		
			Sex Female (Ref)	-	-	-	-	-	-		
			Sex Male	1.181	0.582	2.400	0.362	4727	0.645		
			Age (Years)	0.973	0.689	1.373	0.175	261	0.874		
			Daily ACWR 7:21-period	Same day	Intercept	0.002	<0.001	1.073	3.233	1088	0.053
					Load	0.778	0.313	1.936	0.465	1896	0.589
	Load'	2.970			0.586	15.057	0.827	1268	0.189		
	Next 4 days	Sex Female (Ref)		-	-	-	-	-	-		
		Sex Male		1.326	0.648	2.716	0.365	2592	0.440		
		Age (Years)		1.118	0.785	1.594	0.181	1131	0.536		
		Intercept		<0.001	<0.001	25.567	6.179	104	0.148		
		Load	4.285	1.241	14.793	0.631	498	0.021			
		Load'	0.032	0.007	0.139	0.745	1565	<0.001			
Sex Female (Ref)		-	-	-	-	-	-				
Sex Male	1.278	0.381	4.283	0.617	2328	0.691					
Age (Years)	1.160	0.594	2.266	0.338	110	0.661					

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Population	Load Definition ¹	Injury Definition ²	Variable	OR ³	CI 2.50 %	CI 97.50 %	SE	df	p	
Football U-19	Micro-cycle ACWR 1:3-period	Next micro-cycle	Intercept	0.041	<0.001	40.086	3.502	396	0.362	
			Load	0.210	0.012	3.536	1.439	562	0.278	
			Load'	8.535	<0.001	6136037	6.857	356	0.755	
			Load''	0.144	<0.001	3.52E+20	25.026	296	0.938	
			Sex Female (Ref)	-	-	-	-	-	-	
			Sex Male	1.107	0.478	2.563	0.427	641	0.812	
			Age (Years)	1.070	0.732	1.563	0.193	358	0.726	
Football Elite	sRPE	Same day	Intercept	0.001	<0.001	0.011	1.437	4480	<0.001	
			Load	1.000	0.995	1.005	0.003	4479	0.897	
			Load'	1.001	0.994	1.008	0.004	4475	0.847	
			Age (Years)	1.096	0.997	1.204	0.048	4480	0.056	
			Intercept	<0.001	<0.001	0.022	2.581	1593	0.001	
		Next 4 days	Load	0.998	0.994	1.003	0.002	168	0.501	
			Load'	1.004	0.997	1.011	0.003	99	0.29	
		Daily ACWR 7:21-period	Same day	Intercept	<0.001	<0.001	0.022	2.465	55	0.001
				Load	3.389	0.042	273.286	2.119	22	0.57
	Load'			0.337	0.004	31.613	2.201	24	0.626	
	Age (Years)			1.104	0.994	1.226	0.053	3833	0.064	
	Next 4 days		Age (Years)	1.186	0.991	1.418	0.091	1662	0.062	
			Intercept	<0.001	<0.001	0.015	3.485	300	0.002	
			Age (Years)	1.202	0.978	1.477	0.105	1349	0.081	
			Load	6.731	0.116	390.17	1.948	20	0.339	
	Micro-cycle ACWR 1:3-period	Next micro-cycle	Load'	0.056	0.001	5.583	2.252	29	0.21	
			Intercept	<0.001	<0.001	0.136	2.841	62	0.009	
Age (Years)			1.113	1.016	1.219	0.046	476	0.021		
Load			7.523	0.030	1881.323	2.742	46	0.466		
Load'			0.340	0.005	22.344	2.113	112	0.610		

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Population	Load Definition ¹	Injury Definition ²	Variable	OR ³	CI 2.50 %	CI 97.50 %	SE	df	p
Handball	sRPE	Same day	Intercept	0.083	0.003	2.711	1.777	1632	0.162
			Load	0.999	0.998	0.999	<0.001	9445	<0.001
			Load'	1.002	1.001	1.003	0.001	2603	<0.001
			Sex Female (Ref)	-	-	-	-	-	-
			Sex Male	1.112	0.780	1.586	0.181	11867	0.556
			Age (Years)	0.963	0.787	1.177	0.102	1740	0.711
		Next 4 days	Intercept	0.606	0.007	54.891	2.297	1270	0.827
			Load	1.000	1.000	1.001	<0.001	39	0.063
			Load'	0.999	0.999	1.000	<0.001	21	0.143
			Sex Female (Ref)	-	-	-	-	-	-
			Sex Male	1.053	0.645	1.719	0.25	11521	0.837
			Age (Years)	0.87	0.67	1.129	0.133	1146	0.294
	Daily ACWR 7:21-period	Same day	Intercept	0.041	0.001	2.833	2.157	3372	0.140
			Load	0.743	0.362	1.523	0.366	1301	0.417
			Load'	1.648	0.687	3.952	0.445	394	0.262
			Sex Female (Ref)	-	-	-	-	-	-
			Sex Male	1.127	0.729	1.741	0.222	8737	0.591
			Age (Years)	0.989	0.776	1.259	0.124	3357	0.926
		Next 4 days	Intercept	0.234	0.001	99.719	3.088	2022	0.638
			Load	2.006	1.006	4.002	0.348	98	0.048
			Load'	0.292	0.133	0.643	0.395	70	0.003
		Sex Female (Ref)	-	-	-	-	-	-	
		Sex Male	1.316	0.708	2.449	0.317	7490	0.385	
		Age (Years)	0.886	0.624	1.257	0.179	1426	0.497	

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Population	Load Definition ¹	Injury Definition ²	Variable	OR ³	CI 2.50 %	CI 97.50 %	SE	df	p
Handball	Micro-cycle ACWR 1:3-period	Next micro-cycle	Intercept	0.165	0.003	9.425	2.062	1450	0.382
			Load	0.878	0.397	1.939	0.404	955	0.747
			Load'	1.335	0.599	2.976	0.408	969	0.479
			Sex Female (Ref)	-	-	-	-	-	-
			Sex Male	0.908	0.596	1.384	0.215	1551	0.654
			Age (Years)	1.004	0.795	1.267	0.119	1313	0.976

Abbreviations: ACWR, Acute: Chronic Workload Ratio; CI, 95% Confidence Intervals; df, Degrees of Freedom; Football Elite, Norwegian Premier League; OR, Odds Ratio; SE, Standard Error; sRPE, daily session Rating of Perceived Exertion.

¹Daily ACWR 7:21-period was the 7-day acute sRPE divided by previous 21-day chronic sRPE per day; Micro-cycle ACWR 1:3-period was the 1-micro-cycle acute sRPE divided by previous 3-micro-cycle chronic sRPE per micro-cycle. A micro-cycle was defined as all recovery days after the previous match as well as the training days before the next match.

²Same day was injury same day as the measured load value; Next 4 days was one or more injuries during the four days after the measured load value; Next micro-cycle was one or more injuries during the micro-cycle after the micro-cycle of the measured load values.

³As load was fitted with cubic splines, the effect-size, Odds Ratio, is uninterpretable for this parameter.

Table S4. Odds ratio with 95% confidence intervals, standard error, degrees of freedom and p-values from modelling the relationship between training load and injury risk using mixed effect logistic regression models which assume linearity.

Population	Load Definition ¹	Injury Definition ²	Variable	OR	CI 2.5%	CI 97.5%	SE	df	p		
Football U-19	sRPE	Same day	Intercept	0.003	<0.001	0.795	2.781	942	0.041		
			Load	1.000	0.999	1.001	<0.001	3338	0.755		
			Sex Female (Ref)	-	-	-	-	-	-		
					Sex Male	1.165	0.629	2.156	0.314	3287	0.627
					Age (Years)	1.088	0.800	1.478	0.156	922	0.591
		Next 4 days	Intercept	0.034	<0.001	15.046	3.099	263	0.275		
			Load	1.000	1.000	1.001	<0.001	3015	0.067		
			Sex Female (Ref)	-	-	-	-	-	-		
					Sex Male	1.186	0.585	2.406	0.361	4759	0.636
				Age (Years)	0.969	0.686	1.369	0.175	256	0.86	
	Daily ACWR 7:21-period	Same day	Intercept	0.001	<0.001	0.405	3.181	1341	0.025		
			Load	1.346	0.859	2.107	0.228	492	0.194		
			Sex Female (Ref)	-	-	-	-	-	-		
					Sex Male	1.329	0.645	2.737	0.368	2601	0.440
					Age (Years)	1.139	0.798	1.625	0.181	1289	0.473
		Next 4 days	Intercept	0.003	<0.001	98.996	5.313	108	0.266		
			Load	1.312	0.633	2.722	0.372	1744	0.465		
			Sex Female (Ref)	-	-	-	-	-	-		
				Sex Male	1.408	0.478	4.147	0.551	2514	0.535	
			Age (Years)	1.052	0.583	1.899	0.298	108	0.865		

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Population	Load Definition ¹	Injury Definition ²	Variable	OR	CI 2.5%	CI 97.5%	SE	df	p		
Football U-19	Micro-cycle ACWR 1:3-period	Next micro-cycle	Intercept	0.013	<0.001	10.059	3.396	331	0.199		
			Load	0.850	0.324	2.232	0.492	534	0.741		
			Sex Female (Ref)	-	-	-	-	-	-		
			Sex Male	1.088	0.475	2.492	0.422	645	0.842		
			Age (Years)	1.079	0.738	1.577	0.193	299	0.694		
Football Elite	sRPE	Same day	Intercept	0.001	<0.001	0.008	1.344	4481	<0.001		
			Load	1.000	0.999	1.002	0.001	4481	0.867		
			Age (Years)	1.096	0.998	1.204	0.048	4481	0.055		
			Next 4 days	Intercept	<0.001	<0.001	0.014	2.572	1412	<0.001	
				Load	1.001	0.998	1.003	0.001	15	0.484	
		Age (Years)		1.189	0.994	1.422	0.091	1662	0.058		
		Daily ACWR 7:21-period	Same day	Intercept	<0.001	<0.001	0.008	1.555	3576	<0.001	
				Load	1.255	0.459	3.427	0.512	552	0.658	
				Age (Years)	1.102	0.994	1.222	0.052	3847	0.064	
				Next 4 days	Intercept	<0.001	<0.001	0.042	2.952	1288	0.002
					Load	0.739	0.253	2.165	0.539	70	0.577
		Handball	sRPE	Next micro-cycle	Intercept	0.001	<0.001	0.036	1.665	186	<0.001
					Load	2.183	0.350	13.625	0.910	47	0.396
					Age (Years)	1.115	1.018	1.221	0.046	476	0.019
					Same day	Intercept	0.063	0.002	2.082	1.782	1673
Load	1.000					1.000	1.000	0.000	7341	0.240	
Same day	Sex Female (Ref)			-	-	-	-	-	-		
	Sex Male			1.124	0.788	1.604	0.181	11869	0.519		
	Age (Years)			0.953	0.779	1.166	0.103	1739	0.638		

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Population	Load Definition ¹	Injury Definition ²	Variable	OR	CI 2.5%	CI 97.5%	SE	df	p		
Handball	sRPE	Next 4 days	Intercept	0.603	0.006	56.793	2.317	1367	0.827		
			Load	1.000	1.000	1.000	<0.001	64	0.348		
			Sex Female (Ref)	-	-	-	-	-	-		
			Sex Male	1.045	0.641	1.705	0.250	11524	0.859		
			Age (Years)	0.873	0.671	1.135	0.134	1420	0.310		
			Intercept	0.030	<0.001	2.084	2.159	2373	0.105		
	Daily ACWR 7:21-period	Same day	Same day	Load	1.106	0.846	1.445	0.136	204	0.459	
				Sex Female (Ref)	-	-	-	-	-	-	
				Sex Male	1.129	0.730	1.748	0.223	8738	0.585	
				Age (Years)	0.988	0.775	1.260	0.124	3373	0.921	
				Intercept	0.535	0.001	233.805	3.098	899	0.840	
				Load	0.895	0.599	1.338	0.203	118	0.587	
		Next 4 days	Next 4 days	Next 4 days	Sex Female (Ref)	-	-	-	-	-	-
					Sex Male	1.319	0.710	2.452	0.316	7582	0.381
					Age (Years)	0.874	0.615	1.243	0.179	796	0.454
					Intercept	0.141	0.002	12.674	2.293	1448	0.393
					Load	1.125	0.716	1.769	0.230	771	0.609
					Sex Female (Ref)	-	-	-	-	-	-
Micro-cycle ACWR 1:3-period	Next micro-cycle	Next micro-cycle	Sex Male	0.908	0.567	1.453	0.240	1552	0.686		
			Age (Years)	1.002	0.773	1.300	0.133	1404	0.986		

Abbreviations: ACWR, Acute: Chronic Workload Ratio; CI, 95% Confidence Intervals; df, Degrees of Freedom; Football Elite, Norwegian Premier League; OR, Odds Ratio; SE, Standard Error; sRPE, daily session Rating of Perceived Exertion.

¹Daily ACWR 7:21-period was the 7-day acute sRPE divided by previous 21-day chronic sRPE per day; Micro-cycle ACWR 1:3-period was the 1-micro-cycle acute sRPE divided by previous 3-micro-cycle chronic sRPE per micro-cycle. A micro-cycle was defined as all recovery days after the previous match as well as the training days before the next match.

²Same day was injury same day as the measured load value; Next 4 days was one or more injuries during the four days after the measured load value; Next micro-cycle was one or more injuries during the micro-cycle after the micro-cycle of the measured load values.

Figures

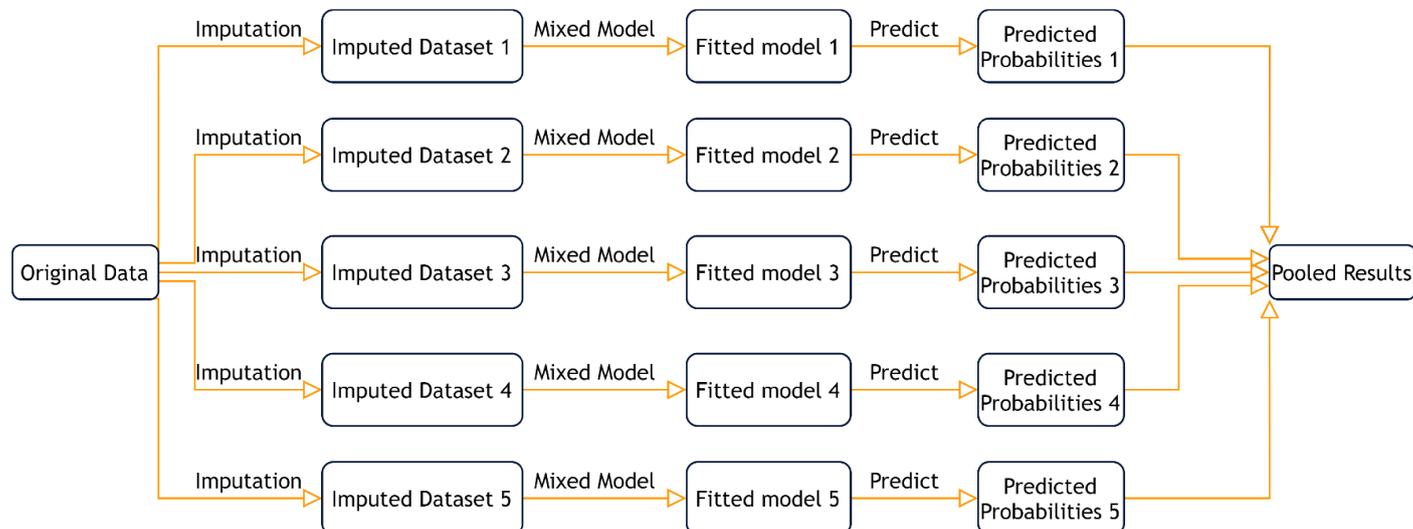


Figure S1. Illustration of the modelling process in the framework of multiple imputation. Following the recommendations in “Flexible Imputation of Missing Data, Second Edition” by Stef van Buuren,¹ which is also available online.² Missing load and age values were predicted and imputed using predictive mean matching.³ All non-derived variables were used to predict imputed values, including age, sex, player position, training activity type among others. The response variable, injury, was also used to predict imputed values,⁴ but was not itself imputed before analysis (guides in Van Buuren¹ 6.3.2, 6.4.1).⁵ The number of imputed datasets, five, is recommended in most cases (Van Buuren section 2.8).¹ A mixed logistic regression model was run on each dataset, returning five fitted models. Each model was used to make predictions, and the mean of the predicted probabilities was used in final visualization, then the model parameters were pooled using Rubin’s rules.⁶

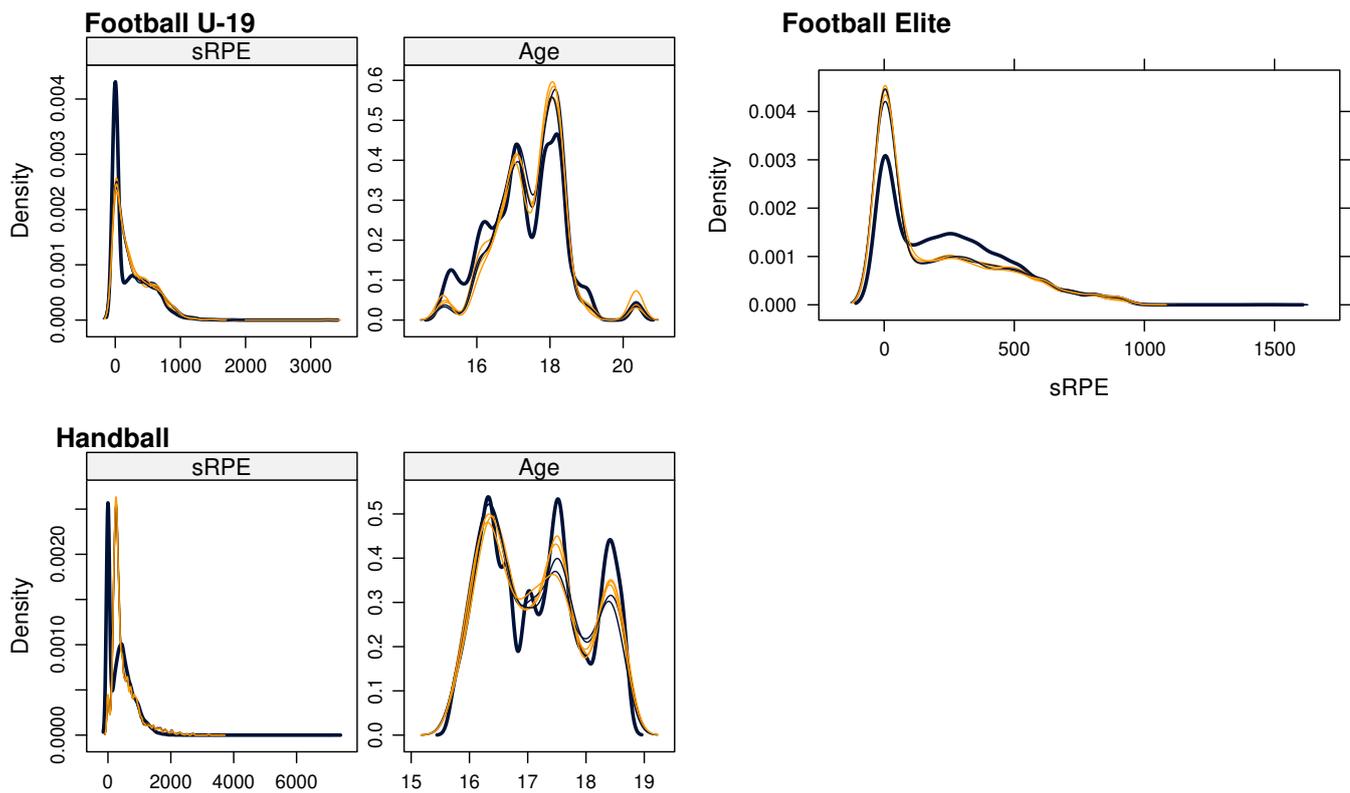


Figure S2. Distribution of real data values (blue) compared to imputed values from five imputed datasets (yellow) for the session Rating of Perceived Exertion (sRPE) measured in arbitrary units, and Age (years) in the Norwegian elite U-19 football dataset (Football U-19), the Norwegian Premier League dataset (Football Elite), and the Norwegian elite youth handball dataset. The Norwegian Premier League dataset had no missing age values.

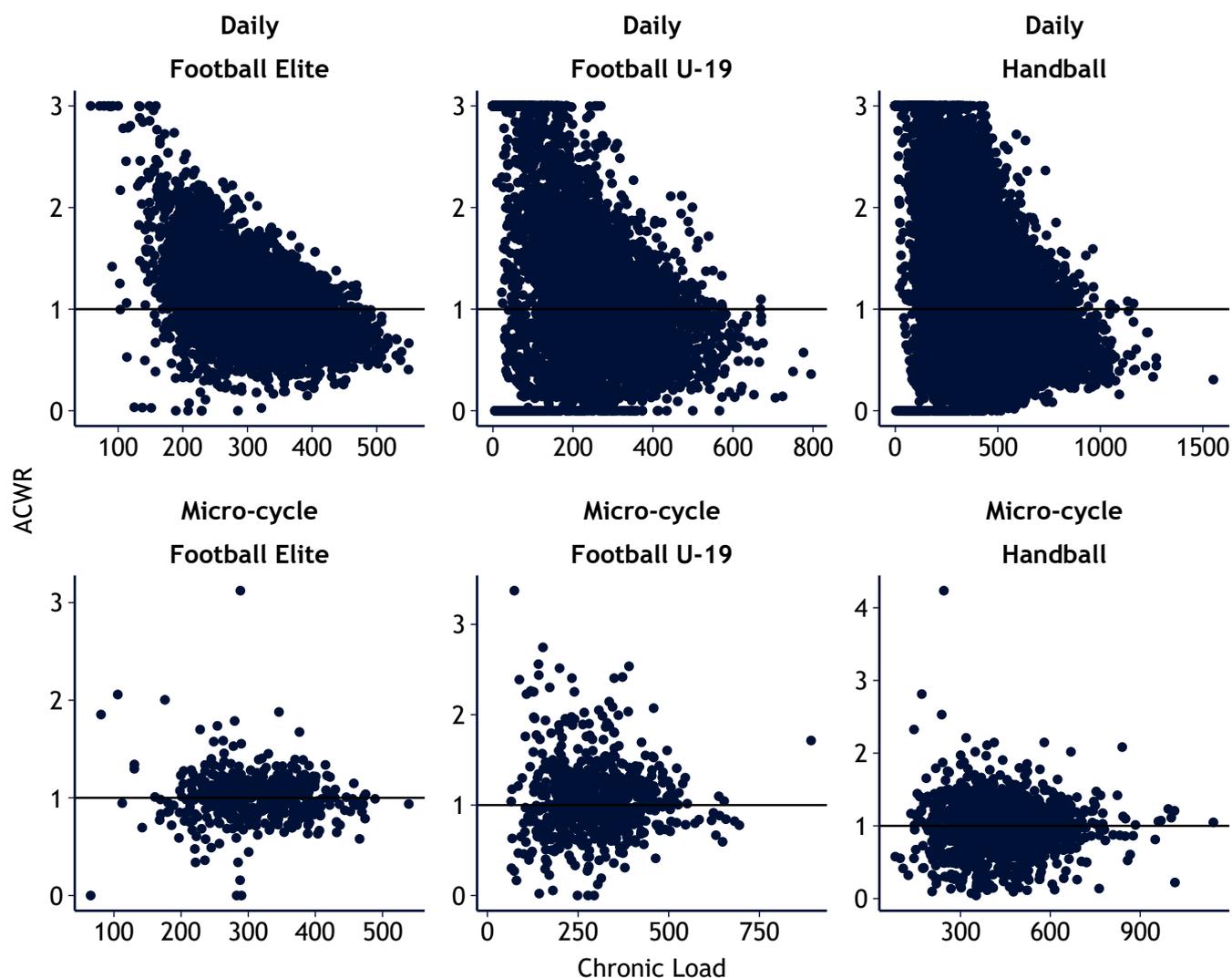


Figure S3. Scatterplot of Acute:Chronic Workload Ratio (ACWR) value vs. corresponding chronic load value (the denominator) in the Norwegian Premier League football dataset (Football Elite), the Norwegian elite U-19 football dataset (Football U-19), and Norwegian elite youth handball dataset (Handball). When computing a ratio, one assumes that there is no relationship between the ratio and the denominator after controlling for the denominator; a ratio is only effective when the relationship between the numerator and the denominator is a straight line that intersects the origin.⁷ For micro-cycle ACWR, the assumption is upheld, while for daily ACWR, the assumption is violated.

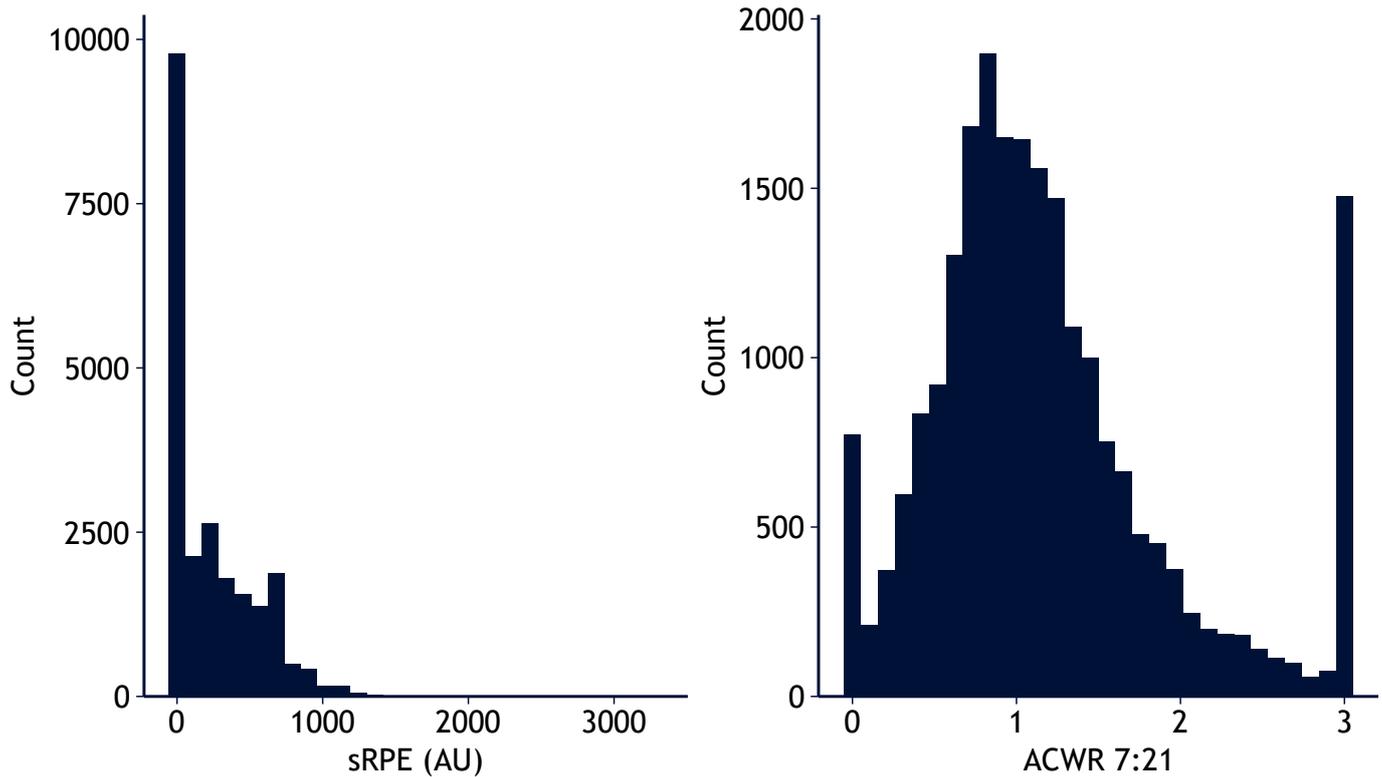


Figure S4. Distribution of the session Rating of Perceived Exertion (sRPE) reported in arbitrary units (AU), and distribution of the 7-day Acute Workload divided by 21-Chronic Workload (ACWR 7:21), from the Norwegian elite U-19 football data used as basis for simulations.

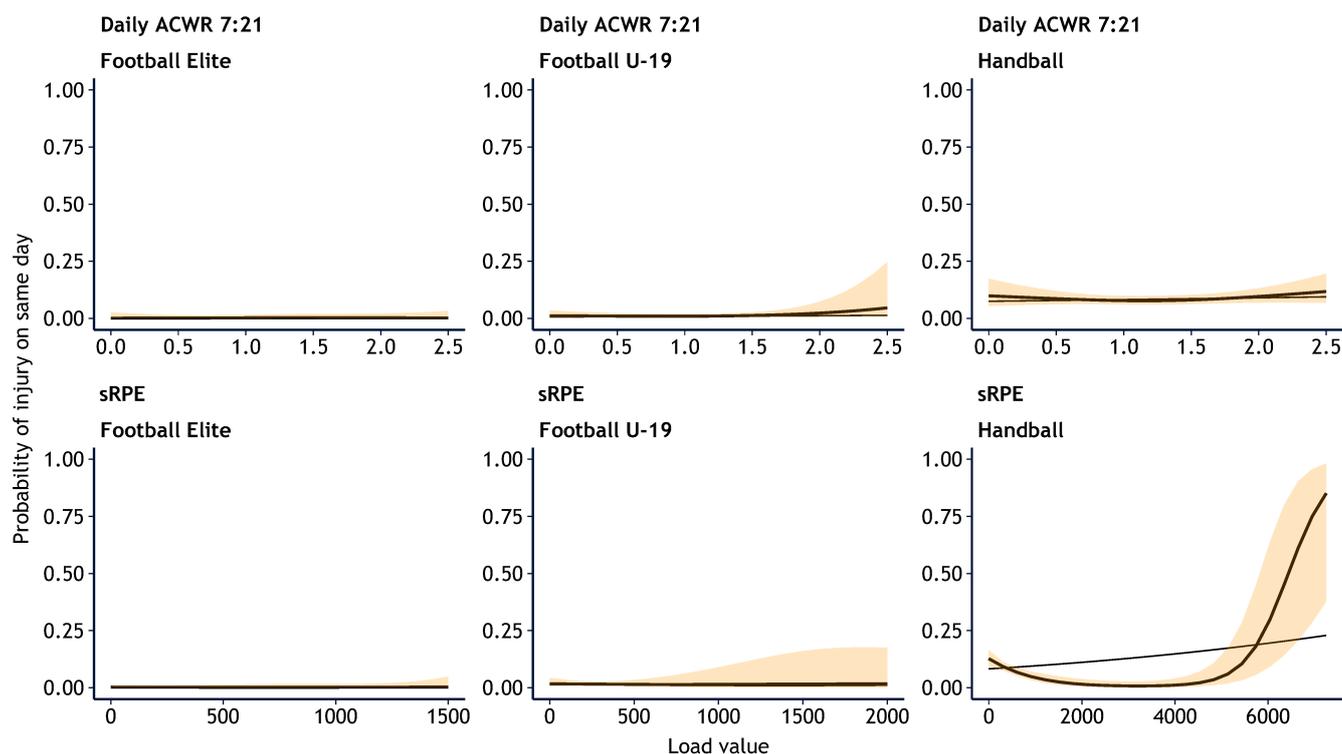


Figure S5. Probability of injury on the same day for each level of session Rating of Perceived Exertion (sRPE) and level of daily Acute:Chronic Workload Ratio (ACWR), in Norwegian Premier League (Football Elite), Norwegian elite U-19 football (Football U-19), and Norwegian elite youth handball (Handball). Probabilities are predicted by mixed-effects logistic regression models with restricted cubic splines. The yellow area represents 95% confidence intervals around predicted values. The straight line shows the same predictions from an equivalent model without splines (i.e. assuming linearity).

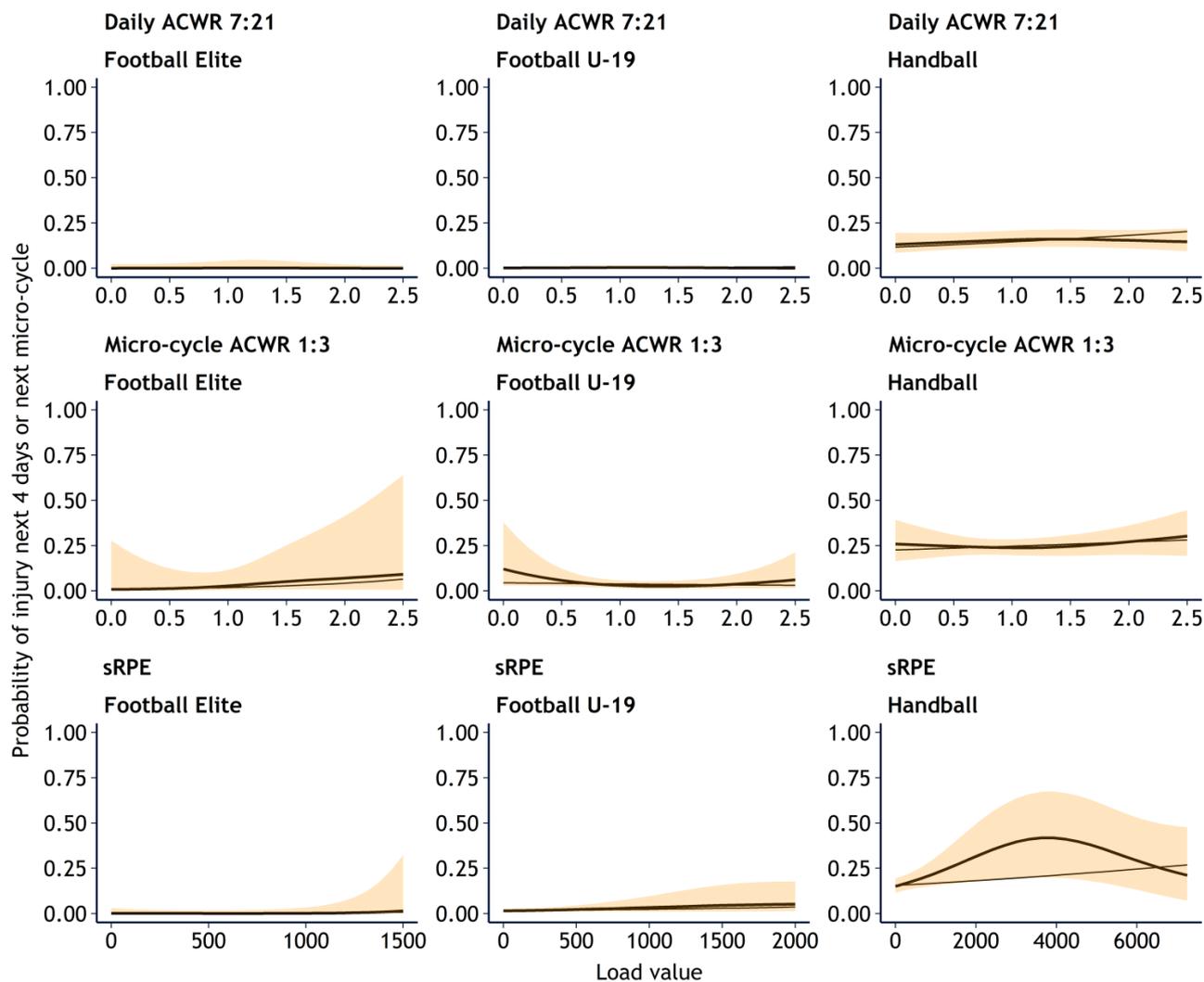


Figure S6. Probability of injury in the future for each level of daily Acute:Chronic Workload Ratio (ACWR), level of Micro-cycle ACWR, and level of session Rating of Perceived Exertion (sRPE), in Norwegian Premier League (Football Elite), Norwegian elite U-19 football (Football U-19), and Norwegian elite youth handball (Handball). Future injury was defined as any injury occurring during the next 4 days for all models except micro-cycle models, where future injury was defined as any injury occurring during the next micro-cycle. Probabilities are predicted by mixed-effects logistic regression models with restricted cubic splines. The yellow area represents 95% confidence intervals around predicted values. The straight line shows the same predictions from an equivalent model without splines (i.e. assuming linearity).

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