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# Is larger eccentric utilization ratio associated with poorer rate of force development in squat jump? An exploratory study

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## ABSTRACT

This exploratory study examines the relationship between the eccentric utilization ratio (EUR) and the rate of force development (RFD) in squat jumps (SJ). EUR, a key metric in sports science, compares performance in countermovement jumps (CMJ) and squat jumps (SJ). The study hypothesizes that a higher EUR is associated with a poorer RFD in SJ. Basketball and soccer players, long-distance runners, alongside physical education students (209 men; age:  $23.2 \pm 4.95$  years and 104 women; age:  $22.7 \pm 4.42$  years) participated. The EUR was calculated from jump height, peak force and peak power. The results indicated a small to moderate but significant negative correlation between EUR based on peak force or peak power and RFD in SJ ( $r = -.41$  and  $-.27$ ), suggesting that a higher EUR might be linked to a diminished ability to rapidly develop force in SJ. Thus, a higher EUR may not indicate superior athletic performance.

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countermovement  
utilization

## 1. Introduction

The concept of the eccentric utilization ratio (EUR), defined as the ratio between the performance in a countermovement jump (CMJ) and a squat jump (SJ), has been a topic of interest in the field of sports science and athletic training (McGuigan et al. 2006; Van Hooren and Zolotarjova 2017; Kozinc et al. 2021). The most straightforward approach is to calculate the EUR from jump heights, while studies have also utilized peak/mean force or power (Kozinc et al. 2021). Traditionally, a higher EUR has been believed to reflect the ability to effectively utilize elastic energy and stretch-shortening cycle mechanisms, thereby enhancing performance in dynamic movements (McGuigan et al. 2006). In recent years, this prevailing assumption has been questioned. Given the availability of alternative methods like the reactive strength index and pre-stretch augmentation for assessing stretch-shortening cycle utilization (Gheller et al. 2023), further research is essential to identify the most accurate indicators of performance capabilities.

First, it has to be clarified that greater force, power and subsequent jump height achieved in CMJ relative SJ are primarily due to the ability to generate high forces before the propulsive phase of the CMJ (Bobbert et al. 1996; Bobbert and Casius 2005). This 'pre-loading' achieved in the breaking phase of the countermovement, allows for a greater average force and power output during the

propulsive phase, contributing to the increased jump height. Therefore, the utilization of elastic energy and the stretch-shortening cycle might contribute only a limited amount to the difference observed between the two types of jumps. Furthermore, recent theories and evidence indicate that a higher EUR might not always reflect superior performance (Van Hooren and Zolotarjova 2017; Kozinc et al. 2021) and suggest a large EUR could result from either superior CMJ performance or poorer SJ performance. Poor SJ performance might be linked to a lower ability to rapidly develop force, or to an increased level of muscle slack (Van Hooren and Zolotarjova 2017). In other words, individuals with poorer rate of force development (RFD) and/or lower stiffness will benefit more from the countermovement, resulting in higher EUR. This notion is also supported by observations that individuals with stiffer tendons (which is advantageous for rapid force development) often display lower EUR values (Kubo et al. 1999). In addition, a comprehensive study involving 712 athletes from nine different sports disciplines and 58 physical education students (totalling 770 participants) revealed that the overall jumping ability does not consistently align with EUR differences (Kozinc et al. 2021).

RFD refers to the ability to quickly generate force, a crucial aspect in many sport activities (Hernández-Davó and Sabido 2014; Maffiuletti et al. 2016). This

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capability is particularly important in activities requiring explosive actions, such as jumping, sprinting, and lifting (McLellan et al. 2011; Zaras et al. 2021). It is suggested that early RFD (i.e. 50–100 ms after contraction onset) primarily reflects the neural factors, while later RFD (i.e. 100–200 ms) is dependant primarily on peripheral (muscular) characteristics (Aagaard et al. 2002). While most commonly assessed during isometric tasks, RFD during vertical jumps is perhaps a more ecologically valid measure (Hernández-Davó and Sabido 2014). In SJ, the RFD is assessed during propulsive phase as the slope of the force-time trace. In the context of this study, understanding the relationship between EUR and RFD offers a comprehensive insight into how the EUR correlates with the athlete's ability to produce force rapidly within the SJ task. By investigating this relationship, the study aims to explore the validity of the rationale for assessing athletic performance based on EUR. In light of these considerations, this exploratory study was performed to specifically investigate the correlation between EUR and the RFD in SJ. We hypothesize that a higher EUR may be associated with poorer rapid force development in SJ. This exploration aims to provide a deeper understanding of EUR and its utility for assessing athletic performance. It is crucial for sports practitioners to understand whether EUR is associated with better or poorer performance. This knowledge will inform the development of more accurate and effective training and assessment protocols, ensuring that EUR is used appropriately in the evaluation of athletic performance.

## 2. Methods

### 2.1. Participants and study design

This was an exploratory study, using data retrospectively extracted from a larger project which was primarily conducted to examine the presence of inter-limb asymmetries among various athletic cohorts. The designation of this study as 'exploratory' stems from the fact that the hypotheses were formulated post hoc, subsequent to the initial data collection phase. Men and women from basketball, soccer and long-distance running were included, alongside

with a sample of physical education students. In total, data was collected from 209 men (body height:  $184.7 \pm 8.65$  cm; body mass:  $77.5 \pm 11.75$  kg; age:  $23.2 \pm 4.95$  years) and 104 women (body height:  $171.5 \pm 7.39$  cm; body mass:  $65.9 \pm 10.8$  kg; age:  $22.7 \pm 4.42$  years). Details regarding body composition and training history for each subgroup are shown in Table 1. Basketball and soccer players were part of regional and national level teams, while the sample of runners was comprised of amateur and professional athletes, as well as recreational athletes participating in running competition and training history of >3 years.

Participants were eligible to enrol in the study if they had been injury-free with normal participation in training activities for the past 6 months. Prior to the commencement of measurements, participants were informed in detail about the study protocol and provided signed informed consent for participation. The protocol was conducted in accordance with the latest revision of the Declaration of Helsinki. The experimental procedures were reviewed and approved Slovenian Medical Ethics Committee (approval no. 0120–99/2018/5).

### 2.2. Measurement procedures

Participants performed the jumps on a Kistler force plate (model 9260AA6, Winterthur, Switzerland). Each jump task was preceded by two or three preparatory trials. The participants were familiar with SJ and CMJ tasks, which they performed either as a part of routine testing (athletes) or practical lessons at the faculty (students). The actual jumps were performed in two sets, separated by a one-minute interval, with participants maintaining their hands on their hips throughout. During SJs, participants descended to a predefined position marked by a  $90^\circ$  knee angle, held briefly for stabilization, and then executed the jump as fast and as high as possible, avoiding any preliminary movement. The system, equipped with software, automatically invalidated trials if a more than 2% body mass force reduction was detected, indicative of unintended countermovement (Hébert-Losier and Beaven 2014). Additionally, force-time curve analysis was conducted offline to further identify any subtle countermovement. For CMJs, participants initiated from a standing position with arms positioned on

**Table 1.** Participant characteristics (means and standard deviations).

Sex	Sport	Age (years)	Body mass (kg)	Body height (m)	Training history (years)*
Men	Basketball ( $n = 106$ )	$16.7 \pm 1.2$	$80.4 \pm 12.6$	$1.88 \pm 0.08$	$7.1 \pm 3.0$
	Students ( $n = 31$ )	$19.6 \pm 0.4$	$76.6 \pm 8.2$	$1.82 \pm 0.06$	/
	Soccer ( $n = 42$ )	$16.6 \pm 1.1$	$70.2 \pm 11.3$	$1.78 \pm 0.07$	$7.4 \pm 2.3$
	Running ( $n = 30$ )	$30.6 \pm 9.3$	$78.1 \pm 6.9$	$1.82 \pm 0.06$	$11.2 \pm 8.7$
Women	Basketball ( $n = 58$ )	$16.7 \pm 1.5$	$70.2 \pm 11.2$	$1.75 \pm 0.05$	$6.6 \pm 3.2$
	Students ( $n = 27$ )	$19.7 \pm 0.7$	$59.8 \pm 7.6$	$1.66 \pm 0.06$	/
	Running ( $n = 19$ )	$36.3 \pm 10.8$	$61.1 \pm 7.4$	$1.68 \pm 0.08$	$7.5 \pm 4.2$

\*Defined as the years of regular participation in sports training.

the hips, employing a rapid countermovement to the same knee angle as in the SJ (90° knee flexion) before jumping maximally.

### 2.3. Data analysis and outcome measures

The force plate captured ground reaction forces at a 1000 Hz sampling rate. This data were processed in real-time using MARS software, with a 5 ms moving average filter applied. EUR was calculated as the ratio between CMJ and SJ for respective variable. To minimize the risk of the family-wise Type 1 error rate, outcome variables to calculate EUR were limited to jump height (EUR<sub>JH</sub>), peak force (EUR<sub>PF</sub>) and peak power (EUR<sub>PP</sub>). Jump height was calculated based on take-off velocity method (Linthorne 2001). RFD<sub>SJ</sub> was defined as the maximum slope of the force-time curve (dF/dt) during the propulsive phase in the SJ. For all variables, the average of the three attempts was used for further analysis. All variables exhibited acceptable reliability – SJ variables (ICC = 0.86–0.88; CV = 3.8–8.2%), CMJ variables (ICC = 0.87–0.96; CV = 3.3–3.8%).

### 2.4. Statistical analysis

We analysed the collected data using the IBM SPSS (version 25.0) software. Descriptive statistics are presented as the mean and standard deviation. The normality of the data distribution was checked using the Shapiro–Wilk test and a visual assessment of histograms. All normality test were non-significant ( $p = .078–.898$ ); therefore, parametric statistical procedures were used. The associations between the outcome variables were examined using Pearson's correlation coefficient. The associations were interpreted as negligible ( $r < 0.1$ ), weak ( $r = 0.1–0.4$ ), moderate ( $r = 0.4–0.7$ ), strong ( $r = 0.7–0.9$ ), or very strong ( $r > 0.9$ ) (Akoglu 2018). Statistically significant differences were accepted at a confidence level of  $\alpha < 0.05$ .

## 3. Results

### 3.1. Descriptive statistics

Table 2 shows the descriptive statistics for outcome measures considered for correlation analysis.

### 3.2. Correlations

Across the whole sample, there was a small but statistically significant negative correlation between EUR<sub>PF</sub> and RFD<sub>SJ</sub> ( $r = -.41$ ;  $p < .001$ ). This finding persisted if the sample was split into men ( $r = -.46$ ;  $p < .001$ ) and women ( $r = -.31$ ;  $p < .041$ ). There was also a small but statistically significant negative correlation between EUR<sub>PP</sub> and RFD<sub>SJ</sub> ( $r = -.27$ ;  $p < .001$ ) across the whole sample, as well as in men only ( $r = -.29$ ;  $p < .001$ ) and women only ( $r = -.20$ ;  $p < .048$ ). There were no statistically significant correlations between EUR<sub>JH</sub> and RFD<sub>SJ</sub>, considering either total sample ( $r = .10$ ;  $p = .074$ ), men only ( $r = .05$ ;  $p = .426$ ) or women only ( $r = .16$ ;  $p = .102$ ).

Correlation analysis was further performed on sport subgroups, which is shown in Table 3. Moderate and statistically significant negative correlations between EUR<sub>PF</sub> and RFD<sub>SJ</sub> were present in male basketball players ( $r = -.58$ ;  $p < .001$ ) and male students ( $r = -.41$ ;  $p = .023$ ). Small and statistically significant negative correlation between EUR<sub>PF</sub> and RFD<sub>SJ</sub> was also noted in male soccer players ( $r = -.36$ ;  $p = .020$ ). There was also a moderate and statistically significant negative correlation between EUR<sub>PF</sub> and RFD<sub>SJ</sub> in women students ( $r = -.43$ ;  $p = .024$ ). For EUR<sub>PP</sub>, statistically significant correlations with RFD<sub>SJ</sub> were found in male basketball players ( $r = -.34$ ;  $p < .001$ ), male soccer players ( $r = -.33$ ;  $p = .034$ ) and male runners ( $r = -.49$ ;  $p = .006$ ). No statistically significant correlations were found between EUR<sub>JH</sub> and RFD<sub>SJ</sub> for any subgroup (see Table 3 for details).

Table 2. Descriptive statistics for main outcome variables.

Outcome variable	Men ( $n = 209$ )		Women ( $n = 104$ )	
	Mean	SD	Mean	SD
SJ Height (cm)	29.11	5.25	22.03	4.15
SJ Peak Force (%BW)	244.9	26.2	221.0	21.9
SJ Peak Power (W/kg)	46.3	7.59	45.1	7.8
CMJ Height (cm)	31.86	5.26	23.75	4.31
CMJ Peak Force (%BW)	249.6	24.0	226.4	19.7
SJ Peak Power (W/kg)	47.4	8.2	45.4	7.5
EUR <sub>JH</sub>	1.11	0.13	1.08	0.11
EUR <sub>PF</sub>	1.03	0.11	1.03	0.10
EUR <sub>PP</sub>	1.01	0.07	1.00	0.07
SJ RFD (N/kg/s)	140.3	63.9	103.3	45.7

SJ – squat jump; CMJ – countermovement jump; EUR<sub>JH</sub> – eccentric utilization ratio based on jump height; EUR<sub>PF</sub> – eccentric utilization ratio based on peak force; EUR<sub>PP</sub> – eccentric utilization ratio based on peak power; RFD – rate of force development; SD – standard deviation.

**Table 3.** Sex and sport-specific correlation analysis.

Sex	Sport	EUR <sub>JH</sub>		EUR <sub>PF</sub>		EUR <sub>P</sub>	
		r	p	r	p	r	p
Men	Basketball ( <i>n</i> = 106)	0.14	0.158	−0.58*	<0.001	−0.34**	<0.001
	Students ( <i>n</i> = 31)	0.29	0.119	−0.41*	0.023	−0.14	0.453
	Soccer ( <i>n</i> = 42)	−0.15	0.335	−0.36*	0.020	−0.33*	0.034
	Running ( <i>n</i> = 30)	−0.14	0.450	−0.29	0.109	−0.49**	0.006
Women	Basketball ( <i>n</i> = 58)	0.17	0.196	−0.24	0.074	−0.22	0.094
	Students ( <i>n</i> = 27)	0.24	0.232	−0.43*	0.024	−0.07	0.728
	Running ( <i>n</i> = 19)	−0.23	0.339	−0.15	0.525	−0.25	0.312

EUR<sub>JH</sub> – eccentric utilization ratio based on jump height; EUR<sub>PF</sub> – eccentric utilization ratio based on peak force.

#### 4. Discussion

In this exploratory study, our aim was to explore the relationship between EUR and RFD in SJ among athletes. The EUR, a ratio of performance in CMJ and SJ, has traditionally been used as an indicator of physical readiness of athletes, specifically purported to reflect the utilization of elastic energy and stretch-shortening cycle (McGuigan et al. 2006). Drawing on data from 313 (209 men and 104 women) athletes across various sports disciplines, including basketball, soccer, and running, as well as physical education students, the study demonstrated small to moderate negative association correlation between EUR based on peak force or peak power and RFD in SJ. This finding suggests that a higher EUR may be indicative of a decreased ability to rapidly develop force in SJ, challenging the conventional understanding of EUR as a straightforward marker of superior athletic performance.

The findings of this study challenge the traditional view of EUR as a straightforward indicator of athletic physical readiness. A large EUR, commonly interpreted as reflecting efficient energy storage and reuse, might alternatively indicate poorer SJ performance, particularly the rapid force generation (Van Hooren and Zolotarjova 2017). Our results, showing a negative correlation between EUR and the rate of force development in SJ, support this assumption. In a previous study, the observation of higher EURs in certain athlete groups, such as track and field, compared to gymnasts and parkour practitioners, despite the latter's superior jumping performance, which casts further doubt about using EUR as a performance metric (Kozinc et al. 2021). Interestingly, only EUR based on peak force and peak power, but not jump height, correlated with SJ RFD. This observation is difficult to explain and possible underlying cause can only be speculated without additional investigation. It is conceivable that factors beyond force and power output, such as joint coordination and postural balance (Tomioka et al. 2001; Granacher et al. 2012), may exert an influence on the achieved jump height, introducing greater variability to this metric and potentially masking any correlations.

The potential mechanistic link between lower RFD in SJ and higher EUR is likely grounded in the dynamics of muscle stimulation, excitation, and contraction (Bobbert and Van Zandwijk 1999; Bobbert and Casius 2005). Stimulation dynamics involve the gradual build-up of muscle stimulation, influenced by motor neuron pool excitation and central commands. Excitation dynamics involve the establishment of the active state within muscles, influenced by electrochemical delays, while contraction dynamics pertain to the generation of force in response to the active state (Bobbert and Van Zandwijk 1999; Van Hooren and Zolotarjova 2017). Recent theories suggest that athletes with deficiencies in this process may demonstrate lower SJ RFD and overall SJ performance. However, they may gain greater advantages from the countermovement, enabling them to pre-activate and pre-tense their muscles before the initiation of the propulsive phase (Van Hooren and Zolotarjova 2017). In addition, muscle stiffness and slack may also influence the performance in SJ. Muscle-tendon units (including fascicles and tendinous tissues) can be in a slackened state when muscles are relaxed. This slack must be taken up, and tendinous tissues stretch before force can be transmitted to initiate joint movement (Van Hooren and Bosch 2016). However, during a countermovement, the attachment points of the muscle-tendon unit move apart, reducing muscle slack. This realignment enables quicker force transmission, ultimately enhancing performance (Finni et al. 2000). On the other hand, athletes with stiffer tendons would benefit less from countermovement and show lower EUR, which was also reported before (Kubo et al. 1999).

This exploratory study, while providing valuable insights, has several limitations. The sample's heterogeneity and exploratory retrospective data analysis raise potential bias concerns. Subgroup analyses, though informative, are constrained by sample sizes. The generalizability of results to diverse populations and the potential influence of unmeasured confounding factors must be considered. The study may not have accounted for all variables that could influence the relationships observed, such as muscle stiffness and slack. Future

investigations could incorporate more comprehensive battery of tests and explore potential confounding factors in greater detail.

## 5. Conclusions

This exploratory study challenges traditional assumptions regarding the EUR. The findings reveal small to moderate negative correlations between EUR based on peak force and RFD in squat jumps. These results urge a reconsideration of EUR as a straightforward marker of athletic performance. Future research should further explore the mechanisms underlying these associations and explore their practical implications for athletic training and assessment.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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