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Reactive Strength Index Modified Differentiates Starters and Non-Starters in Female Volleyball National Team Players

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Abstract: Jumping ability is crucial in volleyball, where both jump height and execution speed significantly influence performance. Previous research has yielded mixed findings on the role of jump force-time characteristics in determining starting status among female volleyball players. This study examined the relationship between countermovement jump (CMJ) force-time metrics and starting status in elite female volleyball players to identify key performance indicators. Nine national team athletes (five starters, four non-starters) performed CMJs on a force platform. Force-time variables from distinct jump phases were analyzed. Reactive strength index modified (RSImod)—the ratio of jump height to time to take-off—was used to assess lower-body explosiveness and reactive strength. Starters demonstrated significantly higher RSImod scores and relative propulsive mean force, indicating superior ability to generate force rapidly. Moderate-to-large effect sizes favoring greater relative strength (force and power normalized to body mass) were observed but were not statistically significant. Reactive strength, as reflected by RSImod, is a key differentiator of starting status in elite female volleyball players. Relative strength also appears to contribute to performance but requires further exploration. Training programs should prioritize lower-body power and reactive strength through targeted plyometric and resistance exercises to enhance volleyball performance.

Keywords: Countermovement Jump, Elite Female Athletes, RSImod, Relative Strength, Jump Performance, Athlete Profiling

1. Introduction

Volleyball is a high-intensity sport characterized by frequent explosive actions, including jumps and rapid directional changes (Akarcesme *et al.,* 2018; Bahr & Bahr, 2014; Tillman *et al.,* 2004). These movements are critical for offensive skills like spiking and defensive actions such as blocking (Lockie *et al.,* 2020; Sheppard *et al.,* 2008; Tramel *et al.,* 2019), making lower-body power a key determinant of performance across competitive levels (D. V. Cabarkapa, Cabarkapa, Bankovic, *et al.,* 2024; Lidor & Ziv, 2010). Consequently, coaches and sports scientists emphasize physical assessments that reflect neuromuscular performance and monitor training adaptations (Bishop, Jordan, *et al.,* 2023; Haugen e*t al.,* 2020).

The countermovement jump (CMJ) is widely regarded as a reliable, non-invasive tool for assessing lower-body power (Markovic et al., 2004). Using force plates, practitioners can capture detailed force-time metrics across CMJ phases, including jump height, peak and mean force and power, phase duration, and reactive strength (Bishop, Jordan, *et al.,* 2023; Kipp *et al.,* 2016). This approach goes beyond traditional metrics (i.e. jump height), offering insights into the biomechanical qualities underlying athletic power, movement efficiency and jumping strategy (Bishop, Jordan, *et al.,* 2023; McMahon *et al.,* 2018; Rauch *et al.,* 2020).

Derived from these force-time metrics, the Reactive Strength Index modified (RSImod)—calculated as jump height divided by contraction time (i.e., time to takeoff)—has gained attention as a meaningful indicator of neuromuscular performance in slow stretch-shortening cycle (SSC) movements like the CMJ (Suchomel, Sole, *et al.,* 2016). Unlike the traditional RSI, which is derived from drop jumps and emphasizes mainly fast SSC function, RSImod better reflects an athlete's ability to generate explosive force under conditions more relevant to volleyball-specific jumping demands (Ebben & Petushek, 2010; Sole *et al.,* 2018; Suchomel, Sole, *et al.*, 2015, 2016).

Research on volleyball players has examined physical characteristics across variables such as sex (Fuchs *et al.,* 2019; Lidor & Ziv, 2010), competitive level (Lidor & Ziv, 2010), and playing position (García-de-Alcaraz *et al.,* 2020; Marques *et al.,* 2009). While elite athletes consistently outperform lower-level players in jump performance, studies frequently prioritize jump height as an outcome metric, over more comprehensive force-time metrics. Notably, Cabarkapa et al. (2024) reported no significant differences in CMJ force-time metrics between starters and non-starters among high-level female volleyball players, suggesting that at advanced levels, physiological attributes may plateau, and other factors—such as technical skills, tactics, and psychological resilience—may become more influential. Although studies in this field are increasing, the sample sizes tend to be small, underscoring the need for further research to validate these findings.

This study aims to add to the growing body of literature on elite female athletes by examining CMJ force-time characteristics in a cohort of national team female volleyball players, comparing those who are regular starters to non-starters. In particular, RSImod will be used to assess reactive strength due to its relevance to CMJ performance and its applicability to volleyball's slow SSC demands.

2. Materials and Methods

2.1 Participants

Data for this study is secondary to routine testing conducted as part of the national team training program. Twelve players participated (libero: n=2; middle blocker: n=3; opposite hitter: n=1; outside hitter: n=5; setter: n=1). All players were starters in their respective clubs, competing in Israel's first division, Europe's first and second divisions, and NCAA colleges in the United States. Testing was conducted one month before a two-game European Championship qualifying campaign, following two months of national team training and after the conclusion of their club seasons. The national team ranked among the top 30 European teams after the campaign (Official Women's Volleyball World Ranking | Volleyball World, n.d.). All participants were injury-free and reported no discomfort that could affect jump performance. Informed consent was obtained from all players, and the study was approved by an institutional review board (approval number 1/2024). All participants were over 18 years of age.

2.2 Testing protocol

Testing took place between 9:00 and 10:00 a.m. Prior to the jump tests, players completed a structured warm-up, led by their strength and conditioning coach, which included light aerobic activity, dynamic stretching, and jump-based activation exercises. Players were weighed on a Kistler piezoelectric dual force plate (Kistler, model 9260AA6, Winterthur, Switzerland), sampling at 1000 Hz, before performing three countermovement jumps (CMJs). During each jump, players dropped to a self-selected depth, keeping their hands on their hips throughout the movement. A rest period of 15–30 seconds was provided between trials, and the best performance was recorded for analysis. Players were instructed to jump as high as possible and received verbal encouragement from their peers.

2.3 Force-time variables

Force-time variables from both the downward (eccentric) and upward (propulsive) phases were selected as performance indicators and measures of jump strategy, based on previous research (Bishop, Jordan, *et al.,* 2023; D. V. Cabarkapa, Cabarkapa, Bankovic, *et al.,* 2024; D. V. Cabarkapa, Cabarkapa, & Fry, 2024; Kipp *et al.,* 2016; McMahon *et al.,* 2018; Merrigan *et al.,* 2021). In this paper, the term "eccentric phase" refers to the combined unweighing and braking phases of the CMJ (i.e., as the center of mass descends), rather than to the type of muscular contraction (i.e., eccentric contraction, as the muscle fibers lengthen). This terminology is commonly used in the literature and practice.

Contraction time (time to take-off or jump time) and jump height were automatically calculated by the force plate analysis software (Kistler MARS, v5.2.1.237). Raw data were exported into Microsoft

Excel, where additional variables were calculated following Chavda et al., (2018). Body mass was recorded directly by the MARS software. Jump height was calculated using two methods: flight time (FT) and take-off velocity (impulse-momentum [IM]) (Moir, 2008; Xu *et al.,* 2023). Reactive strength index modified (RSImod) was calculated as jump height (from both methods) divided by contraction time (time to take-off), resulting in two different measures of RSImod. Countermovement depth (cm) was determined by triple integration of force-time data: net force divided by body mass to calculate acceleration, followed by integration to obtain velocity and displacement (Chavda *et al.*, 2018; McMahon *et al.,* 2018).

2.4 Statistical Analysis

To focus on positions where maximal jumping ability is a key performance indicator, players in the libero (n=2) and setter (n=1) positions were excluded, resulting in a final sample of nine players (5 starters, 4 non-starters). The single setter, always a starter, was excluded as her inclusion was not relevant to the research question. Libero players were excluded as jumping ability is less critical for their role, preventing potential bias in the results. Descriptive statistics (means and standard deviations) were calculated for each variable. The Shapiro-Wilk test assessed normality, and Levene's test assessed homogeneity of variance. For variables that did not meet the normality assumption, the Mann-Whitney U test was applied. For those violating the homogeneity assumption, the Welch t-test was used. When assumptions were met, an independent sample t-test was applied. Hedge's g (for n<20) was used to calculate effect size (ES), where g=0.2-0.5 indicates a small effect, g=0.5-0.8 a moderate effect, and g>0.8 a large effect. Statistical significance was set at p<0.05, and all analyses were conducted using JASP statistical software (JASP Team, 2024, Version 0.19.0).

3. Results

Significant differences and large effect sizes were observed between groups for propulsive relative mean force (p=0.02, g=-1), RSImod from take-off velocity (p=0.03, g=-1.6) and RSImod from FT (p=0.01, g=-1.9). Although not significant, moderate to large effect sizes were noted for body mass (g=0.6), downward phase duration (g=1.02), relative eccentric peak force (g=-0.54), relative eccentric mean power (g=0.56), relative eccentric peak power (g=0.87), propulsive phase duration (g=0.92), take-off velocity (g=-0.67), peak velocity (g=-0.7), propulsive relative mean power (g=-1.2), propulsive relative peak power (g=-1.05), jump height from FT (g=-0.84) and from IM (g=-0.68), and contraction time (g=0.83). Results are summarized in table 1.

4. Discussion

The current study highlights that the RSImod (calculated using both jump height calculation methods) and propulsive relative mean force are key force-time metrics distinguishing starters from non-starters among female national team volleyball players. RSImod, a measure of lower-body explosiveness, reflects an athlete's ability to transition rapidly from downward to upward motion. This ability is critical in volleyball, where high force production under limited time constraints directly impacts jumping performance in actions such as spiking and blocking (Southey *et al.,* 2024).

RSImod is both valid (Kipp *et al.,* 2016) and reliable (Suchomel, Bailey, *et al.,* 2015; Vieira & Tufano, 2020), and highly relevant to the demands of explosive sports (Sole *et al.*, 2018). While the reactive strength index (RSI, typically derived from a drop jump test) is well-established as a predictor of athletic performance (Jarvis *et al.,* 2022), RSImod is a relatively recent parameter introduced in 2010 (Ebben & Petushek, 2010), and the current study adds to the growing body of literature addressing the relationship between RSImod and athletic performance. Interestingly, research suggests that RSI and RSImod are not interchangeable measures of reactive strength, possibly due to the much longer contraction times (i.e., time to take-off) during the CMJ compared to the shorter ground contact times observed during the drop jump (Louder *et al.,* 2021).

Compared to collegiate athlete reference values (Sole et al., 2018), the RSImod scores of starters in our study exceeded the 97th percentile, whereas non-starters ranked within the 80th –85th percentile, reinforcing their elite status. Notably, while no statistically significant differences were found either in jump height or contraction time—the two components of RSImod—moderate to large effect sizes (g=0.68–0.84 for jump height; g=0.83 for contraction time) suggest that starters performed better in these metrics. When combined as RSImod, these differences became statistically significant, with very large effect sizes (g=1.6–1.9), highlighting its utility as a composite measure of reactive strength.

Table 1. Descriptive statistics, mean (standard deviation), for the entire sample, starters, and non-starters, along with statistical significance, and Hedges's g effect sizes between groups. *p<0.05; + moderate effect size; ++ large effect size. a non-normally distributed; b non-equal variance. IM = impulse-momentum; FT = flight time; RSImod = reactive strength index modified; CMJ = countermovement jump.

Variable (unit)	All players, n=9	Starters, n=5	Non-starters, n=4	*p*-value	Hedge's *g*
General					
Age (years)	24.8 (5.8)	26.2 (7)	22.9 (3.9)	0.434	-0.494
Height (cm)	183.7 (4.03)	182.2 (3.2)^{a}	185.5 (4.7)	0.3	0.45
Body mass (kg)^{a}	77.6 (7.1)^{a}	75.9 (7)^{a}	79.8 (7.5)	0.19	0.6^{+}
Eccentric phase	All players, n=9	Starters, n=5	Non-starters, n=4	*p*-value	Hedge's *g*
Braking phase duration (s)	0.152 (0.026)	0.149 (0.024)	0.157 (0.032)	0.66	0.27
Total phase duration (s)	0.461 (0.055)	0.436 (0.041)	0.493 (0.058)	0.13	1.02^{++}
Absolute Mean force (N)^{a}	745 (76.2)^{a}	732.1 (77.9)^{a}	761.1 (82.2)^{a}	0.4	0.4
Relative Mean force (N/kg)	9.6 (0.2)	9.6 (0.2)	9.5 (0.3)	0.52	-0.4
Absolute Peak force (N)	1877.4 (299)	1879.2 (232.4)	1875.2 (407.9)	0.97	-0.01
Relative Peak force (N/kg)	24.1 (2.3)	24.7 (1.6)	23.3 (3.1)	0.39	-0.54^{+}
Absolute Mean power (W)	-514.8 (63.4)	-520.7 (60.3)	-507.5 (75.7)	0.78	0.17
Relative Mean power (W/kg)	-6.7 (0.9)	-6.9 (1.1)	-6.3 (0.6)	0.37	0.56^{+}
Absolute Peak power (W)	-1632.1 (324.7)	-1702.1 (206.9)	-1544.7 (453.6)	0.5	0.42
Relative Peak power (W/kg)	-21 (3.7)	-22.5 (2.8)	-19.1 (4.1)	0.19	0.87^{++}
Propulsive phase	All players, n=9	Starters, n=5	Non-starters, n=4	*p*-value	Hedge's *g*
Total phase duration (s)	0.283 (0.033)	0.269 (0.03)	0.301 (0.03)	0.17	0.9^{++}
Take-off velocity (m/s)^{b}	2.53 (0.15)	2.57 (0.18)	2.46 (0.1)	0.29	-0.67^{+}
Peak velocity (m/s)	2.64 (0.15)	2.69 (0.17)	2.58 (0.1)	0.28	-0.7^{+}
Absolute Mean force (N)^{a}	1491.8 (162.1)	1500.6 (174.5)^{a}	1480.9 (170.7)	0.91	-0.1
Relative Mean force (N/kg)	19.2 (0.9)	19.7 (0.5)	18.5 (0.8)^{a}	0.02*	-1^{++}
Absolute Peak force (N)	1895.3 (274.2)	1880.1 (231.4)	1914.3 (358)	0.87	0.104
Relative Peak force (N/kg)	24.3 (1.8)	24.7 (1.5)	23.8 (2.3)	0.5	-0.43
Absolute Mean power (W)	2016.4 (286.2)	2075.2 (215.2)	1942.9 (379.1)	0.5	-0.4
Relative Mean power (W/kg)	26 (2.6)	27.3 (1.5)	24.2 (2.9)	0.07	-1.26^{++}
Absolute Peak power (W)	3709.4 (286)	3771.1 (263.2)	3632.3 (333.9)	0.5	-0.417
Relative Peak power (W/kg)	48 (4.1)	49.9 (4)	45.6 (3.1)	0.12	-1.05^{++}
Other	All players, n=9	Starters, n=5	Non-starters, n=4	*p*-value	Hedge's *g*

Jump height IM (cm)[b]	32.6 (3.9)	33.9 (4.6)	31.1 (2.5)	0.28	-0.68⁺
Jump height FT (cm)	35.9 (5.5)	38.1 (6.4)	33.2 (2.9)	0.2	-0.84⁺⁺
Contraction (jump) time(s)	0.787 (0.098)	0.748 (0.088)	0.835 (0.098)	0.2	0.83⁺⁺
CMJ Depth (cm)	33.6 (5.4)	33.3 (7.2)	34 (3.2)	0.85	-0.11
RSImod IM (ratio)	0.42 (0.06)[a]	0.453 (0.021)	0.377 (0.06)	0.03*	-1.6⁺⁺
RSImod FT (ratio)	0.46 (0.07)	0.506 (0.029)	0.403 (0.065)	0.01*	-1.9⁺⁺

Physiologically, higher RSImod scores in starters likely reflect their superior neuromuscular function (Kipp *et al.,* 2016; Krzyszkowski *et al.,* 2022). Such superior power performance has been demonstrated to be linked to enhanced motor unit recruitment, greater fast-twitch muscle fiber composition, and higher tendon stiffness (Cormie *et al.,* 2011). These physiological attributes contribute to a more efficient stretch-shortening cycle (SSC), allowing for rapid force production and minimized contraction time during jumping movements (Cormie *et al.,* 2011). Given that volleyball performance heavily depends on explosive actions like spiking and blocking, players with superior reactive strength are more likely to be selected as starters, as their ability to generate force quickly gives them a competitive edge. This aligns with previous research showing that RSImod is strongly associated with rate of force development (RFD), a key determinant of explosive performance in elite athletes (Suchomel, Bailey, *et al.,* 2015).

Our findings partially contrast with those of Cabarkapa *et al.* (2024), who examined professional female volleyball players and found no significant differences in force-time metrics between starters and non-starters. While their results also suggested slightly higher jump heights and faster contraction times for starters, these differences were not statistically significant. Notably, their study included setters and liberos—positions with distinct physical demands—and considered a greater number of matches (exact number unspecified). However, in another study, Cabarkapa *et al.,* (2024) confirmed that RSImod effectively differentiates competitive levels in volleyball (national team, professional league, and collegiate levels), raising the question whether a threshold of physical abilities exist, beyond which no further improvements will affect performance positively.

The use of a cross-sectional "rank order study" framework assumes that starting athletes represent a higher performance level (Stone *et al.,* 2002).This assumption is supported by findings from studies in women's volleyball (Fry *et al.,* 1991), female handball (Radovic *et al.,* 2024), and elite Australian rules football (Young *et al.,* 2005), which emphasize the importance of physical attributes—including strength, power, and speed—in distinguishing performance levels. However, other research has reported no significant physical differences between starters and non-starters, suggesting that non-physical factors may contribute equally or more significantly to starting status (D. Cabarkapa *et al.,* 2023; D. V. Cabarkapa, Cabarkapa, & Fry, 2024; Oliveira *et al.,* 2023; Risso *et al.,* 2017). Discrepancies between studies could reflect differences in force production demands and jumping strategies across sports (Donahue *et al.,* 2023).

Taken together, these findings highlight the multifaceted nature of performance in team sports, where success often depends on a combination of physical and non-physical factors. While physical qualities are critical, factors such as coaching decisions and subjective evaluations (Hoffman *et al.,* 1996), motor coordination (Pion *et al.*, 2015), technical skills (Asterios & Gortsila, 2021; Silva *et al.,* 2014), experience (Young *et al.*, 2005), and team tactics and play style (Vargas *et al.*, 2018) contribute significantly to player selection and overall performance.

4.1 Body mass and relative strength

Our data underscores the significance of relative strength and body mass in performance. Starters in this study exhibited lighter body mass with a moderate effect size (ES, g=0.6, p>0.05), although the difference was not statistically significant. Moreover, when force and power metrics were normalized to body mass, their ES increased substantially compared to absolute values. For example, the mean absolute ES for normalized force and power during the eccentric phase was g=0.59, compared to g=0.25 for absolute values. Similarly, during the propulsive phase, the mean ES increased from g= 0.26 (absolute) to g=0.94 (normalized). When force and power parameters were normalized to body mass, out of eight total ES, three shifted from small to large, one shifted from trivial to large, two shifted from trivial to moderate, one shifted from trivial to small, and one changed from small in one direction (g=0.4) to small in the opposite direction (g=-0.4), representing a change of -0.8 (Figure 1).

These findings suggest that body mass plays a significant role in determining performance, with lighter athletes demonstrating greater relative strength and power output. Relative strength, defined as the ratio of force production to body mass, is crucial in sports where athletes must dynamically manipulate their center of mass (Dowson et al., 1998; Loturco et al., 2021; Suchomel, Nimphius, et al., 2016; Tramel et al., 2019). This ratio can be improved by either increasing force production without adding body mass or by reducing body mass while maintaining strength. For instance, minimizing non-functional fat mass while preserving muscle mass may enhance relative strength. Research and practical data indicate that strength does not scale in proportion to body mass, meaning smaller athletes often possess greater relative strength. For instance, the clean and jerk world record in the -55 kg category (166 kg) is 3.02 times the athlete's body weight, whereas the record in the +109 kg category (267 kg) is only 1.45 times the athlete's body weight (Senior Men's World Records, n.d.).

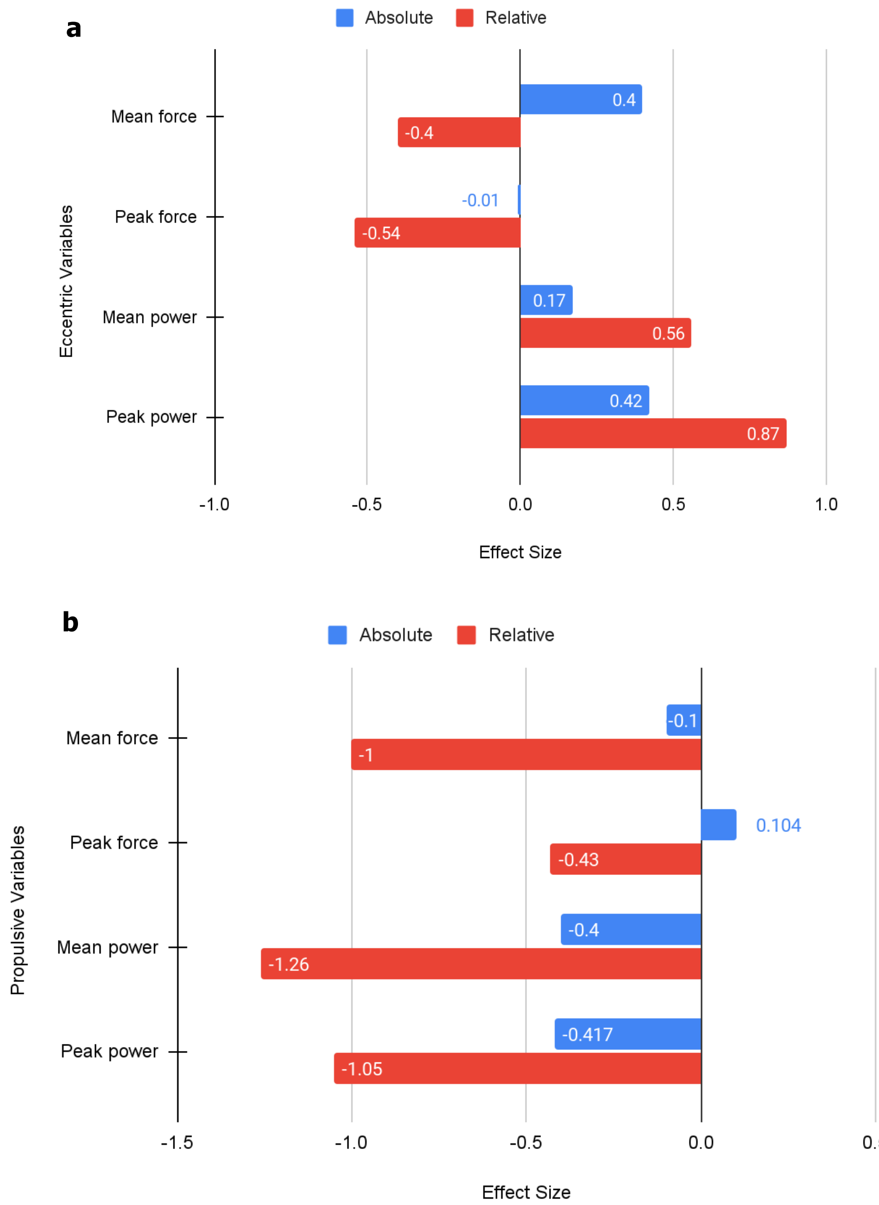

Figure 1. Hedge's g effect sizes for absolute and relative force and power variables during the eccentric (a) and propulsive (b) phases. Effect sizes were classified as trivial (0–0.2), small (0.2–0.5), moderate (0.5–0.8), and large (>0.8). Negative effect sizes indicate an advantage for the starter group, except for eccentric power variables, where positive effect sizes indicate an advantage for the starter group.

4.2 Practical applications

The jump-reach and attack-jump tests are widely used in volleyball performance assessments (Sattler *et al.,* 2012). However, at higher levels of play, where athletes are closely matched, jump height alone may no longer be a decisive factor in differentiating success (D. V. Cabarkapa, Cabarkapa, & Fry, 2024). In such cases, evaluating athletes' reactive strength using the RSImod may provide more meaningful insights. Since ratio metrics like RSImod does not reveal the underlying factors driving this metric (Bishop, Shrier, *et al.,* 2023), strength and conditioning programs should be individualized based on the individual metrics obtained from these assessments. For athletes who have achieved sufficient jump height for their positional demands, training should emphasize reducing the time required to reach peak height rather than striving for marginal increases in jump height. This shift can be supported by integrating high-velocity training modalities, such as weighted jumps, plyometric exercises, and Olympic weightlifting or its derivatives (Suchomel *et al.,* 2017, 2020). These methods enhance the rate of force development (RFD), which has been shown to improve RSImod by increasing athletes' ability to generate force both rapidly and efficiently (Blazevich et al., 2020; Rebelo *et al.,* 2022).

Strength and conditioning staff should also prioritize optimizing the strength-to-mass ratio. This can be achieved by tracking trends in force output relative to body mass and body composition during regular testing sessions. Pairing physical performance assessments, such as countermovement jump (CMJ) or one-repetition maximum (1-RM) tests, with body composition measurements will provide comprehensive insights into training progress. To avoid excessive or unwanted hypertrophy that could hinder relative strength, particularly in non-contact sports like volleyball, coaches should employ training strategies designed to minimize increases in body mass. These include maintaining a relatively low total training volume (sets × repetitions) and avoiding exercises performed near muscular failure (Grgic *et al.,* 2022; Morton *et al.,* 2019; Schoenfeld *et al.,* 2017). Conversely, such restrictions may not apply to contact sports like rugby or soccer, where increased body mass can confer a performance advantage due to the physical nature of the sport.

4.3 Limitations

This study has several limitations. First, the small sample size of players (common in studies involving elite athletes) and matches reduces the generalizability of our findings. The study's low power (post-hoc analysis ranging from 0.38 to 0.82 for effect sizes of 1.0 to 1.9) warrants cautious interpretation, as it increases the risk that observed effects may be overestimated or influenced by random variation. Future research should include more participants of elite level, and greater number of matches to improve statistical power and enhance the applicability of findings. Second, both analyzed matches began with our team on offense, meaning the libero was not on the court during the opening rotations. This resulted in data from five starters being included instead of four, as would typically occur when starting on defense. This methodological limitation may have affected the representativeness of our findings. Including matches with diverse starting scenarios could address this issue. However, some coaches might view the player replacing the libero during offensive rotations as a "seventh starter," supporting our methodological analysis choice. Standardizing the definition of starters in future studies could improve consistency and comparability.

5. Conclusions

This study highlights the importance of reactive strength (expressed as RSImod) and relative propulsive mean force in distinguishing starters from non-starters in elite female volleyball. Relative strength, expressed as force and power normalized to body mass, also emerged as an interesting and important performance factor warranting further exploration. Training programs should prioritize enhancing force production, controlling body mass, and improving rapid force generation to align with these findings. While these results provide valuable insights, the limited sample size and match data necessitate careful interpretation to apply these findings broadly.

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Authors Contribution Statement

Idan Harat - Conceptualization, Investigation, writing Original Draft, Writing -Review & Editing. Nadav Lanesman - Methodology, Data Collection, writing Original Draft, Writing -Review & Editing. Both the authors read and approved the final version of this manuscript.

Ethics Approval Statement

The study was approved by an institutional review board (approval number 1/2024).

Consent to participate

All participants signed an informed consent form prior to participation.

Informed Consent

The consent form was signed before the commencement of the study.

Conflict of Interest

The authors declare that there was no conflict of interest.

Does this article pass screening for similarity?

Yes