



Figure 1. Flow diagram of the study, dataset and estimate selection process.

[Footnote]

*Refer to Table 2.

**estimates from the same study describing the same relationship for a grouped construct (e.g. TRIMP vs TD using both Banisters TRIMP and Edwards TRIMP, or using separate within-athlete and partial correlation analyses) or training mode (e.g. all training modes combined and within a discrete training mode metabolic conditioning)

***< 2 datasets from < 2 independent studies describing a relationship between internal and external load/intensity.

Abbreviations: sRPE: session rating of perceived exertion, sRPE-TL: session rating of perceived exertion training load, TRIMP: heart-rate-derived training impulse, TD: total distance covered, HSRD: distance covered at high speeds ($\geq 13.1\text{--}15.0\text{ km}\cdot\text{h}^{-1}$), VHSRD: distance covered at very high speeds ($\geq 16.9\text{--}19.8\text{ km}\cdot\text{h}^{-1}$), AL: accelerometer-derived load, Impacts: total number of sustained impacts ($> 2\text{--}5\text{ G}$).

Table 1. Database search strategy.

Search Term	Keywords
1. Team-sport	team-sport OR soccer OR "soccer player*" OR footballer* OR "football player*" OR futsal OR "futsal player*" OR rugby OR "rugby football*" OR "rugby player*" OR "rugby football player*" OR "rugby union" OR "rugby union player*" OR "rugby league" OR "rugby league player*" OR "Australian rules football*" OR "Australian football*" OR "Australian rules football player*" OR "Australian football player*" OR "Gaelic football*" OR "Gaelic football player*" OR hurling OR "hurling player*" OR hurler* OR basketball OR basketballer* OR "basketball player*" OR handball* OR "handball player*" OR handballer* OR hockey OR "hockey player*" OR lacrosse OR "lacrosse player*" OR netball OR "netball player*" OR netballer*
2. Internal load	"internal load*" OR "internal training load*" OR "internal TL" OR "internal intensit*" OR "internal work*" OR "perceived exertion" OR RPE OR sRPE OR "s-RPE" OR "sRPE-TL" OR dRPE OR "d-RPE" OR "RPE-B" OR "RPEres" OR "RPE-L" OR "RPEmus" OR "subjective intensit*" OR "perceived intensit*" OR "subjective load*" OR "perceived load*" OR "subjective training load*" OR "perceived training load*" OR "Heart rate" OR HR OR "HRmax" OR %HRmax OR "HRpeak" OR %HRpeak OR "HRmean" OR "Training impulse" OR TRIMP OR iTRIMP OR "Summated heart rate zones" OR "Summated HR zones" OR SHRZ
3. External load	"external load*" OR "external training load*" OR "external TL" OR "external intensit*" OR "external work*" OR workload* OR "physical performance*" OR "physical demand*" OR "match performance*" OR "match demand*" OR "match activit*" OR "match intensit*" OR "game performance*" OR "game demand*" OR "game activit*" OR "game intensit*" OR "training performance*" OR "training demand*" OR "training activit*" OR "training intensit*" OR "training output*" OR "tracking system*" OR "video" OR "camera*" OR "time-motion" OR "image recognition system" OR "match analysis system" OR "notational analysis" OR "multi-camera system*" OR "global positioning system*" OR GPS OR "micromechanical-electrical system*" OR MEMS OR microsensor* OR microtechnology OR accelerometry OR "inertial measurement unit*" OR IMU OR distance* OR TD OR meters OR "low-speed*" OR LSR OR LSA OR "low-intensit*" OR LIR OR LIA OR "high-speed*" OR HSR OR HSA OR "high-intensit*" OR HIR OR HIA OR "maximal-speed*" OR "maximal-intensit*" OR "maximal-effort*" OR sprint* OR "repeated sprint*" OR "repeated high-intensity effort*" OR RHIE OR "repeated maximal effort*" OR "repeated maximal bout*" OR velocit* OR speed* OR "work:rest" OR "work-to-rest" OR accelerat* OR decelerat* OR impact* OR tackl* OR collision OR "accelerometer load*" OR "body load*" OR "Player Load*" OR "PlayerLoad*" OR "metabolic power" OR "metabolic load" OR "high power distance*" OR "equivalent distance*" OR Pmet OR "exertion index"
Search Phrase:	1 AND 2 AND 3

Table 2. Study inclusion-exclusion criteria

Criteria	Inclusion	Exclusion
1	Article is related to human physical performance.	Studies with non-human subjects or with no outcome measures relating to physical performance (e.g. physiological, health markers, etc.).
2	Original research article	Reviews, surveys, opinion pieces, books, periodicals, editorials, case studies, non-academic/non-peer-reviewed text.
3	Competitive team-sport athletes (intermittent, field- or court-based sports).	Non-team sports (e.g. solo, racquet/bat, or combat sports, etc.), ice-, sand- or water-based team sports, match officials, recreational athletes or non-athletic populations.
4	Participants \geq 18 years old or defined as senior athletes.	Participants $<$ 18 years old or defined as adolescent, junior, youth or child athletes.
5	Healthy, able-bodied, non-injured athletes	Special populations (e.g. clinical, patients), athletes with a physical or mental disability, and athletes considered to be injured or returning from injury.
6	Normal team-sport training or match-play.	Experimental trials (e.g. crossover, controlled trial), including lab-based studies and field-based studies where a) usual training was coupled with an experimental intervention (e.g. environment manipulation, nutritional or recovery interventions, use of ergogenic aids, etc.), or b) only data from performance testing was reported (e.g. pre-post fitness changes).
7	Full text available in English	Cannot access full text in English.
8	Reported a measure of RPE (category-ratio scaled) or HR as an indicator of internal load or intensity domain	Did not report a measure of category-ratio scaled RPE or HR measured in the time or frequency domain as an indicator of internal load/intensity.
9	Reported at least one a measure of external load or intensity	Did not report at least measure of external load/intensity measured in the time or frequency domain.
10	Report of a correlation statistic between internal and external measures of session load or intensity.	No report of a correlation statistic between an RPE- or HR-based measure of internal load/intensity and at least one external measure of load/intensity measured in the same session, or correlations drawn from cumulative values (e.g. weekly training loads).

Table 3. Summary of the meta-analysed measures of internal and external load and intensity.

Construct	Measure	Measurement	Threshold or Metric Calculation Method	
Internal	Intensity	sRPE	CR10, CR100 [42]	
	Load	sRPE-TL	CR10, CR100 [42]	Foster et al. [4]
		TRIMP	Heart rate telemetry (Polar, Catapult Sports)	Banister* [44], Edwards** [45], Modified Edwards** [32], Individualised* [46],
External	Intensity	TD per min	5–10 Hz GPS (Catapult Sports, GPSports)	
		HSRD per min	5–10 Hz GPS (Catapult Sports, GPSports, STATSport)	$\geq 13.1\text{--}15.0 \text{ km}\cdot\text{h}^{-1}$, arbitrary
		AL per min	100 Hz MEMS (Catapult Sports, GPSports)	PlayerLoad ^{TM***} , Body Load ^{TM**}
		Impacts per min	100 Hz MEMS (GPSports, STATSports)	$> 2\text{--}5 \text{ G}$
	Load	TD	5–10 Hz GPS (Catapult Sports, GPSports)	
		HSRD	5–10 Hz GPS (Catapult Sports, GPSports, STATSport)	$\geq 13.1\text{--}15.0 \text{ km}\cdot\text{h}^{-1}$, arbitrary
		VHSRD	5–10 Hz GPS (Catapult Sports)	$\geq 16.9\text{--}19.8 \text{ km}\cdot\text{h}^{-1}$, arbitrary and individualised
		AL	100 Hz MEMS (Catapult Sports, GPSports, Freescale)	PlayerLoad ^{TM***} , Body Load ^{TM**}
	Impacts	100 Hz MEMS (GPSports, STATSports)	$> 2\text{--}5 \text{ G}$	

*Exponentially weighted

**Summated zones

***Vector magnitude calculation

Abbreviations. AL: accelerometer-derived load, CR10: Borg's Category-Ratio 10 (deci-Max) scale, CR100: Borg's Category-Ratio 100 (centi-Max) scale, GPS: global positioning system, HSRD: distance covered at high speeds, Impacts: total number of sustained impacts, MEMS: micro-electrical mechanical system, sRPE: session rating of perceived exertion, sRPE-TL: session rating of perceived exertion training load, TD: total distance covered, TRIMP: heart-rate-derived training impulse, VHSRD: distance covered at very high speeds.

Table 4. Descriptive study information.

Reference	Sport	Athletes			Study Defined Training Mode(s)	Observation Sample		Session duration (minutes; mean \pm SD)	Measures of Intensity and Load*					
		n	Competitive Level	Age (years; mean \pm SD)		Obs. Per athlete (mean \pm SD)	Total individual Obs.		Internal		External			
									Intensity	Load	Intensity**	Load	Device specification, (manufacturer, model)	
Bartlett et al. [19]	AF	41	Australian Football League	23 \pm 4	Field-based AF sessions	66 \pm 13	2711	59 \pm 25	sRPE (CR10)	-	Relative distance, percentage of total distance covered > 14.4 km·h ⁻¹	Total distance, distance covered > 14.4 km·h ⁻¹	10 Hz GPS & 100 Hz MEMS (Catapult Sports, Optimeye S5)	
Casamichana & Castellano [22]	SO	14	Spanish Regional	21 \pm 2	SSG	not reported	217	not reported	sRPE (CR10) mean %HR _{max}	-	Relative distance, relative distances and frequency of efforts > 18.0 and > 21.0 km·h ⁻¹ , accelerometer load ^c	-	10 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX v.4.0)	
Casamichana et al. [24]	SO	28	Spanish Third Division	23 \pm 4	SSG, running exercises, technical & tactical drills	not reported	210	90 \pm 23	-	sRPE-TL (CR10)	Work: rest ratio (\geq 4: < 4 km·h ⁻¹)	Total distance, distances and frequency of efforts > 18.0 and > 21.0 km·h ⁻¹	10 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX v.4.0)	
Gallo et al. [25]	AF	39	Australian Football League	23 \pm 3	SSG, technical & tactical drills & match practice scenarios	7 \pm 6	270	59 \pm 14	-	sRPE-TL (CR10)	Relative distance	Total distance, distance covered at individualised high-speeds ^f , total and low velocity (< 7.2 km·h ⁻¹) accelerometer load ^c	10 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX team 2.5)	
Gaudino et al. [26]	SO	22	English Premier League	26 \pm 6	Team field-based training sessions	86 \pm 28	1892	57 \pm 16	sRPE (CR10)	sRPE-TL (CR10)	Relative distance covered > 14.4 km·h ⁻¹ , relative number of impacts (> 2 G), relative number of accelerations (> 3 m·s ⁻²)	Total distance covered > 14.4 km·h ⁻¹ , total number of impacts (> 2 G), total number of accelerations (> 3 m·s ⁻²)	10 Hz GPS & 100 Hz MEMS (STATSports, Viper)	
Lovell et al. [22]	RL	32	National Rugby League	24 \pm 4	Conditioning	15 \pm 3	398	28 \pm 14	sRPE (CR10) mean %HR _{max}	sRPE-TL (CR10) TRIMP (Banister)	Relative distance, relative distance covered at speeds > 15.0 km·h ⁻¹ , relative accelerometer load ^d ,	Total distance, total distance covered at speeds > 15.0 km·h ⁻¹ , total accelerometer load ^d ,	5 Hz GPS & 100 Hz MEMS (GPSports, SPI Pro)	
					Skills	34 \pm 13	1097	44 \pm 11						
					Skills-conditioning	14 \pm 2	365	46 \pm 19						

Author [ref]	Level	Age	League	Speed (km·h ⁻¹)	Activity	Speed (km·h ⁻¹)	Distance (km)	Time (min)	HR (b·min ⁻¹)	HR _{max} (b·min ⁻¹)	Relative distance covered, relative distance covered at speeds ≥ 13.1 km·h ⁻¹ , relative accelerometer load ^c	Total distance covered, total distance covered at speeds > 14.4 km·h ⁻¹ , accelerometer load ^c	Accelerometer load ^c	GPS & MEMS
Pustina et al. [27]	SO	20	NCAA Division I	22 ± 2	Speed	11 ± 1	262	17 ± 7	-	sRPE-TL (CR10) ^a	-	Total distance covered, total distance covered at speeds > 14.4 km·h ⁻¹ , accelerometer load ^c	10 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX v.4.0)	
					Wrestle	12 ± 1	278	18 ± 7						
Scanlan et al. [28]	BB	8	Australian 2 nd tier	26 ± 7	NCAA Division I match-play	15 ± 2	304	75 ± 24	-	sRPE-TL (CR10) TRIMP (Banister & Edwards)	-	Total distance covered, total distance covered and time spent at speeds < 14.4, ≥ 14.4 and ≥ 19.8 km·h ⁻¹ , accelerometer load ^c	4 x 100 Hz tri-axial accelerometers, Freescale (Semiconductor, MMA7361L)	
					Field-based team training	30 ± 2	598	69 ± 17						
Scott et al. [29]	SO	15	Australian A-League	25 ± 5	Field-based team training	7 ± 3	99	73 ± 17	-	sRPE-TL (CR10) TRIMP (Banister & Edwards)	-	Total distance covered, total distance covered and time spent at speeds < 14.4, ≥ 14.4 and ≥ 19.8 km·h ⁻¹ , accelerometer load ^c	5 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX 2.0)	
Scott et al. [30]	AF	10	Australian Football League	19 ± 2	Skill-based training	18 ± 3	183	63 ± 23	sRPE (CR10 & CR100) mean %HR _{max}	sRPE-TL (CR10 & CR100) TRIMP (Banister & Edwards)	Relative distance covered, relative distance covered at speeds ≥ 13.1 km·h ⁻¹ , relative accelerometer load ^c	Total distance covered, total distance covered at speeds ≥ 13.1 km·h ⁻¹ , total accelerometer load ^c	10 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX team 2.5)	
Weaving et al. [31]	RL	17	English Super League	25 ± 3	Skills-conditioning	5 ± 1	88	37 ± 14	-	sRPE-TL (CR10) TRIMP (individualised ^b)	-	Total distance covered > 15 km·h ⁻¹ , total number of impacts (> 5 G), total accelerometer load ^d	5 Hz GPS & 100 Hz MEMS (GPSports, SPI Pro XII)	
					Conditioning	10 ± 3	170	52 ± 22						
					Skills	15 ± 4	263	40 ± 24						
					Speed	6 ± 2	99	28 ± 8						
					Wrestle	2 ± 1	41	19 ± 8						
Weaving et al. [32]	RL	23	English Championship	24 ± 3	Strongman	4 ± 1	60	21 ± 8	-	sRPE-TL (CR10) TRIMP (Modified Edwards)	-	Total distance covered at individualised high-	10 Hz GPS & 100 Hz MEMS (Catapult Sports, Optimeye X4)	

					Conditioning	8 ± 2	192	25 ± 12			speeds ^g , total accelerometer load ^c	
Weston et al. [33]	AF	26	Australian Football League	22 ± 3	Australian Football League match-play	5 ± 2	129	104 ± 9	sRPE (CR100) sRPE-B (CR100) sRPE-L (CR100)	-	Relative distance covered, relative distance covered at speeds ≥ 14.4 km·h ⁻¹ , relative distance covered at high instantaneous metabolic power (> 20 W·kg ⁻¹) Total distance, total distance covered at speeds < 14.4 and ≥ 14.4 km·h ⁻¹ , total tri- and bi-axial accelerometer load ^c , total distance covered at high instantaneous metabolic power (> 20 W·kg ⁻¹), equivalent total distance covered for steady-state running, average metabolic power, estimated energy expenditure	10 Hz GPS & 100 Hz MEMS (Catapult Sports, MinimaxX S4)

*Only measures that were examined via correlation analyses are reported. Some studies [19,26] report other measures that were not analysed

**external measures of intensity are expressed per-minute

^aMatch sRPE-TL calculated as sRPE × a) minutes played, b) minutes played + halftime, c) minutes played + warm-up, d) minutes played + halftime and warm-up, e) match duration, f) match duration + halftime, g) match duration + warm-up, h) match duration + halftime and warm-up.

^bIndividually weighted using each player's exponential blood lactate-HR relationship (derived from a staged treadmill test) [45].

^cCatapult Sports PlayerLoad™ (vector magnitude)

^dGPSports Body Load™ (summated zones)

^eMeasured using Freescale Semiconductor accelerometers (MMA7361L) and calculated using Catapult Sports' PlayerLoad™ algorithm (vector magnitude)

^fIndividualised as each player's mean 2-km time trial speed. Mean = 18.1 km·h⁻¹, range = 16.9–19.7 km·h⁻¹.

^gIndividualised as each player's final running speed during the 30–15 intermittent fitness test. Mean = 19.6 ± 0.6 km·h⁻¹, range = 18.5–20.5 km·h⁻¹.

Abbreviations. %HR_{max}: percentage of maximum heart rate, AF: Australian Football, BB: Basketball, Banister's: exponentially weighted TRIMP calculated according to Banister [44], CR10: Borg's Category-Ratio 10 (deci-Max) scale [42], CR100: Borg's Category-Ratio 100 (centi-Max) scale [42], Edwards: summated zones TRIMP calculated according to Edwards [45], MEMS: micro-electrical mechanical system, Modified Edwards: summated zones TRIMP calculated according to Edwards [45], but utilising arbitrary exponential weighting factors [32], RL: Rugby League, SD: standard deviation, SO: Soccer, sRPE: session rating of perceived exertion, sRPE-B: session rating of perceived breathlessness, sRPE-L: session rating of perceived leg muscle exertion, sRPE-TL: session rating of perceived exertion training load, SSG: small-sided games, TRIMP: heart-rate-derived training impulse.

Table 5. Meta-analysed relationships between internal and external measures of load and intensity in team-sport athletes during training and competition.

Relationship		Number of...		Meta-Analyses		
Internal	External	Estimates	Studies	Pooled Effect (<i>r</i> [90% CI])	Inference	τ (<i>r</i>)
sRPE	TD per min	9	5	0.29 (0.16 to 0.42)	unclear	0.00
	HSRD per min	8	4	0.22 (0.08 to 0.34)	unclear	0.00
	AL per min	7	3	0.25 (0.10 to 0.40)	unclear	0.00
	Impacts per min	6	2	0.27 (0.12 to 0.42)	unclear	0.00
	TD	2	2	0.57 (0.02 to 0.86)	-	0.47
	HSRD	2	2	0.51 (0.08 to 0.78)	-	0.36
sRPE-TL	TD	11	6	0.79 (0.74 to 0.83)	possibly very large	0.10
	HSRD	16	6	0.47 (0.32 to 0.59)	likely moderate	0.31
	VHSRD	5	4	0.25 (0.03 to 0.45)	unclear	0.22
	AL	20	9	0.63 (0.54 to 0.70)	likely large	0.22
	Impacts	12	3	0.57 (0.47 to 0.64)	possibly large	0.07
TRIMP	TD	2	2	0.74 (0.56 to 0.86)	-	0.00
	HSRD	7	2	0.28 (0.10 to 0.45)	unclear	0.14
	VHSRD	4	3	0.17 (-0.04 to 0.36)	unclear	0.08
	AL	11	5	0.54 (0.40 to 0.66)	possibly large	0.17

- inference not possible ($n \leq 3$)

Abbreviations. sRPE: session rating of perceived exertion, sRPE-TL: session rating of perceived exertion training load, TRIMP: heart-rate-derived training impulse, TD: total distance covered, HSRD: distance covered at high speeds (≥ 13.1 – 15.0 km·h⁻¹), VHSRD: distance covered at very high speeds (≥ 16.9 – 19.8 km·h⁻¹), AL: accelerometer-derived load, Impacts: total number of sustained impacts (> 2 – 5 G), *r*: Pearson's product moment correlation coefficient, τ : Tau (between-estimate heterogeneity [standard deviation representing unexplained variation]), CI: confidence interval.