Supplementary I: Results

FIGURES

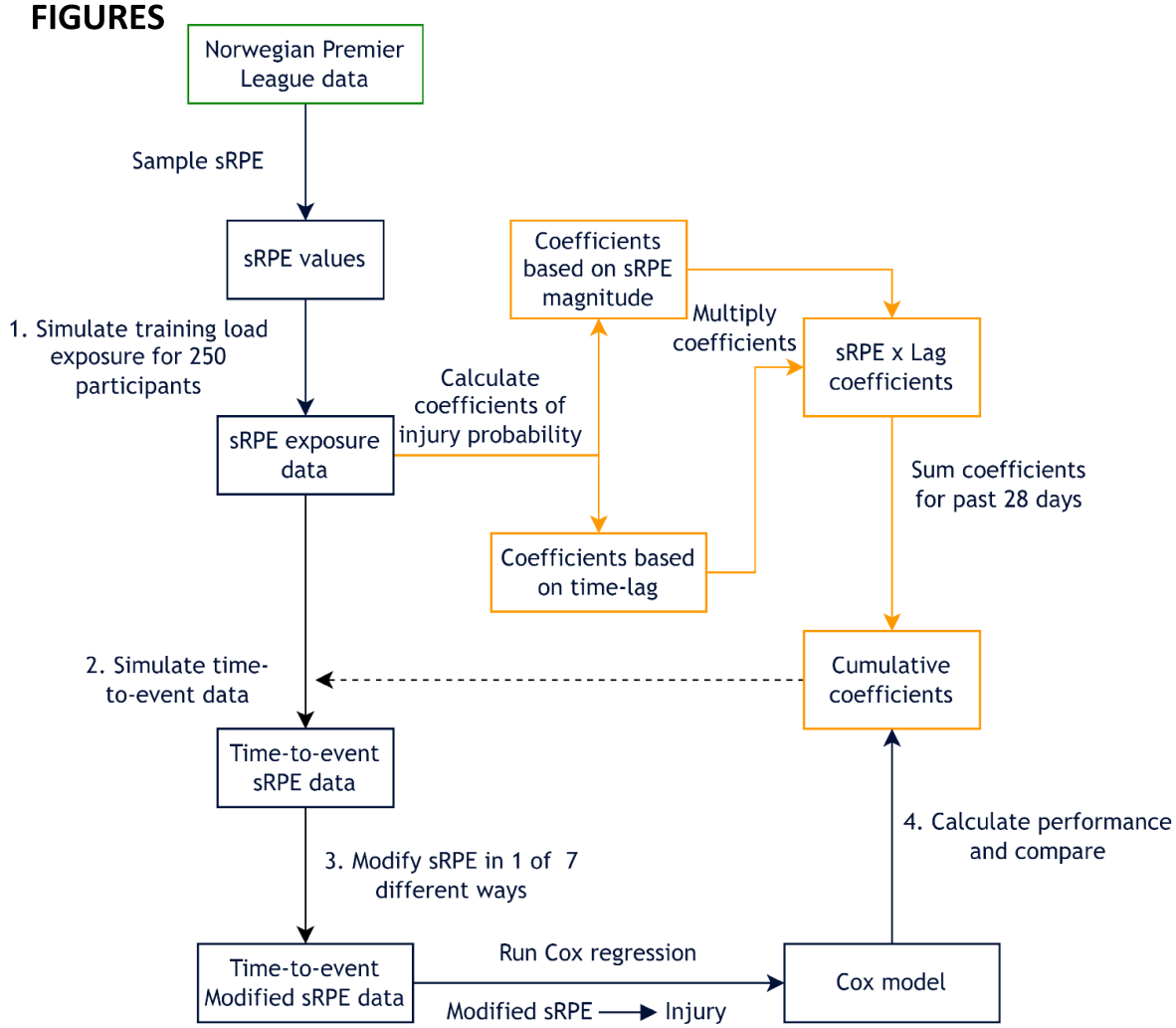

Figure S1. Summary of the simulation workflow. In Step 1, training load exposure measured by session Rating of Perceived Exertion (sRPE) was extracted from the Norwegian Premier League dataset and used to simulate training load exposure for 250 participants across 300 days. In Step 2, injury probabilities were calculated based on the cumulative training load observed the last 28 days; a combination of effect from both the magnitude of the training load (level of sRPE or %ΔsRPE) and the time since the training load occurred. Injuries were simulated based on these probabilities to generate time-to-event data. In Step 3, the absolute and relative training load exposures were modified and modelled in seven different Cox regression models. Finally, in Step 4, performance measures were calculated, and the accuracy of the different Cox models to detect the simulated relationship was assessed. Steps 1–4 were repeated 1 900 times for each of seven different simulated relationships (four for sRPE and three for %ΔsRPE) and each of seven methods.

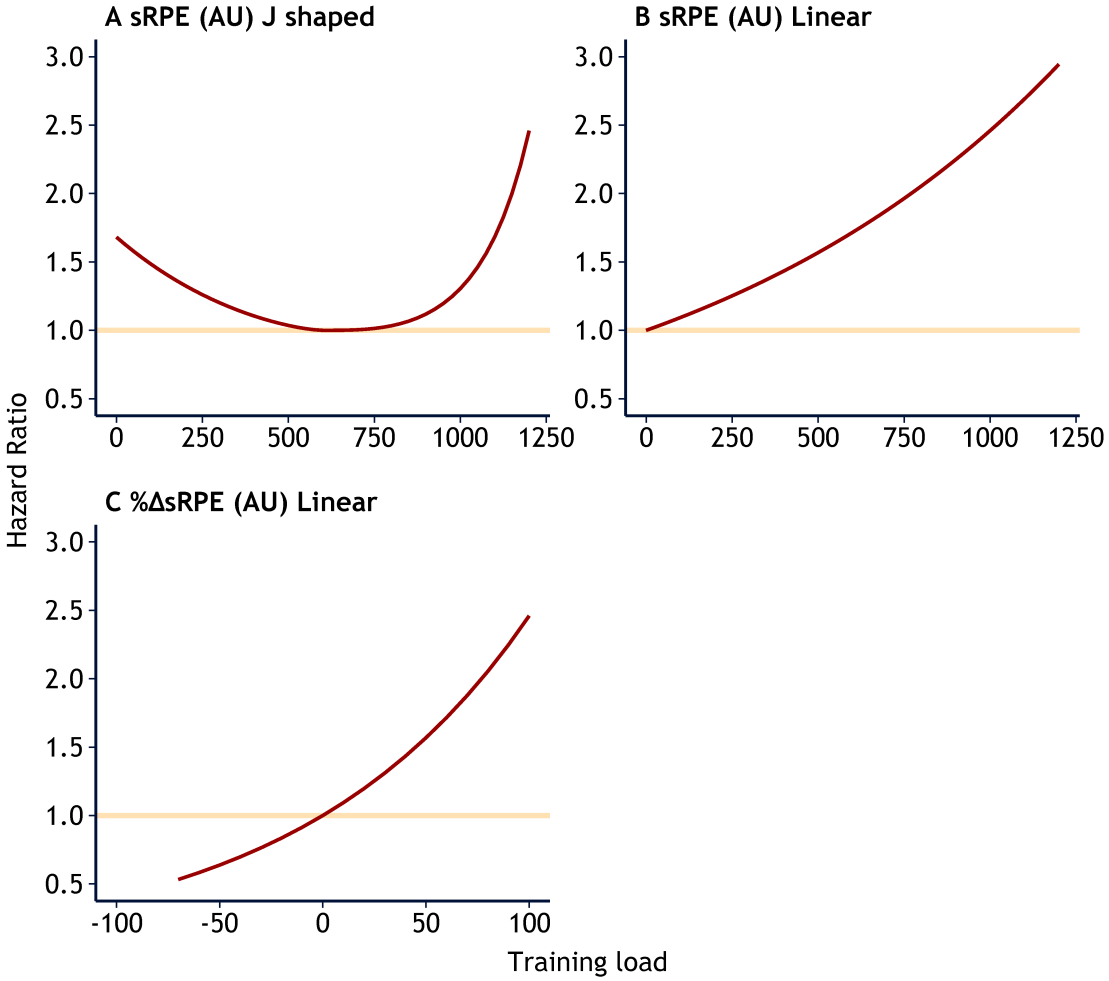

Figure S2. The simulated relationships between training load and injury risk, independent of the time since the training load exposure. Injury risk is measured by the Hazard Ratio (HR), where values > 1 (above the yellow line) indicates an increased risk and values < 1 (below the yellow line) indicates a decreased risk. Shown for (A–B) the absolute training load measured by the session Rating of Perceived Exertion (sRPE) measured in Arbitrary Units (AU), and (C) the relative training load compared to the previous day measured by the symmetrized percentage difference (%Δ) in sRPE. The absolute training load exposure was simulated with two different relationships, one J-shaped (A), and one linear (B).

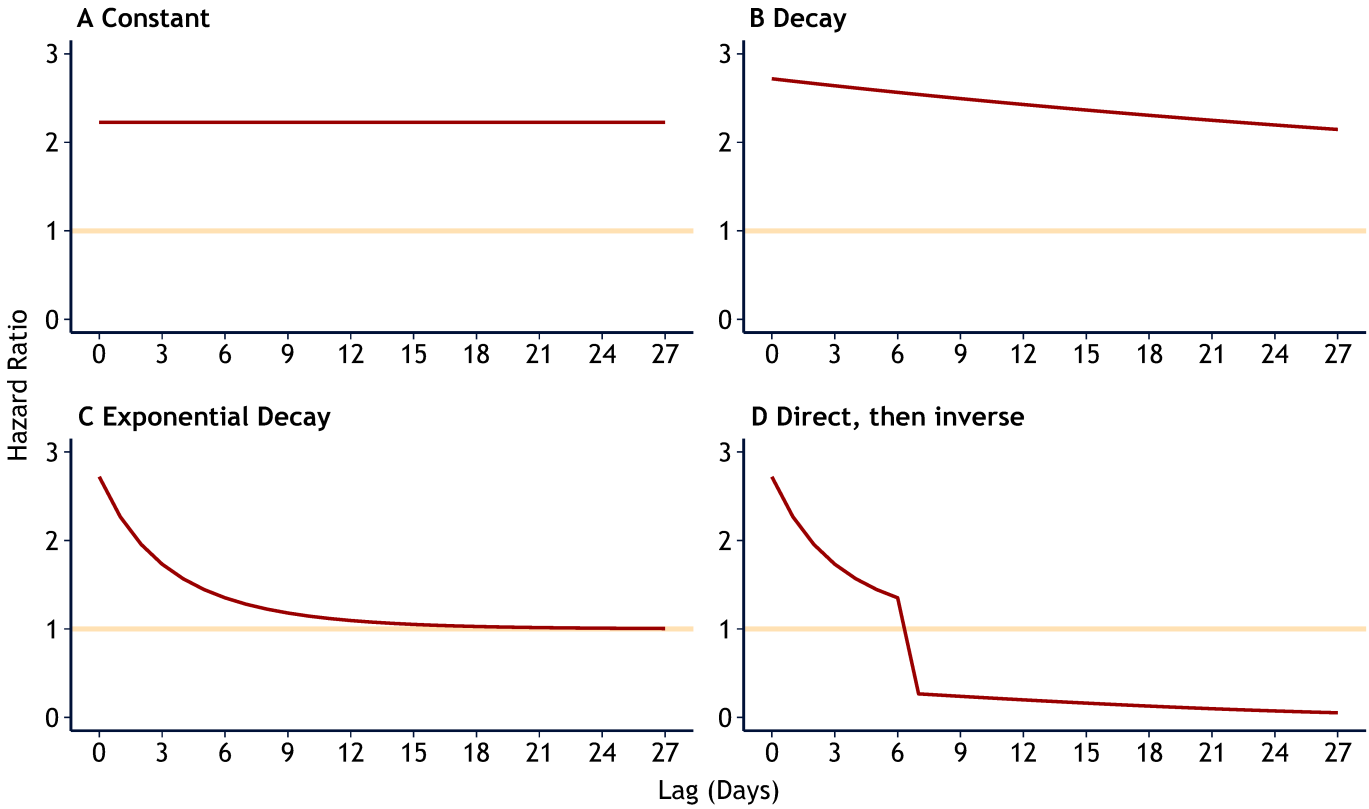

Figure S3. The simulated relationships between the time since current day (Day 0) that the training load exposure was sustained, and injury risk. Injury risk is measured by the Hazard Ratio (HR), where values > 1 (above the yellow line) indicates an increased risk and values < 1 (below the yellow line) indicates a decreased risk. The four risk shapes were (A) Constant, where the risk of training load is constant over time; (B) Decay, where the effect-size of the effect of training load is at its highest on the current day (Day 0) and is reduced for each lag day back in time; (C) Exponential Decay, where the risk of training load is at its highest on the current day (Day 0) and is reduced exponentially for each lag day back in time; (D) Direct, then inverse; where training load increases injury risk during the current week (Day 0–Day 6), but decreases injury risk thereafter. Training load had no effect after the 27th lag day (4 weeks) in all four scenarios (not shown).

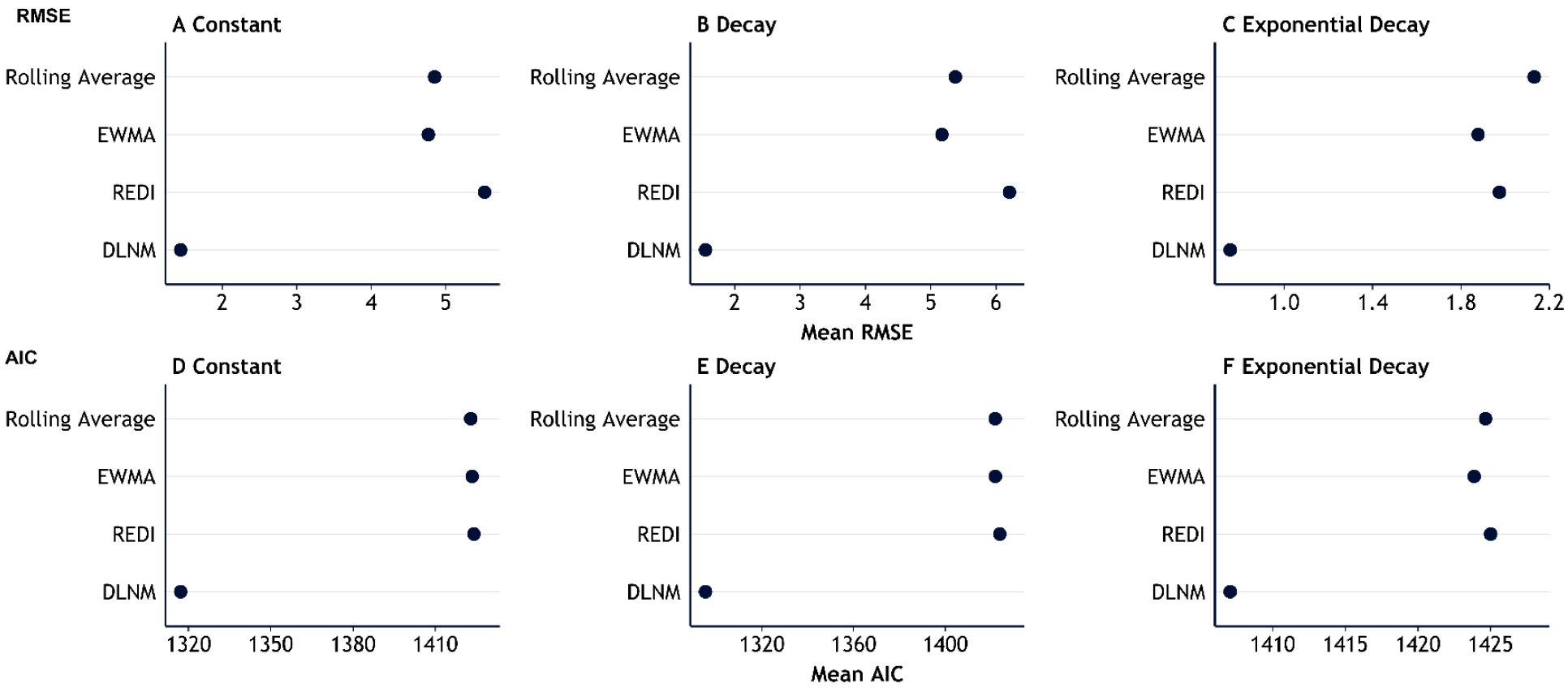

Figure S4. The mean Root-Mean-Squared Error (RMSE) and mean Akaike's Information Criterion (AIC) across 1 900 simulations of estimating the effect of absolute training load on injury risk. Due to variation in the effect sizes, calculations yield different scales for RMSE and AIC (x-axis) between relationship shapes; they cannot be compared between the three shapes, only within each shape. EWMA = Exponentially Weighted Moving Average; DLNM = Distributed Lag Non-Linear Model; REDI = Robust Exponential Decreasing Index. RMSE is calculated on the difference between the predicted risk and the simulated, true risk (External RMSE).

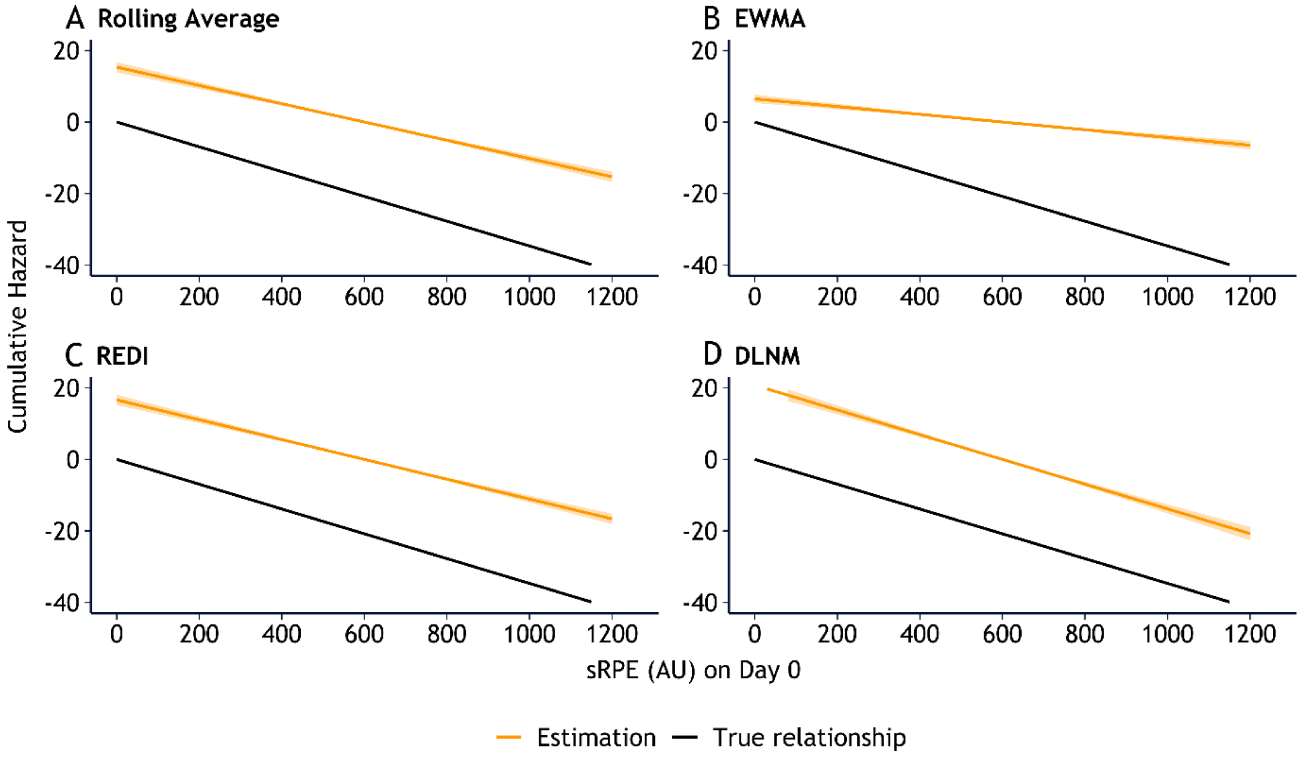

Figure S5. The relationship between absolute training load measured by the session Rating of Percieved Exertion (sRPE) in arbitrary units (AU) and the risk of injury on the current day (Day 0) estimated by four different methods (yellow line), compared with the simulated, true relationship (black line). The relationship scenario was "Direct, then inverse", where training load increases injury risk during the current week (Day 0–Day 6), but decreases injury risk thereafter (Day 7–Day 27). The Y axis denotes the cumulative hazard – the sum of all instantaneous risks of injury from the past up until the current day. Methods used to detect these effects were (A) the Rolling Average, (B) the Exponential Weighted Moving Average (EWMA), (C) The Robust Exponential Decreasing Index (REDI), and (D) the Distributed Lag Non-Linear Model (DLNM). Yellow bands are 95% confidence intervals. The figure shows 1 random simulation of 1 900 performed.

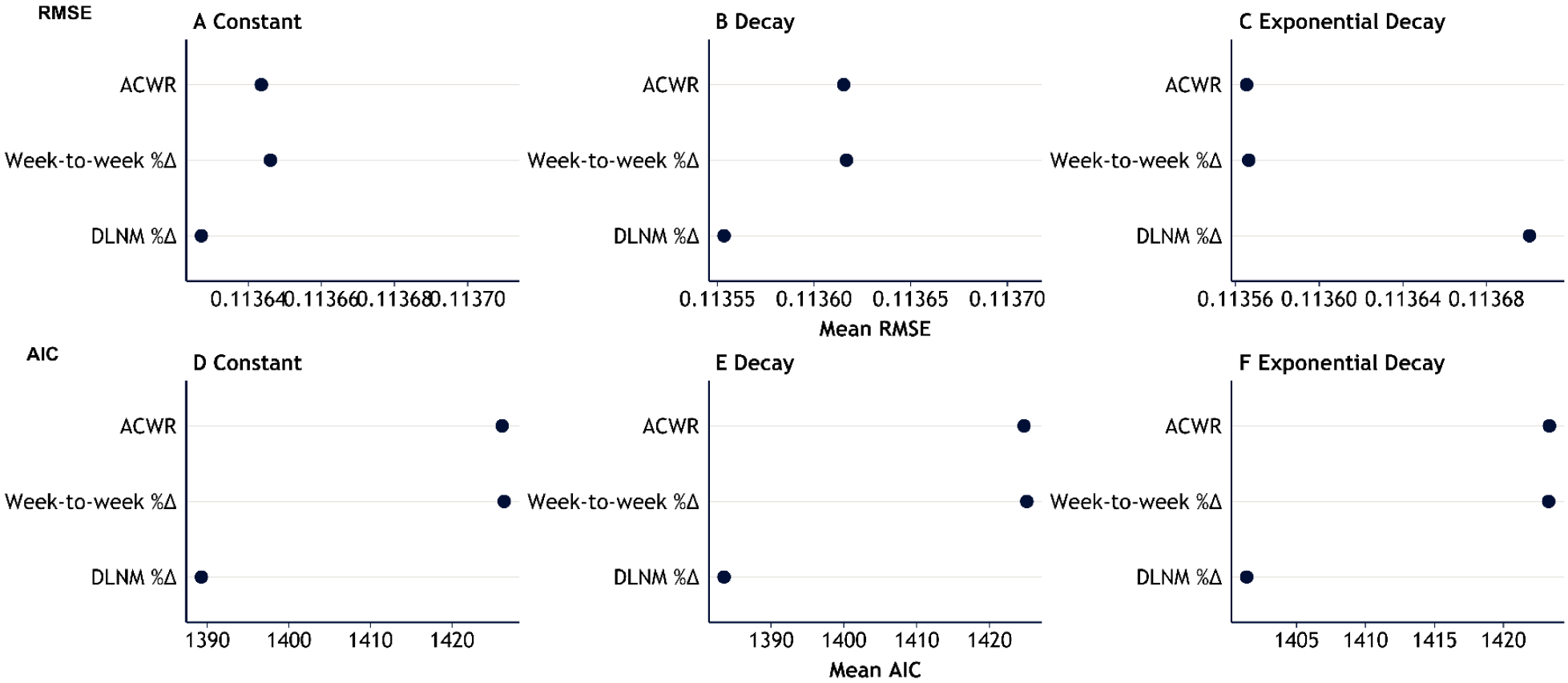

Figure S6. The mean Root-Mean-Squared Error (RMSE) and mean Akaike's Information Criterion (AIC) across 1 900 simulations of estimating the effect of relative training load on injury risk. Due to variation in the effect sizes, calculations yield different scales for RMSE and AIC (x-axis) between relationship shapes; they cannot be compared between the three shapes, only within each shape. ACWR = Acute:Chronic Workload Ratio; DLNM = Distributed Lag Non-Linear Model. RMSE is calculated on the model residuals (Internal RMSE).

TABLES

Table S1. The percentage of 1 900 simulations where methods of absolute training load had the lowest RMSE and AIC (Rank 1), had the 2nd lowest RMSE and AIC (Rank 2), and so on.

Metric	Lag scenario	Rank	Rolling Average (%)	EWMA (%)	REDI (%)	DLNM (%)
RMSE	Constant	1	2	1	0	97
		2	31	45	22	2
		3	52	27	21	1
		4	15	27	58	0
	Decay	1	1	1	0	98
		2	29	48	21	2
		3	54	26	19	0
		4	15	25	60	0
	Exponential Decay	1	11	13	13	63
		2	19	28	26	27
		3	36	27	29	8
		4	34	31	32	3
	Direct, then inverse	1	0	0	1	99
		2	0	0	99	1
		3	100	0	0	0
		4	0	100	0	0
AIC	Constant	1	0	0	0	100
		2	31	39	31	0
		3	58	24	18	0
		4	11	38	51	0
	Decay	1	0	0	0	100
		2	31	45	24	0
		3	59	24	17	0
		4	10	31	59	0
	Exponential Decay	1	1	1	1	97
		2	19	52	28	2
		3	55	22	23	0
		4	26	25	48	1
	Direct, then inverse	1	0	0	0	100
		2	0	0	100	0
		3	100	0	0	0
		4	0	100	0	0

Abbreviations: AIC = Akaike's Information Criterion; EWMA = Exponentially Weighted Moving Average; DLNM = Distributed Lag Non-Linear Model; REDI = Robust Exponential Decreasing Index; RMSE = Root-Mean-Squared Error

Table S2. Mean performance of methods used to estimate the effect of absolute training load on injury risk under the "Direct, then inverse" scenario.

	Rolling Average	EWMA	REDI	DLNM
External RMSE[1]	21.1	22.6	20.9	20.8
Internal RMSE	0.111	0.113	0.106	0.101
AIC	1116	1373	910	790
Coverage[1]	0%	0%	0%	0%
AW	1.48	1.25	1.56	1.94

Abbreviations: AIC = Akaike's Information Criterion; AW = Average Width of 95% confidence intervals; Coverage = Coverage of 95% confidence intervals; EWMA = Exponentially Weighted Moving Average; DLNM = Distributed Lag Non-Linear Model; REDI = Robust Exponential Decreasing Index; RMSE = Root-Mean-Squared Error

[1] Monte Carlo Standard Error was < 0.001 for RMSE, and 0.5 for coverage of 95% confidence intervals for all methods.

Table S3. The percentage of 1 900 simulations where methods of relative training load had the lowest RMSE and AIC (Rank 1), had the 2nd lowest RMSE and AIC (Rank 2), and so on.

Metric	Lag scenario	Rank	ACWR (%)	Week-to-week %Δ (%)	DLNM %Δ (%)
RMSE	Constant	1	25	23	52
		2	49	49	2
		3	26	29	46
	Decay	1	23	21	57
		2	50	48	2
		3	28	31	41
	Exponential Decay	1	31	29	41
		2	48	50	2
		3	22	21	57
AIC	Constant	1	0	0	100
		2	56	44	0
		3	44	56	0
	Decay	1	0	0	100
		2	59	41	0
		3	41	59	0
	Exponential Decay	1	1	1	99
		2	49	51	0.5
		3	52	49	0.9

Abbreviations: ACWR = Acute:Chronic Workload Ratio; AIC = Akaike's Information Criterion; DLNM = Distributed Lag Non-Linear Model; RMSE = Root-Mean-Squared Error

Table S4. The model coefficients from a Cox regression estimating the relationship between training load and risk of injury in a handball cohort (n players = 205, n injuries = 472).

Term[12]	HR	95% CI Lower–Upper	SE	DF	p-value
sRPE 1	0.80	0.11–5.70	0.897	11.758	0.81
sRPE 2	0.99	0.87–1.13	0.059	11.909	0.88
sRPE 3	0.77	0.01–99.10	2.259	13.435	0.91
sRPE 4	0.96	0.70–1.33	0.150	13.445	0.81
Age	0.97	0.79–1.21	0.109	456.684	0.80
Sex					
Female (Reference)	-	-	-	-	-
Male	1.13	0.781-1.641	0.189	462.46	0.51

Abbreviations: CI = Confidence Interval; df = Degrees of Freedom; HR = Hazard Ratio; SE = Standard Error; sRPE = session Rating of Perceived Exertion

[1]The frailty term for within-individual variance was significant at $p < 0.00001$

[2]The sRPE terms are the four intervals demarcated by 3 knots in the restricted cubic splines