RPeM: a smartphone-derived index of concentric propulsive efficiency in university athletes. An exploratory cross-sectional analysis

RPeM: un índice de eficiencia propulsiva concéntrica derivado de smartphone en atletas universitarios. Un análisis transversal exploratorio

Authors

Cristian Alexis Lasso-Quilindo [1]
Carlos Manuel Chacón-Rodríguez [2, 3]
José Raúl Hoyos-Flores [4, 5, 6]
Giovani Camacho-Tristán [4]
Omar Oswaldo Ayón-Barreras [7]
Felipe Villegas [8]
Pablo Tadeo Ríos-Gallardo [4]

[1] Corporación Universitaria Autónoma del Cauca (Colombia)
[2] Anáhuac University (Mexico)
[3] University of Veracruz (Mexico)
[4] Autonomous University of Nuevo León (Mexico)
[5] National Commission for Physical Culture and Sport (Mexico)
[6] State Institute of Physical Culture and Sport of Nuevo León (Mexico)
[7] State University of Sonora (Mexico)
[8] Instituto Universitario Veracruzano (Mexico)

Corresponding author:
Pablo Tadeo Ríos-Gallardo
pablo.riosg@uanl.edu.mx

Received: 11-03-26
Accepted: 30-05-26

How to cite in APA

Lasso-Quilindo, C. A., Chacón-Rodríguez, C. M., Hoyos-Flores, J. R., Camacho-Tristán, G., Ayón-Barreras, O. O., Villegas, F., & Ríos-Gallardo, P. T. (2026). RPeM: a smartphone-derived index of concentric propulsive efficiency in university athletes. An exploratory cross-sectional analysis. *Retos, 83*, 450-461. https://doi.org/10.47197/retos.v83.119004

Abstract

Background. Vertical jump height does not capture the time over which propulsive force is produced. This study introduces RPeM (Relative Propulsive efficiency Metric), an exploratory index relating jump height to concentric time in university athletes. RPeM is descriptive and is not proposed as a measure of fatigue, readiness, or injury risk.
Methods. 349 university athletes (216 men, 133 women) performed SJ, CMJ, and CMJFree, assessed with My Jump Lab at 240 fps; 567 observations were retained after quality-control and best-attempt selection. RPeM (jump height ÷ concentric time; $cm \cdot s^{-1}$) was analysed with a log-transformed linear mixed model (jump type, sex, and sport as fixed effects; athlete as random effect); non-parametric tests served as sensitivity checks.
Results. The model explained substantial variance (marginal R^2 = 0.324; conditional R^2 = 0.960). RPeM differed by modality ($F_{2,195}$ = 300.18, p < .001, η^2p = 0.755), sex ($F_{1,327}$ = 75.67, p < .001, η^2p = 0.188), and sport ($F_{6,408}$ = 7.42, p < .001, η^2p = 0.098). Estimated marginal means increased from SJ (94.3) to CMJ (111.0) to CMJFree (132.6 $cm \cdot s^{-1}$) and were higher in men (135.5) than women (91.8).
Conclusions. RPeM behaves coherently across modalities and sex but shares 60–70% of its variance with jump height (r = 0.78–0.84), largely re-expressing the variable from which it is derived. It is an exploratory, transparent descriptor requiring further evaluation before applied use; the readiness output showed zero variance and could not be analysed.

Keywords

Concentric phase; exploratory index; mixed-effects model; propulsive efficiency; smartphone assessment; vertical jump.

Resumen

Antecedentes. La altura del salto vertical no captura el tiempo de producción de fuerza propulsiva. Este estudio introduce el RPeM (*Relative Propulsive efficiency Metric*), índice exploratorio que relaciona la altura del salto con el tiempo concéntrico en atletas universitarios; no se propone como medida de fatiga, preparación ni riesgo de lesión.
Métodos. 349 atletas universitarios (216 hombres, 133 mujeres) ejecutaron SJ, CMJ y CMJFree con My Jump Lab a 240 fps; se retuvieron 567 observaciones tras control de calidad. El RPeM (altura ÷ tiempo concéntrico; $cm \cdot s^{-1}$) se analizó con modelo lineal mixto log-transformado (tipo de salto, sexo y deporte como efectos fijos; atleta como efecto aleatorio); pruebas no paramétricas como verificación de sensibilidad.
Resultados. El modelo explicó varianza sustancial (R^2 marginal = 0.324; R^2 condicional = 0.960). El RPeM difirió por modalidad ($F_{2,195}$ = 300.18, p < .001, η^2p = 0.755), sexo ($F_{1,327}$ = 75.67, p < .001, η^2p = 0.188) y deporte ($F_{6,408}$ = 7.42, p < .001, η^2p = 0.098). Las medias marginales aumentaron de SJ (94.3) a CMJ (111.0) y CMJFree (132.6 $cm \cdot s^{-1}$) y fueron mayores en hombres (135.5) que en mujeres (91.8).
Conclusiones. El RPeM se comporta coherentemente entre modalidades y sexos, pero comparte un 60–70% de su varianza con la altura del salto (r = 0.78–0.84), re-expresando la variable de la que deriva. Se presenta como descriptor exploratorio y reproducible que requiere mayor evaluación antes de su uso aplicado; el indicador de readiness no pudo analizarse por varianza nula en la muestra.

Palabras clave

Eficiencia propulsiva; evaluación con smartphone; fase concéntrica; índice exploratorio; modelo de efectos mixtos; salto vertical.

Introduction

The vertical jump is among the most widely used field expressions of lower-limb neuromuscular function: a brief, low-burden test yields an objective index of explosive capacity that tracks training status and distinguishes performance levels across sports (Klavora, 2000). Jump height (the vertical displacement of the centre of mass) is the conventional outcome and remains the most reported variable in applied settings. Yet height summarises only the result of the movement, not the manner in which force is expressed across the propulsive phase; two athletes may reach the same height through markedly different temporal strategies. Consistent with this, training-induced improvements in jump height have been shown to arise from changes in movement velocity and centre-of-mass displacement rather than from peak force, underscoring that height alone does not capture the underlying biomechanical strategy (Sánchez-Sixto & Floría, 2017). This distinction has motivated growing interest in descriptors that situate jump height within the time over which propulsive force is produced.

Beyond the height attained, the vertical jump is a temporally structured action: the propulsive phase unfolds over a finite time during which force is expressed, and force-time analysis of the countermovement jump shows that athletes reaching comparable heights can differ markedly in the temporal organisation of the movement (McMahon et al., 2018). The countermovement and squat jump are also mechanically distinct (the former permits a preparatory countermovement that the latter excludes) so a given height is reached through different propulsive dynamics depending on modality (Bobbert et al., 1996). These observations indicate that jump height, while informative, does not capture how rapidly propulsive force is produced, and they motivate descriptors that explicitly incorporate the time over which the jump is executed.

Operationalising such time-inclusive descriptors has typically relied on the force–velocity profile, which characterises the lower-limb capacity to produce force across velocities and is computed from jump height, push-off distance, and movement velocity using accessible field equations (Samozino et al., 2008). Profiles derived this way have shown acceptable validity and reliability and discriminate between athletes of differing disciplines and competitive levels (Baena-Raya et al., 2021). Historically these computations required force platforms or linear transducers, but smartphone applications now estimate jump height and related kinematics with sufficient accuracy for field use (Balsalobre-Fernández et al., 2015), making the underlying mechanical quantities (velocity, push-off distance, and the time over which force is expressed) obtainable outside the laboratory. This accessibility motivates exploratory descriptors that relate jump height to the temporal cost of producing it.

Building on this rationale, the present study introduces RPeM (Relative Propulsive efficiency Metric), an exploratory index that relates jump height to the time over which propulsive force is expressed. Operationally, RPeM is the ratio of jump height to concentric time (t_con), where t_con is derived from push-off distance and mean concentric velocity, yielding units of $cm \cdot s^{-1}$; higher values denote greater vertical displacement per unit of propulsive time. The index is descriptive rather than diagnostic: it summarises how efficiently height is produced relative to its temporal cost, and is not proposed, nor here validated, as a measure of neuromuscular fatigue, readiness, recovery, or injury risk. Accordingly, the aim of this cross-sectional study was to characterise RPeM across jump modalities, sex, and sport in university athletes, and to examine its statistical behaviour and its association with jump height, treating the index as an exploratory descriptor whose properties and limitations are evaluated rather than assumed. Unlike proprietary readiness algorithms, RPeM is computed from transparent, reproducible quantities, allowing its assumptions and limitations to be examined directly.

Method

Study Design

This study used a cross-sectional, exploratory design based on retrospectively collected vertical-jump assessments in university athletes. The analysis centred on the Relative Propulsive efficiency Metric (RPeM), a smartphone-derived index of concentric propulsive efficiency computed from jump height and concentric time (defined below). We examined how RPeM varied across sport disciplines, jump modalities, and sex. Because the design is cross-sectional and the index draws in part on model-based estimates, RPeM was treated throughout as an exploratory, descriptive metric rather than a validated criterion measure.

Participants

A total of 356 university athletes were recruited, contributing 2,910 vertical-jump trials. After quality control (see Statistical Analysis), 82 trials were removed and the best attempt per athlete and jump modality was retained, yielding a final analytic sample of 567 observations from 349 athletes (216 men, 133 women). All participants were physically active students enrolled in institutional sport-performance programmes or recreational exercise initiatives between 2023 and 2025. The cohort spanned a broad range of disciplines (basketball, volleyball, soccer, swimming, diving, and Fireball Extreme Challenge (FXC), an emerging co-ed sport (Ríos-Gallardo, Gotoo-Vázquez, et al., 2026) together with a large group of recreationally active students who did not compete formally and a small number of athletes from additional disciplines; for modelling, sports represented by fewer than 10 athletes were grouped into an "Other" category (see Statistical Analysis).

Eligibility required participants to be university students within the typical undergraduate age range (approximately 18–28 years), to have accumulated at least six months of continuous training (a standard threshold for trained individuals; Kraemer et al., 2002), and to be free of musculoskeletal injury or movement-limiting pain at the time of assessment. Only athletes with at least one valid attempt in a given modality were retained for that modality, and trials with missing values or technical inconsistencies were excluded. All procedures conformed to the Declaration of Helsinki. The study protocol was reviewed and approved by an institutional research ethics committee of the Vice-Rectorate for Research of the Autonomous University Corporation of Cauca through Resolution No. 0149 of 2025 dated May 23, 2025. Written informed consent was obtained from all participants during the original assessment sessions, and all data were de-identified before analysis.

Instruments and RPeM derivation

Vertical jump performance was recorded with My Jump Lab (version 4.5.9), an integrated application suite that includes the My Jump 2 module, operated in its manual mode on an iPhone 14 Pro (Apple Inc., Cupertino, CA; iOS 17). Trials were filmed at 240 frames·s^{-1} and 1080p. For each jump, a single trained operator manually selected the take-off and landing frames, from which the application computed flight time and, in turn, jump height. This flight-time procedure is the validated core of the tool: its agreement with force platforms, photocells, and contact mats has been established across populations and jump modalities (Balsalobre-Fernández et al., 2015; Gallardo-Fuentes et al., 2016; Ríos-Gallardo, Carranza-García, et al., 2026).

Beyond flight time, the application returns a set of kinetic and temporal variables (mean concentric velocity, force, power, impulse, and push-off distance) derived from the recorded flight time, the participant's body mass, and individual anthropometric inputs (stature, lower-limb length, and segment lever) entered for each athlete before testing. These variables are model-based estimates rather than direct kinetic measurements: the application computes mean concentric velocity, force, and power from jump height, body mass, and the per-athlete anthropometric inputs using Samozino's method (Samozino et al., 2008), the validated set of equations implemented in the My Jump family of applications (Balsalobre-Fernández & Varela-Olalla, 2024). No force–time curve is recorded. The RPeM index was built from two of these exported variables. Concentric time (t_con) was defined as the push-off distance divided by the mean concentric velocity, and RPeM as jump height divided by t_con:

RPeM = jump height / t_con = (jump height × mean concentric velocity) / push-off distance,

expressed in cm·s^{-1}. Because every term is read directly from the application's export file, the full computation is transparent and reproducible from the raw data and the analysis code. The de-identified dataset and analysis code supporting this study are available to reviewers through an anonymized repository link: https://figshare.com/s/c4a9415d59f7a6def4f7. Upon acceptance, these materials will be released publicly under a CC-BY 4.0 licence with a permanent DOI to ensure full reproducibility.

This derivation carries an explicit boundary. Jump height rests on the validated flight-time measurement, whereas t_con inherits the model-based status of its inputs. RPeM is therefore presented as an exploratory, descriptive index of propulsive efficiency rather than a validated criterion measure; its interpretation and limits are addressed in the Discussion.

Jump Protocol

Each participant performed three vertical-jump modalities in a fixed order: the squat jump (SJ), initiated from a static 90° knee-flexion position without countermovement; the countermovement jump (CMJ), performed with a self-paced countermovement and the hands on the hips; and the free countermovement jump (CMJFree), which allowed arm swing to reflect natural jumping mechanics. Participants completed three valid trials per modality, with 30 s of rest between attempts and 2 min between modalities to limit fatigue. The best attempt per modality, defined by the highest jump height, was retained for analysis. The application also returned a colour-coded flag (green, orange, or red) that it labels as a readiness status; this flag was recorded but, for the reasons set out below, was reported descriptively only and not modelled.

Data analysis

All processing and analyses were performed in R (version 4.5.2; R Core Team, 2025) within the RStudio environment (Posit, PBC). Data were cleaned and standardised with the tidyverse and janitor packages. Before modelling, a physiological-plausibility quality-control filter was applied at the trial level, retaining only trials with jump height > 0 and ≤ 75 cm, mean concentric velocity > 0, push-off distance between 0.10 and 0.70 m, and concentric time between 150 and 800 ms; values outside these bounds indicate erroneous capture of flight or push-off variables. This filter removed 82 of 2,910 trials. The best attempt per athlete and modality was then selected from the trials passing quality control, yielding the analytic sample. Because RPeM showed positive skewness (skewness = 0.66) and heteroscedastic residuals, a natural-logarithm transformation was applied [log(RPeM)] before all inferential analyses, which reduced skewness to −0.48 and improved variance homogeneity; residual distributions were checked with the Shapiro–Wilk test and Q–Q plots. Descriptive statistics (mean, standard deviation, and 95% confidence interval) were computed for jump height, concentric time, and RPeM, stratified by sport, sex, and modality, and are reported on the original $cm \cdot s^{-1}$ scale.

To examine the effects of sport, modality, and sex on RPeM, a linear mixed model (LMM) was fitted with sport, jump modality, and sex as fixed effects and individual athlete as a random intercept, accounting for the repeated-measures structure in which each athlete contributed observations across modalities (lme4; Bates et al., 2015; lmerTest; Kuznetsova et al., 2017). This specification handles within-athlete correlation without violating the independence assumption, in contrast to non-parametric alternatives such as the Kruskal–Wallis test, which would be violated when the same athletes perform multiple modalities. To avoid estimating a fixed-effect level from a single athlete, sports with fewer than 10 athletes were pooled into an "Other" category before modelling. Fixed effects were evaluated with Type III tests and partial eta-squared; model fit was summarised with marginal and conditional R^2. Estimated marginal means were compared with Bonferroni-corrected contrasts and back-transformed to the $cm \cdot s^{-1}$ scale (emmeans). The Kruskal–Wallis and Mann–Whitney tests were retained only as a secondary sensitivity check. To confirm that conclusions did not depend on the quality-control bounds, the full pipeline was re-run under stricter and more lenient threshold sets, and the influence of individual observations on the primary model was assessed; effect sizes and estimated marginal means were stable across all conditions.

Regarding the readiness flag, every classified CMJ trial in the analytic sample carried a green status, while SJ and CMJFree trials had no readiness value recorded; the resulting single-category, zero-variance distribution rendered any association between readiness and RPeM non-estimable. (In the raw trial pool the flag did vary, but the best-attempt selection retained predominantly green CMJ trials.) Readiness was therefore reported descriptively rather than modelled, and its implications for future longitudinal designs are considered in the Discussion. Figures were produced with ggplot2. Statistical significance was set at $p < .05$. Consistent with open-science reproducibility principles, the de-identified data and analysis code are openly available (see Instruments and RPeM derivation).

Results

The analytic sample comprised 567 observations from 349 university athletes (216 men, 133 women) distributed across seven sport categories and three jump modalities. Descriptive statistics for jump height, concentric time (t_con), and RPeM, stratified by sport, sex, and modality, are presented in Table 1.

Table 1. Descriptive statistics by sport, sex, and jump modality. Values are mean (SD); RPeM on the cm·s^{-1} scale. SJ = squat jump; CMJ = countermovement jump; CMJFree = countermovement jump with arm swing; t_con = concentric time. Sports with fewer than 10 athletes are pooled as "Other". Cells with n < 3 report the mean only.

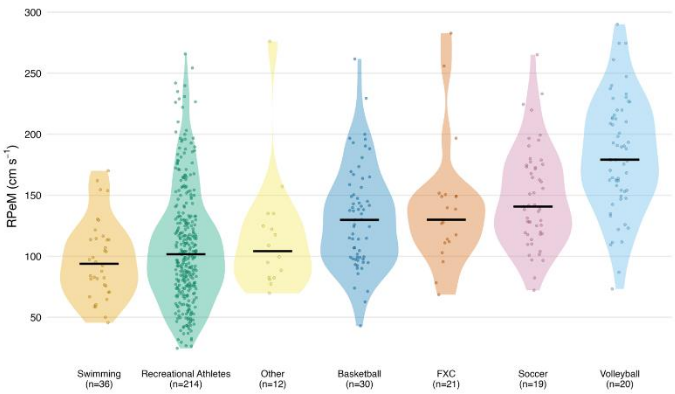
Sport	Sex	Jump type	n	Jump height (cm)	t_con (ms)	RPeM (cm s-1)
Basketball	Female	CMJ	13	42.55 (10.21)	306.2 (54.1)	144.44 (47.41)
	Male	SJ	17	31.88 (7.26)	318.4 (47.3)	102.09 (27.02)
		CMJ	16	36.96 (7.57)	297.8 (46.5)	126.65 (31.19)
		CMJFree	17	42.16 (8.96)	276.6 (42.9)	155.70 (40.11)
FXC	Female	CMJ	10	33.39 (6.33)	295.9 (44.2)	115.49 (27.58)
	Male	CMJ	11	43.09 (7.95)	279.9 (62.8)	162.95 (58.63)
Recreational Athletes	Female	SJ	18	27.17 (7.60)	355.6 (66.7)	79.75 (32.21)
		CMJ	85	23.89 (6.14)	348.0 (80.7)	74.53 (32.46)
	Male	SJ	57	32.98 (5.64)	317.6 (69.2)	109.05 (31.28)
		CMJ	128	34.11 (7.80)	299.7 (77.9)	124.18 (48.86)
		CMJFree	32	39.54 (6.82)	289.5 (64.2)	144.01 (43.48)
Soccer	Male	SJ	17	31.17 (3.88)	262.1 (46.6)	122.91 (28.12)
		CMJ	16	34.70 (3.98)	248.5 (43.4)	143.99 (31.12)
		CMJFree	18	39.77 (5.04)	234.1 (40.7)	175.79 (41.68)
Swimming	Female	CMJ	15	24.67 (4.55)	335.9 (66.6)	77.06 (24.80)
	Male	CMJ	21	37.02 (6.19)	341.8 (50.9)	111.22 (28.50)
Volleyball	Female	SJ	1	37.15 (NA)	251.9 (NA)	147.51 (NA)
		CMJ	1	41.73 (NA)	237.8 (NA)	175.51 (NA)
		CMJFree	1	48.54 (NA)	220.8 (NA)	219.86 (NA)
	Male	SJ	19	43.23 (6.71)	285.6 (41.7)	155.52 (36.82)
		CMJ	19	46.97 (6.96)	273.8 (39.3)	175.95 (39.59)
		CMJFree	19	54.17 (7.08)	254.2 (35.2)	217.83 (44.11)
Other	Female	SJ	2	21.95 (1.53)	293.8 (51.5)	75.41 (8.01)
		CMJ	8	31.49 (6.77)	262.7 (62.2)	131.43 (64.99)
	Male	SJ	2	30.05 (6.07)	287.2 (39.9)	104.18 (6.64)
		CMJ	4	33.92 (5.20)	314.3 (61.6)	110.46 (22.28)

Note. N = 349 unique athletes (567 observations). Three athletes were assessed in more than one testing context (a course-based recreational session and a representative-team session); discipline-level counts therefore sum to 352 rather than 349. The single female volleyball athlete is reported without dispersion.

Descriptive patterns across sports and modalities

Across cohorts, RPeM increased progressively from the squat jump to the countermovement jump and to the free countermovement jump, consistent with the successive contributions of the stretch–shortening cycle and arm swing to vertical displacement per unit of concentric time. At the sport level (Figure 1), volleyball athletes showed the highest RPeM, followed by soccer, basketball, and Fireball Extreme Challenge athletes, whereas swimmers and recreationally active students showed the lowest values; the pooled "Other" category fell between these extremes. The same ordering was apparent for jump height and was mirrored, inversely, by concentric time, with the highest-performing cohorts combining greater jump height and shorter concentric time.

Figure 1. RPeM Across the Seven Sport Categories.



Notes: Violin plots show the distribution of RPeM (cm·s^{-1}); horizontal bars denote group means, and points are individual observations. Sports represented by fewer than 10 athletes are pooled into the "Other" category. RPeM = Relative Propulsive efficiency Metric.

Primary mixed-model analysis

In the primary linear mixed model, jump modality was by far the strongest determinant of log(RPeM) (F(2, 195) = 300.2, p < .001, partial η^2 = 0.755), followed by sex (F(1, 327) = 75.7, p < .001, partial η^2 = 0.188) and sport (F(6, 408) = 7.42, p < .001, partial η^2 = 0.098). Fixed effects together explained 32.4% of the variance in log(RPeM) (marginal R^2 = 0.324); adding the athlete random intercept raised the explained variance to 96.0% (conditional R^2 = 0.960), indicating that RPeM was highly stable within individuals and that most of the total variance reflected differences between athletes rather than between conditions (Table 2).

Table 2. Primary linear mixed model for log(RPeM). Panel A. Fixed effects (Type III tests).

Effect	F	df	p	Partial η^2 [95% CI]
Jump modality	300.18	2, 195	< .001	0.755 [0.710, 1.00]
Sex	75.67	1, 327	< .001	0.188 [0.129, 1.00]
Sport	7.42	6, 408	< .001	0.098 [0.048, 1.00]

Marginal R^2 = 0.324; conditional R^2 = 0.960.

Table 2B. Estimated marginal means (back-transformed, cm·s^{-1}).

Level	Mean	95% CI
SJ	94.3	[88.7, 100.3]
CMJ	111.0	[104.6, 117.7]
CMJFree	132.6	[124.6, 141.2]
Female	91.8	[84.7, 99.5]
Male	135.5	[126.7, 144.8]

Table 2C. Pairwise contrasts (Bonferroni-corrected).

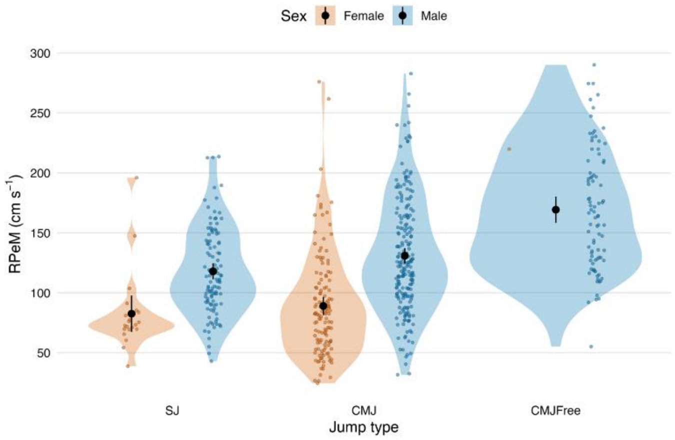
Contrast	Ratio	p
SJ vs CMJ	0.85	< .001
SJ vs CMJFree	0.71	< .001
CMJ vs CMJFree	0.84	< .001
Female vs Male	0.68	< .001

Note. Model: log(RPeM) ~ jump modality + sex + sport + (1 | athlete); 567 observations from 349 athletes. Sports with fewer than 10 athletes were pooled as "Other". Ratios are back-transformed mean differences on the natural-log scale. The upper bound of partial η^2 is capped at 1.

Back-transformed estimated marginal means increased monotonically across modalities — SJ 94.3 cm·s^{-1} (95% CI [88.7, 100.3]), CMJ 111.0 cm·s^{-1} ([104.6, 117.7]), and CMJFree 132.6 cm·s^{-1} ([124.6, 141.2]) — and all three pairwise contrasts were significant after Bonferroni correction (all p < .001), including the SJ–CMJ difference. Male athletes showed higher RPeM than female athletes in the squat jump and countermovement jump (Figure 2), with estimated marginal means of 135.5 cm·s^{-1} (95% CI [126.7, 144.8]) versus 91.8 cm·s^{-1} ([84.7, 99.5]); this corresponds to a female-to-male ratio of 0.68 (F(1,

327) = 75.7, p < .001). In the free countermovement jump the female sample comprised a single athlete, so the sex comparison for that modality is not interpretable.

Figure 2. RPeM by Sex Across the Three Jump Modalities.



Note: Violins and jittered points show the distribution of RPeM (cm·s^{-1}) for female and male athletes across the squat jump (SJ), countermovement jump (CMJ), and free countermovement jump (CMJFree). Black markers denote the mean and its 95% confidence interval. No group summary is shown for the female CMJFree cell, which comprised a single athlete. RPeM = Relative Propulsive efficiency Metric.

Readiness

The application's readiness flag could not be analysed against RPeM. In the analytic sample, every classified CMJ trial carried a green flag (346 of 347, with one value missing), and no readiness value was recorded for any SJ or CMJFree trial, producing a single-category, zero-variance distribution (Figure 4). In the full raw-trial pool the flag did vary (green 48.4%, red 4.7%, orange 2.0%, missing 44.9%), but best-attempt selection retained predominantly green CMJ trials. Readiness was therefore reported descriptively and not modelled; the absence of usable variance in a cross-sectional, best-attempt design, and its implications for longitudinal monitoring, are considered in the Discussion.

Figure 4. Distribution of the Readiness Flag in the Raw-Trial and Analytic Sets.

Note: Bars show the relative frequency of the application's readiness categories (green, orange, red) and missing values in the full raw-trial pool and in the analytic (best-attempt) set, by jump modality. In the analytic set the flag was uniformly green for the countermovement jump (CMJ) and absent for the squat jump (SJ) and free countermovement jump (CMJFree), precluding any association with RPeM. RPeM = Relative Propulsive efficiency Metric.

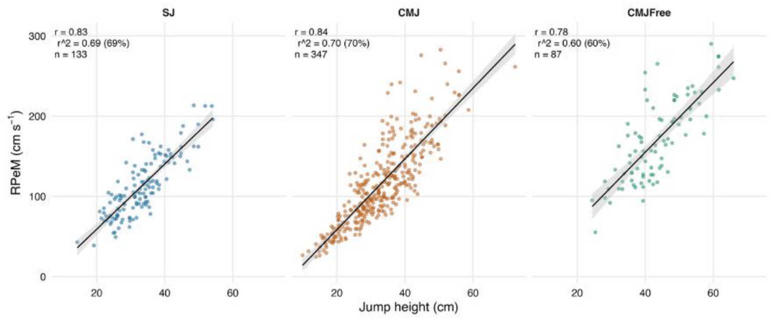
Robustness and model diagnostics

Conclusions were robust to analytic choices. The natural-logarithm transformation reduced the skewness of RPeM from 0.66 to −0.48, and residual diagnostics indicated acceptable normality and homogeneity of variance for the transformed model, aside from mild heavy tails at the most extreme quantiles (Supplemental Figure S1, quantile–quantile and scale–location plots). Under stricter and more lenient quality-control thresholds, partial η^2 values remained essentially unchanged (jump modality 0.748–0.755, sex 0.184–0.199, sport 0.098–0.114), as did the estimated marginal means (e.g., SJ 92.9–94.3, CMJFree 129.5–132.6 cm·s^{-1}) and the modality-specific RPeM–height correlations. Excluding influential observations preserved the rank order and significance of all effects (jump modality > sex > sport). As a non-parametric cross-check, Kruskal–Wallis and Mann–Whitney tests agreed with the mixed-model results for every factor.

Association between RPeM and jump height

As shown in Figure 3, RPeM was strongly associated with jump height within each modality (SJ $r = 0.83$, $n = 133$; CMJ $r = 0.84$, $n = 347$; CMJFree $r = 0.78$, $n = 87$; all $p < .001$), corresponding to 60–70% shared variance (68.6%, 70.3%, and 60.1%, respectively). Because jump height is one of the two terms in the RPeM formula, this association is expected and largely structural rather than independent: RPeM is substantially, but not wholly, determined by jump height, and the remaining 30–40% of variance reflects the temporal component of the index (mean concentric velocity and push-off distance). This relationship is therefore best understood as a property of the index's construction rather than as evidence of external validity, an interpretation developed in the Discussion.

Figure 3. Association Between RPeM and Jump Height Within Each Jump Modality.



Note. Scatterplots show the relationship between RPeM (cm·s^{-1}) and jump height (cm) for the squat jump (SJ), countermovement jump (CMJ), and free countermovement jump (CMJFree), with the Pearson correlation, coefficient of determination, and sample size per panel. Because jump height is one of the two terms in the RPeM formula, the association is expected and largely structural. RPeM = Relative Propulsive efficiency Metric.

Discussion

This study examined how a smartphone-derived index of concentric propulsive efficiency (RPeM) varied across jump modalities, sex, and sport in university athletes. The clearest pattern was that jump modality accounted for the large majority of the explained variance in log(RPeM) (partial $\eta^2 = 0.755$), far exceeding the contributions of sex (0.188) and sport (0.098). Estimated marginal means increased systematically from the squat jump (94.3 cm·s^{-1}) to the countermovement jump (111.0) to the free countermovement jump (132.6), and male athletes showed higher values than female athletes overall (135.5 vs 91.8 cm·s^{-1}). We interpret these patterns as descriptive properties of an exploratory index rather than as evidence of a validated construct, and we set out below both what RPeM captures and what it does not.

Mechanical coherence of the modality gradient

The ordering across modalities is mechanically coherent. The countermovement jump exceeds the squat jump because the preparatory countermovement allows the muscles to build up a high active state and force before shortening, so that more work is produced over the first part of the propulsive range; storage and reutilisation of elastic energy contributes little to this difference (Bobbert et al., 1996; Van Hooren & Zolotarjova, 2017). The free countermovement jump adds the contribution of the arm swing, which accelerates and raises the centre of mass toward take-off (Lees et al., 2004). Because RPeM is jump height divided by concentric time, any modality that increases height without a proportional increase in concentric time will increase RPeM; the observed gradient (estimated marginal means of 94.3, 111.0, and 132.6 cm·s^{-1} for SJ, CMJ, and CMJFree) therefore expresses established jump mechanics through the index. This coherence is reassuring, but, as we discuss next, it is partly a built-in consequence of how the index is defined.

The denominator: a model-based, not measured, quantity

A central limitation concerns the denominator of the index. Concentric time was derived from the application's estimates of mean concentric velocity and push-off distance, which are computed with Samozino's method (Samozino et al., 2008), a method originally validated for the squat jump, rather than obtained from a force–time record. RPeM consequently inherits the assumptions of that model: it is transparent and fully reproducible from the exported variables, yet it is not anchored to a criterion measurement of the propulsive phase. We have therefore been deliberate in presenting RPeM as an exploratory, descriptive index rather than as a validated criterion of neuromuscular efficiency. Determining whether the model-based concentric time tracks force-plate–derived propulsive time is a necessary step before the index can support inferential or diagnostic use. This distinction between directly measured and model-estimated jump variables has been emphasised in a recent systematic review of vertical-jump assessment methods, which classified force platforms as primary instruments and smartphone or timing-based tools as secondary, estimate-based alternatives (Pereira Salustiano Mallen da Silva et al., 2026).

What the association with jump height does and does not show

The strong association between RPeM and jump height (r = 0.78–0.84; approximately 60–70% shared variance) must be interpreted with care. Because jump height is one of the two terms in the RPeM formula, this association is expected and largely structural; it is not independent evidence that the index is valid. The more informative question is what the remaining approximately 30–40% of variance represents. That residual is carried by the concentric-time component of the index (t_con, itself derived from mean concentric velocity and push-off distance), which is the only part of RPeM not already contained in jump height. The practical value of RPeM, if any, therefore depends on whether this temporal component adds information beyond height alone, for instance by distinguishing athletes who reach a similar height through different force–time strategies. This is an open and testable question, and it is the proper focus of future validation rather than a claim that can be made from the present cross-sectional data.

Sex differences

The higher RPeM of male athletes (estimated marginal means of 135.5 versus 91.8 cm·s^{-1}; female-to-male ratio of 0.68) is consistent with well-documented sex differences in vertical jump performance. In a detailed phase analysis of the countermovement jump, men jumped substantially higher than women primarily by generating a larger concentric impulse and thus reaching a greater take-off velocity, whereas relative peak force was similar between sexes (McMahon et al., 2017). Within RPeM, a higher jump height in males would raise the index directly through its numerator. The sex comparison could not be evaluated in the free countermovement jump, where the female sample comprised a single athlete; this imbalance, together with the sparse representation of women in several disciplines, constrains the strength of any sex-specific inference.

Readiness could not be evaluated

The application's readiness flag could not be related to RPeM. In the analytic best-attempt set the flag was uniformly green for the countermovement jump and absent for the other modalities, leaving no variance to model. This is a structural feature of a single-session, best-attempt design rather than a substantive finding: the application derives its readiness classification from the best trial itself, and selecting that attempt concentrated the green category accordingly. Whether RPeM is sensitive to genuine within-athlete fluctuations in readiness can only be answered by longitudinal designs that repeatedly sample the same individuals across states of fatigue and recovery.

Limitations

Several limitations qualify these findings. First, the kinetic and temporal inputs to RPeM are model-based application estimates rather than direct measurements, and they were not validated here against a force plate. Second, the design is cross-sectional and retrospective, which precludes causal and longitudinal inference. Third, RPeM is substantially redundant with jump height, so its incremental value over height remains unproven. Fourth, the readiness flag carried no usable variance, and some disciplines (particularly among women) were sparsely represented, with three athletes assessed in more than one testing context. Finally, RPeM is introduced here as an exploratory index: the present results characterize its behaviour but do not establish its validity or reliability, both of which require dedicated criterion and test–retest studies.

Practical considerations and future directions

Within these boundaries, RPeM offers a transparent and fully reproducible quantity that can be computed from a widely accessible smartphone application without specialised hardware (Balsalobre-Fernández & Varela-Olalla, 2024). Its appeal is practical rather than mechanistic: it summarises height per unit of concentric time in a single value that practitioners can record and track. Realising that potential depends on future work that validates the model-based concentric time against criterion measures, tests whether the temporal component adds information beyond jump height, and examines whether the index responds to within-athlete change over time. Until such evidence exists, RPeM is best regarded as a promising but exploratory descriptive metric rather than a measure of neuromuscular readiness or fatigue.

Conclusions

In this exploratory cross-sectional study, RPeM (a transparent, smartphone-derived index of concentric propulsive efficiency) varied primarily with jump modality (partial η^2 = 0.755) and, to a lesser extent, with sex and sport. The index increased systematically from the squat jump to the countermovement jump to the free countermovement jump and was higher in male than in female athletes, patterns that follow established jump mechanics. RPeM was, however, substantially redundant with jump height (approximately 60–70% shared variance), and it should therefore be understood as a descriptive summary of height per unit of concentric time rather than as an independent or validated measure of neuromuscular efficiency.

Because the concentric time in the denominator is derived from model-based application estimates rather than from a force–time record, and because the design was single-session and cross-sectional, RPeM does not constitute a validated indicator of readiness, fatigue, or injury risk; the readiness flag, being invariant in the analytic set, could not be evaluated against it. The practical appeal of the index lies in its accessibility and full reproducibility, but its applied value remains conditional on future work: criterion validation of the model-based concentric time against force-plate measurement, a direct test of whether the temporal component adds information beyond jump height, and longitudinal designs able to capture within-athlete change over time. Until such evidence is available, RPeM is best regarded as a promising but exploratory metric.

Acknowledgements

We sincerely thank all the athletes and sports teams who generously participated in this study, as their contribution was fundamental to the successful completion of this research.

Financing

This research received external funding. The publication costs associated with this article were supported by the Corporación Universitaria Autónoma del Cauca.

References

Baena-Raya, A., Soriano-Maldonado, A., Conceição, F., Jiménez-Reyes, P., & Rodríguez-Pérez, M. A. (2021). Association of the vertical and horizontal force–velocity profile and acceleration with change of direction ability in various sports. *European Journal of Sport Science, 21*(12), 1659–1667. https://doi.org/10.1080/17461391.2020.1856934

Balsalobre-Fernández, C., Glaister, M., & Lockey, R. A. (2015). The validity and reliability of an iPhone app for measuring vertical jump performance. *Journal of Sports Sciences, 33*(15), 1574–1579. https://doi.org/10.1080/02640414.2014.996184

Balsalobre-Fernández, C., & Varela-Olalla, D. (2024). The validity and reliability of the My Jump Lab app for the measurement of vertical jump performance using artificial intelligence. *Sensors, 24*(24), 7897. https://doi.org/10.3390/s24247897

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bobbert, M. F., Gerritsen, K. G. M., Litjens, M. C. A., & Van Soest, A. J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine & Science in Sports & Exercise, 28*(11), 1402–1412. https://doi.org/10.1097/00005768-199611000-00009

Firke, S. (2024). *janitor: Simple tools for examining and cleaning dirty data* (Version 2.2.1) [R package]. https://CRAN.R-project.org/package=janitor

Gallardo-Fuentes, F., Gallardo-Fuentes, J., Ramírez-Campillo, R., Balsalobre-Fernández, C., Martínez, C., Caniuqueo, A., Cañas, R., Banzer, W., Loturco, I., Nakamura, F. Y., & Izquierdo, M. (2016). Intersession and intrasession reliability and validity of the My Jump app for measuring different jump actions in trained male and female athletes. *Journal of Strength and Conditioning Research, 30*(7), 2049–2056. https://doi.org/10.1519/JSC.0000000000001304

Klavora, P. (2000). Vertical-jump tests: A critical review. *Strength and Conditioning Journal, 22*(5), 70.

Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., Feigenbaum, M. S., Fleck, S. J., Franklin, B., Fry, A. C., Hoffman, J. R., Newton, R. U., Potteiger, J., Stone, M. H., Ratamess, N. A., Triplett-McBride, T., & American College of Sports Medicine. (2002). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine & Science in Sports & Exercise, 34*(2), 364–380. https://doi.org/10.1097/00005768-200202000-00027

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Lees, A., Vanrenterghem, J., & De Clercq, D. (2004). Understanding how an arm swing enhances performance in the vertical jump. *Journal of Biomechanics, 37*(12), 1929–1940. https://doi.org/10.1016/j.jbiomech.2004.02.021

Lenth, R. (2025). *emmeans: Estimated marginal means, aka least-squares means* (Version 1.11.1) [R package]. https://CRAN.R-project.org/package=emmeans

McMahon, J. J., Rej, S. J. E., & Comfort, P. (2017). Sex differences in countermovement jump phase characteristics. *Sports, 5*(1), 8. https://doi.org/10.3390/sports5010008

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the key phases of the countermovement jump force-time curve. *Strength and Conditioning Journal, 40*(4), 96–106. https://doi.org/10.1519/SSC.0000000000000375

Pereira Salustiano Mallen da Silva, G. C., Rosa, G., Lopes Silva, Y. R., Ruiz Garcia Rosa Bastos, L., Miranda de Oliveira, J. G., Santos Meireles, A., de Souza Costa Conceição, M. C., Moreira Nunes, R. de A., Braga de Mello, D., & Gomes de Souza Vale, R. (2026). Methods for assessing vertical jump in resistance-trained men: A systematic review. *Retos, 74*, 346–360. https://doi.org/10.47197/retos.v74.116788

R Core Team. (2025). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Ríos-Gallardo, P. T., Carranza-García, L. E., Balsalobre-Fernández, C., & Montalvo, S. (2026). Reliability and Validity of an AI-Driven Smartphone Application for Measuring Countermovement Jump Height: A Comparison with Force Platform, Infrared Optical Timing, and Manual Video Analysis. *Measurement in Physical Education and Exercise Science, 30*(1), 73–86. https://doi.org/10.1080/1091367X.2025.2532391

Ríos-Gallardo, P. T., Gotoo-Vázquez, P. J., López-Walle, J., Mendoza-Farias, F. J., Figueroa-Jimenez, M. O., & Montalvo, S. (2026). Profiling Fireball Extreme ChallengeTM athletes: An exploratory multidimensional study in an emerging co-ed sport. *The Journal of Sports Medicine and Physical Fitness. 66*(5), 593-605. https://doi.org/10.23736/S0022-4707.25.17557-9

Sánchez-Sixto, A., & Floría, P. (2017). Efecto del entrenamiento combinado de fuerza y pliometría en variables biomecánicas del salto vertical en jugadoras de baloncesto. *Retos, 31*, 114–117. https://doi.org/10.47197/retos.v0i31.53340

Samozino, P., Morin, J.-B., Hintzy, F., & Belli, A. (2008). A simple method for measuring force, velocity and power output during squat jump. *Journal of Biomechanics, 41*(14), 2940–2945. https://doi.org/10.1016/j.jbiomech.2008.07.028

Van Hooren, B., & Zolotarjova, J. (2017). The difference between countermovement and squat jump performances: A review of underlying mechanisms with practical applications. *Journal of Strength and Conditioning Research, 31*(7), 2011–2020. https://doi.org/10.1519/JSC.0000000000001913

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag New York. https://ggplot2.tidyverse.org

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., … Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software, 4*(43), 1686. https://doi.org/10.21105/joss.01686

Authors' and translators' details:

Cristian Alexis Lasso-Quilindo	cristian.lasso.q@uniautonoma.edu.co	Author
Carlos Manuel Chacón-Rodríguez	Carlos.chacon@anahuac.mx	Author
José Raúl Hoyos-Flores	jose.hoyosfl@uanl.edu.mx	Author
Giovani Camacho-Tristán	giovani.camachotn@uanl.edu.mx	Author
Omar Oswaldo Ayón-Barreras	ayonoswaldo711@gmail.com	Author
Felipe Villegas	felipe.villegas@iuv.edu.mx	Author
Pablo Tadeo Ríos-Gallardo	pablo.riosg@uanl.edu.mx	Author
Melissa Guerra Jauregui	mel.jauregui@tec.mx	Translator