

Overhead ballistic ball throw performance: Youth vs. senior female national-level volleyball players

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Abstract:

Background: The integration of inertial measurement units (IMUs) in medicine balls allows for the collection of metric-derived data across various performance tests in athletes. **Purpose:** This study aimed to (1) compare overhead throw performance between senior and youth national-level female volleyball players using an IMU-equipped ballistic ball, and (2) document inter-limb asymmetry across different throwing metrics. A total of 31 national-level volleyball players participated in this study, comprising 16 seniors and 15 youths. A standing two-arm (ST-OH) and single (dominant and non-dominant arm; ST-IOH) overhead medicine ball throw test was used to evaluate upper-body muscle performance (peak velocity, peak force, and peak power). **Results:** The senior group recorded significantly higher values for all metrics in ST-OH compared with the youth group (all $P < 0.01$). For ST-IOH, the dominant-arm produced higher values across all ballistic ball metrics within both the senior (all $P < 0.01$) and youth groups (all $P < 0.01$), respectively. The senior group was able to produce a greater throw velocity in the dominant arm compared with the comparable arm in the youth group ($P = 0.026$). For the non-dominant arm, a significant between-group inter-limb asymmetry was only noted for force (all $P < 0.037$). **Conclusion:** Our findings support the use of the IMU-integrated medicine ball to develop the upper-body power of youth volleyball athletes based on meeting the benchmarking criteria of senior athletes. Moreover, our data suggest the medicine ball may be used to identify the presence of upper-body inter-limb asymmetry in volleyball players. Incorporating unilateral resistance training and using targeted training implements (i.e., bands, medicine ball, ballistic ball) should be employed on an individual basis to reduce asymmetry by targeting the force-velocity curve.

Key Words: Medicine ball, Upper-body power, Inertial-measurement unit, Asymmetry

Introduction

Volleyball is an intermittent team sport characterized by repeated bouts of high- and low-intensity movements, which require complex actions and high levels of technical and tactical skill (Forthomme et al., 2005; Gabbett and Georgieff, 2007; Sheppard et al., 2008). During a competitive match, athletes perform a variety of skills including serves and spikes (Tooth et al., 2023) which require the coordination of the upper- and lower-body musculature to generate the necessary power during offensive actions (Baena-Raya et al., 2021; Gonçalves et al., 2021). Therefore, assessing upper-body power is fundamental to enhancing the performance of overhead athletes of varying age and playing abilities (Tooth et al., 2023).

Explosive throwing movements enable the projection of an implement utilizing the entire kinetic chain, without the deceleration phase at peak velocity that is encountered during resistance training (i.e., compound lifts). This has led to medicine ball throw distance becoming widely adopted as a proxy for assessing maximal power production of the upper-body (Gabbett and Georgieff, 2007; Marques et al., 2009, 2008). However, the recent integration of inertial-measurement units (IMU) inside medicine balls has enabled the direct evaluation of velocity-based metrics during throwing movements (Beckham et al., 2019; Sato et al., 2018). While this technology offers a promising approach to inform the training process via athlete profiling, to date, few studies have incorporated this technology to assess maximal upper-body power.

To support talent identification and the physical development of youth athletes, benchmarking performance against senior players is conducted to establish the standards required at higher levels of competition (Dodd and Newans, 2018; Lidor and Ziv, 2010; Robertson et al., 2022; Rubajczyk and Rokita, 2020). It has previously been demonstrated that elite volleyball players possess superior upper-body explosive power compared to their sub-elite counterparts (Gonçalves et al., 2021; Shahbazi-Moghaddam, 2002a). However, past studies examining the expression of maximal power across different athlete cohorts have favored the standing two-arm backward overhead (Beckham et al., 2023; Mayhew et al., 2005; Stockbrugger and Haennel, 2001) or seated chest (Alonso-Muñoz et al., 2023; Gonçalves et al., 2021; Sayers and Lorenzetti, 2020) throwing assessments, which lack the ecological validity of performing a volleyball spike. In contrast, standing single-arm medicine ball tests enable the comparison of throw performance between dominant and non-dominant arms in a manner more representative of a spiking action. These unilateral tests may also help identify inter-limb asymmetries that can lead to performance decrements and/or increased injury risk (Kyritsis et al., 2016; Maloney, 2019). While the magnitude of inter-limb asymmetry in the lower body is well-documented in sports

involving repeated jumping actions (Fort-Vanmeerhaeghe et al., 2016), few studies have investigated upper-body asymmetry in overhead sports (Hadzic et al., 2014). Notably, females may be more susceptible to developing inter-limb asymmetries (Bailey et al., 2015; Bishop et al., 2020), a group generally under-represented in sport science research (Anderson et al., 2023; Doherty et al., 2024). Therefore, IMU medicine balls may be utilized during a sport-specific throwing action (i.e., volleyball spike) to assess both maximal upper-body power and the magnitude of inter-limb asymmetry across different velocity-based metrics.

Accordingly, the primary aim of this study was to examine the difference in bilateral and unilateral upper-body performance between youth and senior national-level female volleyball players using an IMU medicine ball during sport-specific movement tasks. Our secondary aim was to document and compare the magnitude of inter-limb (arm) asymmetry across the different IMU derived metrics. We hypothesized that senior players would attain higher bilateral and unilateral throw values compared with the youth players. In contrast, no formal hypotheses are declared for the magnitude of inter-limb asymmetry within and between groups due to the exploratory (observational) nature of this aspect of the study.

Materials & Methods

Experimental Design

This study utilized a between-subject cross-sectional research design. A cohort of senior and youth volleyball players belonging to the same national training center were recruited to take part in this study. All participants were asked to attend the laboratory on a single occasion, which was scheduled to avoid strenuous in-season team training in the preceding 24 h. Participants arrived at the training center in the morning (07:00 h) after an overnight fast. After changing into training shorts and a vest, participants had their anthropometric and body composition (InBody 570 analyzer, InBody Co. Ltd., Korea) parameters recorded (Table 1). Participants then completed a standardized 10-minute warm-up, which included movements similar the players pre-game warm up routine, and a familiarization session, before commencing the experimental protocol.

Table 1. General characteristics of the female volleyball players.

Variable	Senior N = 16 [†]	Youth N = 15 [†]
Age (years)	26.6 (4.2)	15.8 (0.6)
Height (cm)	176.8 (4.9)	177.0 (6.6)
Body mass (kg)	68.5 (8.0)	67.1 (7.0)
BMI (kg·m ²)	21.9 (2.3)	21.4 (2.2)
Muscle mass (kg)	32.0 (3.3)	29.7 (2.2)
FFM-D (kg)	3.0 (0.3)	2.7 (0.2)
FFM-ND (kg)	2.9 (0.3)	2.6 (0.2)

[†]Mean (SD); FFM-D: Fat-free mass-dominant arm; FFM-ND: Fat-free mass-non-dominant arm.

Participants

Thirty-one female volleyball players (senior players, $n=16$; youth players, $n=15$) were recruited to take part in this study. Participants were excluded from the study if they reported a musculoskeletal injury/surgery in the last 6 months. Each participant's dominant arm was considered the favored arm to perform a volleyball spike. Due to the limited number and accessibility of players affiliated with the national training center, a sensitivity analysis was performed to determine the effect size detectable with our sample size. A between-subject (Senior, Youth) analysis of variance (ANOVA) with repeated measures (2 levels for Arm) with 31 participants would be sensitive to detecting effects of $f = 0.54$. All participants provided their voluntary written informed consent to participate after having the experimental procedures fully explained. The institutional research ethics committee approved the study (MU-CIRB 2023/080.2702), which conformed with the latest amendment of the Declaration of Helsinki.

Overhead Medicine Ball Throws

Participants were familiarized with the standing double-arm (ST-OH) and single-arm (ST-IOH) overhead medicine ball throws using 3 submaximal trials performed at 50% of subjective maximal effort. An IMU integrated 3-kg medicine ball (Ballistic Ball™ X, USA), which enabled measures of force, power, and velocity to be recorded via Bluetooth connection to an iOS software application (MoveFactorX, MI, USA), was used for all experimental trials. After a 10-minute rest period (following familiarization), participants were asked to perform the medicine ball throw tests in a standardized order (ST-OH, ST-IOH). For the ST-OH, participants were instructed to stand at a marked horizontal line with their feet shoulder-width apart and toes pointing forwards. Participants held the medicine ball in both hands extended directly above their head, before rapidly extending their shoulder into extension and throwing the medicine ball forwards as far as possible (i.e., into shoulder flexion; Figure 1). A slight bend of the knees and extension of the back was permitted. For ST-IOH, participants positioned their feet in a staggered position and held the medicine ball in their dominant hand above their head. The shoulder was then rapidly extended with horizontal external rotation before throwing the medicine ball forwards as far as possible. The same procedure was repeated for the non-dominant arm. Three trials were performed for each task, which were separated by a 2-minute rest period. Each throw task was separated by a 5-minute rest period. If participants stepped beyond the marked horizontal line, or lost control of

the medicine ball upon throwing, the trial was not recorded and repeated. The metrics derived from the inertial-sensor medicine ball (peak velocity, peak power, peak force) were recorded from each trial, with the highest values used for data analysis.

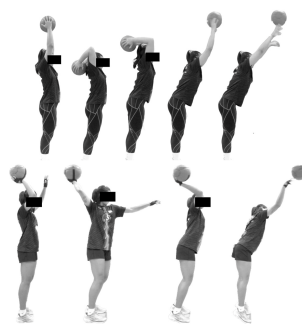


Figure 1. The throwing technique for the ST-OH (top) and ST-1OH (bottom) tests.

Data Analysis

The normality of the data was assessed using standard diagnostic residual checks. Independent *t*-tests were used to examine between-group differences in ST-OH metrics (peak velocity, peak power, peak force). Random-intercept linear effects mixed models (LMM), estimated using restricted maximum likelihood (REML), were employed to examine between-arm differences in ST-1OH throw metrics. LMM fixed effects included Group [Senior, Youth] and Arm [Dominant, Non-Dominant] and Participant as the random effect in the model formula: [Outcome ~ Group * Arm + (1|Participant)]. Our primary focus was placed upon interaction effects. Where significant main effects were found, post hoc pairwise comparisons with a Holm-Bonferroni correction were applied. Cohen's *d* effect sizes were calculated for pairwise comparisons and interpreted against the following benchmarks: 0.20 - 0.60 (small), 0.60 - 1.20 (medium), 1.20 - 2.00 (large), and ≥ 2.00 (very large) (Cohen, 1988). The percentage of inter-limb (arm) asymmetry was calculated using the Bilateral Strength Asymmetry (BSA) formula (Bishop et al., 2016; Impellizzeri et al., 2007): $BSA = (\text{max value} - \text{min value} / \text{total value} \times 100)$. Independent *t*-tests were used to examine for between-group differences in inter-limb asymmetry across medicine ball metrics. Statistical analyses were performed using RStudio (version 2024.04.2, Posit Software, PBC, Boston, MA, USA). The significance level was set at $P < 0.05$. The mean and 95% confidence intervals (95% CI) are reported, unless otherwise stated.

Results

The absolute values obtained from the overhead medicine ball throwing tasks are available in a supplementary file (Table S1).

Standing Two-Arm Overhead Medicine Ball Throw Test (ST-OH)

For ST-OH, a significantly higher peak velocity (mean difference = $0.90 \text{ m}\cdot\text{s}^{-1}$, 95% CI [0.20,1.60], $P = 0.014$, $d = 0.95$; Figure 2A), peak power (mean difference = 213 W, 95% CI [90, 335], $P < 0.01$, $d = 1.27$; Figure 2B), and peak force (mean difference = 22.5 N, 95% CI [9.3, 35.7], $P < 0.01$, $d = 1.24$; Figure 2C) was recorded in the senior group compared with the youth group.

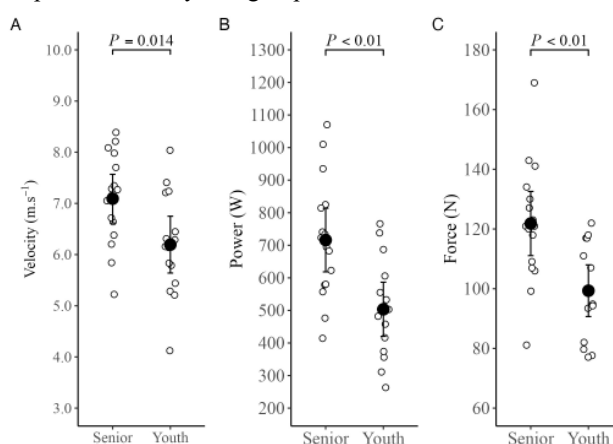


Figure 2. The peak velocity (A), peak power (B) and peak force (C) recorded from the standing two-arm overhead medicine ball throw tests (ST-OH) in the senior and youth groups (mean $\pm$ 95% CI). The open circles represent individual data points.

Standing Single-Arm Medicine Ball Throw test (ST-1OH)

For the ST-1OH task, a significant group $\times$ arm interaction effect was found for medicine ball throw peak force ($P < 0.01$). However, no significant interaction effect was found for medicine ball throw peak velocity

($P=0.122$), or peak power ($P=0.906$). In the senior group, the dominant arm produced significantly higher peak velocity (mean difference = $1.10 \text{ m}\cdot\text{s}^{-1}$, 95% CI [0.73, 1.46], $P < 0.001$, $d = 2.17$; Figure 3), peak power (mean difference = 104 W , 95% CI [72, 137], $P < 0.001$, $d = 2.37$; Figure 3), and peak force (mean difference = 8.7 N , 95% CI [4.3, 13.0], $P < 0.01$, $d = 1.49$; Figure 3) values compared with the non-dominant arm. Similarly, significantly higher peak velocity (mean difference = $0.69 \text{ m}\cdot\text{s}^{-1}$, 95% CI [0.31, 1.06], $P < 0.01$, $d = 1.36$; Figure 3), peak power (mean difference = 101 W , 95% CI [69, 134], $P < 0.001$, $d = 2.31$; Figure 3), and peak force (mean difference = 17.3 N , 95% CI [13.0, 21.6], $P < 0.001$, $d = 2.98$; Figure 3) values were noted for the dominant-arm within the youth group. Between group comparisons showed a significantly higher peak throw velocity in the dominant arm of the senior group (mean difference = $0.65 \text{ m}\cdot\text{s}^{-1}$, 95% CI [0.17, 1.14], $P = 0.026$, $d = 1.29$; Figure 3) compared with dominant arm in the youth group for the ST-1OH task. However, no significant between-group differences in the dominant arm were observed for peak power (mean difference = 64 W , 95% CI [11, 116], $P = 0.06$, $d = 1.45$; Figure 3) or peak force (mean difference = 1.5 N , 95% CI [-6.3, 9.3], $P = 0.700$, $d = 0.26$; Figure 3) metrics, respectively. In comparing non-dominant arms, a significantly higher peak throw force was recorded in the senior group (mean difference = 10.1 N , 95% CI [2.4, 17.9], $P = 0.036$, $d = 1.75$; Figure 3). However, no significant between-group difference was noted for throw peak velocity (mean difference = $0.24 \text{ m}\cdot\text{s}^{-1}$, 95% CI [-0.24, 0.73], $P = 0.31$, $d = 0.49$; Figure 3) or peak power (mean difference = 61 W , 95% CI [9, 113], $P = 0.057$, $d = 1.39$; Figure 3) metrics.

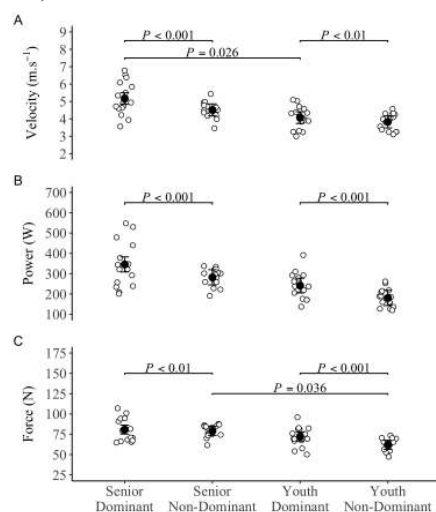


Figure 3. The peak velocity (A), peak power (B) and peak force (C) recorded from the standing one-arm overhead medicine ball throw tests (ST-1OH) using the dominant and non-dominant arms in the senior and youth groups (mean $\pm$ 95% CI). The open circles represent individual data points.

Inter-limb Asymmetry

The magnitude of inter-limb asymmetry for peak force values was significantly different between the senior and youth groups (mean difference = -6.9% [-13.3, -0.5], $P=0.037$, $d = -0.79$; Figure 4). However, there was no significant difference in inter-limb asymmetry observed for peak velocity (mean difference = -3.3% [-5.5, 12.2] $P=0.446$, $d = 0.28$; Figure 4) or peak power (mean difference = -5.7% [-15.8, 4.4] $P=0.259$, $d = -0.41$; Figure 4) metrics.

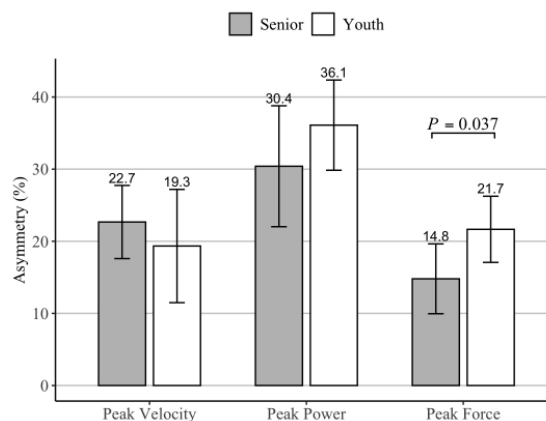


Figure 4. The inter-limb asymmetry calculated for peak velocity, peak power, and peak force metrics from the standing one-arm overhead medicine ball throw (ST-1OH) tests. The bars (and values) and error bars indicate the mean $\pm$ 95% CI.

Discussion

The main findings from this study indicated that senior volleyball athletes produced higher ST-OH values across all metrics compared to their youth counterparts. Both groups recorded higher values in the dominant arm during the ST-IOH tests, with senior athletes achieving a higher peak velocity. In the non-dominant arm, senior athletes also recorded higher peak force values compared to the youth group. The differences in velocity-based metrics (between arms) contributed to a relatively large magnitude of inter-limb asymmetry observed within both groups, with the youth group exhibiting significantly greater asymmetry in peak force compared with the senior athletes. Collectively, our findings, which utilized an IMU-integrated medicine ball to derive velocity-based measures, have implications for developing the explosive upper-body power of youth volleyball athletes to progress to higher levels of performance, and for informing the training process to address the upper-body inter-limb asymmetries of volleyball players.

In the present study, senior players produced markedly higher values for each ST-OH metric derived from the ballistic ball compared to their youth counterparts (Figure 2). Among the few studies that have employed IMU-integrated medicine balls to test upper body power, peak velocity values have typically been the primary focus in validation studies, making comparisons with our findings challenging. However, Beckham et al (Beckham et al., 2019) reported lower peak velocity values (range: 3.85-3.92 m·s⁻¹) during a seated IMU medicine ball throw test (4.55 kg) compared to the youth and senior aged volleyball players during the ST-OH test in our study (Figure 2). Additionally, we observed lower ST-OH peak velocity values compared to those reported by Sato et al (Sato et al., 2018), where recreationally active adults performed standing static and countermovement chest throws using 3.63 kg (3.94 m·s⁻¹ and 4.33 m·s⁻¹) and 5.44 kg (3.92 m·s⁻¹ and 4.15 m·s⁻¹) IMU medicine balls, respectively. The disparity between our current findings and previous studies may be attributed to variations in throw positions (seated vs. standing), throw types (static vs. countermovement; chest vs. overhead), mass of the ballistic balls, and/or the sport activity level and age of the participants.

We also observed a significant between-group difference for all ST-OH metrics, with markedly higher values recorded in the senior group (Figure 3). To date, no available studies have utilized an IMU medicine ball (or medicine ball *per se*) to make direct comparisons between volleyball players of different ages or playing levels. Nevertheless, the between-group difference in throw metrics is unsurprising due to the disparity in age and maturation status of the players. Future work may be conducted to enable direct comparisons of velocity-based performance measures between volleyball players of different playing levels to provide normative data for benchmarking criteria with the goal of reaching higher levels of performance (Dodd and Newans, 2018; Lidor and Ziv, 2010; Robertson et al., 2022; Rubajczyk and Rokita, 2020).

The application of the ST-IOH tests permitted comparisons of the dominant and non-dominant arms both within and between groups. We observed the dominant arm to produce higher values for each throw metric within the senior and youth groups, respectively (Figure 3), with peak velocity significantly greater in the senior group compared with the youth group ($d = 1.29$; Figure 3). In contrast, between-group comparisons of the non-dominant arm showed the senior group were able to produce greater peak force values ($d = 1.75$; Figure 3). Previous studies attempting to assess single-arm upper-body power, are again, limited. However, Shahbazi-Moghaddam et al (Shahbazi-Moghaddam, 2002b) provided velocity-based data using video motion analysis on beginner, university-level, and national-level volleyball players (age range = 18-24 yrs) using a ball suspended from a pendulum. Consistent with our findings, Shahbazi-Moghaddam et al (Shahbazi-Moghaddam, 2002b) reported higher peak velocity and force values in both standing and overhead jump serves among senior national-level players compared to university and beginner-level participants. In our study, it can be speculated that the disparity in velocity-based measures in the dominant (and non-dominant) arm between groups is attributed to variations in maturation and training status. Currently, normative reference values for upper-extremity functional performance in overhead athletes (Borms and Cools, 2018), particularly for velocity-based data, are limited. Therefore, in addition to serving as a benchmarking tool for athletes, the data herein, can be used to establish clinical cut-off values for return-to-play criteria (Borms and Cools, 2018) when using the same sport-specific ST-OH and ST-IOH assessments with volleyball players.

The ST-IOH assessment allowed inter-limb asymmetry values to be calculated across the different IMU velocity-based measurements. We observed asymmetry values of substantial magnitude (i.e., >15%; (Fort-Vanmeerhaeghe et al., 2016; McElveen et al., 2010)) in both the senior and youth groups, indicating that both cohorts may be at increased risk of injury or reduced performance; although this interpretation has shown not to be consistent across lower-limb asymmetry studies (Bishop et al., 2018). Between-group comparisons demonstrated that the youth players possessed a significantly greater inter-limb asymmetry in peak force compared with the senior group ($d = 0.79$; Figure 4). Extrapolating this finding, it may be inferred that training the force end of the velocity curve should be emphasized in youth volleyball players. This may be achieved by performing upper-body unilateral resistance exercise to reduce peak force asymmetry. Nevertheless, it is pertinent to recommend that these training decisions are conducted on an individual basis (within both groups), dependent on the magnitude (and direction) of asymmetry identified for each metric (Bishop et al., 2020). While much work has been conducted to identify lower-limb asymmetries in volleyball players during various jumping tasks (Fort-Vanmeerhaeghe et al., 2016; Kozinc and Šarabon, 2020), fewer studies have investigated the presence of inter-limb asymmetries in the upper-body. Nevertheless, isokinetic dynamometry data examining

concentric force production of the shoulder internal and external rotators of volleyball players has also highlighted the presence of marked asymmetry between dominant and non-dominant arms (Hadzic et al., 2014).

The adoption of an IMU medicine ball (ballistic ball) as part of periodic training assessments is not without limitations. Since our study was observational, velocity-based measurements were only taken at a single timepoint. Longitudinal studies are needed to assess seasonal changes in upper-body explosive power and inter-limb asymmetry using the IMU medicine ball in ST-OH and ST-IOH assessments. Additionally, as we purposively placed an emphasis on collecting data in an all-female cohort, it is recommended that data collection be expanded to include male national level players of various ages and playing levels to establish appropriate benchmarking criteria. Finally, IMU medicine ball data on explosive power and asymmetry could potentially be used to explore associations with various measures of athletic performance (Fox et al., 2023).

Conclusions

In summary, this study showed senior national-level players demonstrated superior ST-OH performance compared with their youth counterparts across all metrics. In both groups, the dominant arm produced the highest values (for all metrics) across the ST-IOH tests, with a higher peak velocity observed in the senior group. In comparing non-dominant arms, significantly higher peak force values were recorded in the senior group. The difference in ST-IOH metrics between the dominant and non-dominant arms leading to a large magnitude of inter-limb asymmetry being observed within both athlete cohorts. Taken together, our data suggests that targeting both ends of the force-velocity curve is required to aid the development of youth athletes to improve performance outcomes. Given the high magnitude of upper body inter-limb asymmetry in both senior and youth groups, incorporating unilateral resistance training and using training implements (i.e., bands, medicine ball, ballistic ball) is recommended to be employed on an individual basis to reduce asymmetry by targeting the force-velocity curve. Our findings support the use of the IMU-integrated medicine ball to develop the upper-body power of youth volleyball athletes based on meeting the benchmarking criteria of senior athletes.

Conflicts of interest: All authors declare no conflicts of interest

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Supplementary Table

Table S1. Absolute values recorded for the ST-OH and ST-IOH tasks.

<i>Variables</i>	Senior (N = 16¹)			Youth (N = 15¹)		
	<i>ST-OH</i>	<i>ST-IOH-D</i>	<i>ST-IOH-ND</i>	<i>ST-OH</i>	<i>ST-IOH-D</i>	<i>ST-IOH-ND</i>
Peak Velocity (m·s ⁻¹)	7.1 (0.9)	5.2 (0.9)	4.1 (0.6)	6.19 (1.0)	4.5 (0.5)	3.8 (0.5)
Peak Power (W)	716 (183)	365 (140)	241 (64)	503 (150)	282 (43)	181 (45)
Peak Force (N)	122.8 (20.2)	83.6 (19.2)	72.0 (11.7)	99.3 (15.6)	79.2 (7.6)	61.9 (7.7)

¹Mean (SD); ST-OH: Standing overhead medicine ball throw; ST-IOH-D: Standing dominant-arm overhead medicine ball throw; ST-IOH-ND: Standing non-dominant-arm overhead medicine ball throw.