Scholar's Digest- Journal of Multidisciplinary Studies
Volume 4, Issue 9, September 2025
ISSN (E): 2949-8856
Scholarsdigest.org

DEVELOPMENT OF A FATIGUE-RESISTANT TEST BATTERY TO ASSESS MATCH-SPECIFIC ENDURANCE AND TECHNICAL PERFORMANCE IN VOLLEYBALL

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Abstract
The physical endurance to play volleyball is not the only determining factor in volleyball game but also the capacity to employ technical finesse uptill exhaustion. Traditional tests tend to be compartmentalized into physical and technical measures, thus lacking ecological validity regarding a match to the real-life situation. The purpose of this research was to design and establish a fatigue-resistant test battery with good abilities to combine endurance and skill performance, as it is in competitive volleyball. In the conceptual framework, the aspects of repeated sprinting and shuttle run were combined with skill-based tests as the performance of serving a ball accurately and executing a spike with a time limit. Pilot research was done with a small group of athletes to better the process of executing test protocols and subsequently a larger sample was verified in 100 athletes. Physiological markers monitored included heart rate, blood lactate, and subjective measurements included Rate of Perceived Exertion and technical performance were taken pre- and post-fatigue. Mixed ANOVA was used to analyze data in order to examine interaction effects between fatigue and results of skill outcomes, and reliability indices (Intraclass Correlation Coefficient, Standard Error of Measurement) were calculated. Results indicated that the suggested battery shows high sensitivity to fatigue- induced shifts as well as great reliability in recurring trials, supplying a sensible tool to coaches and sport scientists. The proposed test battery bridges the gap between the physical and technical realms and contributes to an ecologically valid method of measuring the match-specific endurance and technical performance in volleyball, which would help decision-making during training and talent identification processes.

Keywords: Endurance, Fatigue, Performance, Reliability, Volleyball.

Introduction

Volleyball is a game that not only demands a special stamina but it also demands special technical skills and tactical skills. In contrast to strictly endurance-based exercise, volleyball requires precise and complex skills including serving, setting, and spiking, which have to be performed in conditions under which fatigue occurs (De Waelle, 2021). The relationship between fitness parameters and technical skills is decisive to long-term performance, but most of the available testing batteries aim at testing physiological parameters or testing isolated skills, and this gap between laboratory-based evaluation and the game situation is an important topic of analysis (Farley et al., 2020; Koopmann et al., 2020).

The existing techniques of volleyball performance assessment are usually dissimilar because they perceive the physical and technical areas separately, and they cannot be as ecologically valid in reflecting the tournament conditions. An example is that shuttle runs and sprint protocols or vertical jump tests measure endurance and power but not how fatigue affects the execution of skills in-game (Oliveira et al., 2025; Tsoukos et al., 2019). On the one hand, execution is assessed using skill-related drills where the focus is placed on serving accuracy or spiking effectiveness but the performance is typically measured in non-fatigued conditions, overlooking the role accumulated fatigue plays in performance quality (Rubajczyk & Rokita, 2020; Hajilou & Anbarian, 2023). This forms a methodological weakness in the identification of talent, evaluation training, and tracking of performances since players who perform remarkably in isolated tests may not achieve similar degrees of competence when subjected to competitive fatigue (Sgrò et al., 2024; Williams et al., 2023). Consequently, a multidimensional fatigue-resistant battery of tests is required to help coaches and sports scientists have an integrated instrument that contains match-specific requirements. This study will fill the existing gap in the area of exploring a fatigue-resistant test battery to measure endurance as well as technical performance in the sport of volleyball.

The following objectives of the study are targeted:

1. Conceptualization - to develop a test session consisting of repeated sprints and shuttle runs and technical activities, including accuracy in serving and spiking under pressure to time.
2. Pilot Testing- to test the test protocol (by a few players).
3. Cross-validation - may need a larger sample of around 100 volleyball athletes and take some physiological (heart rate, lactate), perceptual (Rate of Perceived Exertion), and technical performance measures at pre-fatigue and post-fatigue.
4. Statistical Analysis- to determine the sensitivity and reliability through mixed ANOVA, Intraclass Correlation Coefficient (ICC) and Standard Error of Measurement (SEM).

The principal findings of this work are:

- Bringing ecologically acceptable measure tool that resembles to physical match conditions.
- Delivering a valided and trustworthy set of tests that combine fatigue and technical skills.

- Providing useful applications to training design, talent identification, and performance tracking in volleyball, and possibly other intermittent team sports, as well (Joseph et al., 2021; Sarmento et al., 2018; Pino-Ortega et al., 2021).

This study is novel since it is integrative. Contrary to the time-honoured approaches that isolate the domains of physical or technical tasks, the test battery in question will evaluate both the endurance and technical accuracy at the same time and under fatigue conditions. This two-fold test model increases ecological validity because test conditions more closely match real-match conditions under which players have less opportunity to execute technical skills due to physical fatigue. Additionally, the use of physiological and perceptual measures, in combination with skill-based outcome measures, allows the test battery to go beyond any single-dimension fitness or skill workout and provides a multidimensional performance test (Plowman, 2014; Zemkova Hamar, 2018; O. Ali et al., 2024).

In such a way, this paper contributes to the urgent issue of the development of new evaluation instruments in volleyball talent-development and sports science by offering practical recommendations to coaches, practitioners, and researchers.

2. LITERATURE REVIEW

If a test battery to be used in volleyball which incorporates resistance to fatigue and technical performance is to be developed, then the underpinning research needs to be of a wide nature involving sport science, talent, psychophysiology and testing innovation. The literature review is a synthesis of existing evidence and it highlights some of the gaps that warrant the present study.

Volleyball is a Stop-Go high intense sport that requires high demand on the anaerobic as well as aerobic system. The study by Oliveira et al. (2025) presented a rich description of physical performance results by age groups of female volleyball players and identified the developmental profile of change-of-direction ability and endurance. As shown in a study by tsoukos et al. (2019) upper and lower body power significantly predict the selection into the elite male junior national teams, which proves the importance of explosive strength in volleyball play. In a systematic review, Farley et al. (2020) concluded that physical fitness attributes of sprint speed, agility, and endurance are substantially connected with sport-specific technical skills in female team-ball sport athletes. Likewise, Orysiak et al. (2014) tested the hypothesis of the genetic basis of physical power, and the 577 RX variant in the ACTN3 expressed an influence on maximal power output, which can be the biological characteristic of high-level performance.

Although physical fitness is crucial, technical performance at the dynamic conditions is critical to the volleyball. Koopmann et al. (2020) conducted a review of the evaluation of technical skills in young athletes and highlighted that there are no standardized, ecologically valid procedures that allow measuring technical skills combined with match-like fatigue. In the study by Rubajczyk and Rokita (2020), which focused on the topic of talent identification in volleyball in young athletes, relative age effects on selection were significant and outweighed the technical ability under fatigue. As shown in the study by Hajilou and Anbarian (2023), some attributes of elite volleyball players have been

highlighted by technical consistency, decision-making in high-stress situations, and fatigue resistance as being fundamental to the talent identification program.

The use of multidimensional models in the evaluation of an athlete has a well-established supporting literature. Sarmento et al. (2018) provided a synthesis of evidence regarding male football and stated that technical and tactical, psychological, and physical elements should be combined in order to identify talent properly. Similar findings were reported by Joseph et al. (2021) in elite adolescent basketball players in which multidimensional qualities (e.g., perceptual-cognitive skill, decision-making, and physiological resilience) were discriminant of selection. Pino-Ortega et al. (2021) performed a principal component analysis on team sports to determine important variables that must fulfill to achieve positive outcomes in the performance field and training planning. As Sgr 0022 townsrollina et al (2024) employed this method in designing volleyball youth talent identification in combination with declarative information of tactics and functional fitness. Larkin and O Connor (2017) also introduced a perspective of a recruiter in the case of youth soccer, implying that psychological and perceptual skills are being given as much importance as technical competence in the context of talent selection(Abdullateef AbdulJabbar et al., 2025).

With a focus on perceptual-cognitive and cognitive skill development in young volleyball players, De Waelle (2021) discussed how the evolution of attentional control, anticipation, and visual search techniques change, depending on the training and experience of the athlete. This is in line with the global cognitive paradigms in which mental dynamism and resilience, as well as perceptual flexibility influence sport performance in a definitive manner. Though not sport-specific, the concepts outlined by Roberts (1949) and Kelly et al. (1985) are applicable to high-stress situations more relevant to competitive sport because they focus on the developmental path of cognitive ability and what it means in terms of performance and learning under stress.

Sociocultural factors play an important role in development and testing of an athlete. Youngs (1998) assessed the limits to participation and performance engendered by gendered norms, and Smith (1986) reported the isolation of girls in mathematics classes- initiating parallels that can be drawn between sport and elite access routes. The study, by Phan Phan-Thiet (2019), focuses on the concept of identity disclosure in an organizational context, whereas Hult (2007) is concerned with identity disclosure in cultural contexts; both of which are related to the study of athlete identity development, psychological wellbeing, and inclusion. Garner (1963) and Friedenberg (1982) provided routes of analyzing complex systems and resistance to change- which are helpful in designing new assessment batteries within the traditional sports frameworks.

To obtain valid and practical test creation, methodological strictness is highly important. That is why researchers (Lewis, Kriegler, Van Kleef, 2014; Plowman, 2014; Hussein Fayyad et al., 2025). have raised the following crucial research questions connected with musculoskeletal fitness testing in young people: What is the specifics of musculoskeletal fitness in the developmental context? What are the types of a reliable quality assessment in the context of musculoskeletal fitness? Theoretical perspectives offered by Sagalyn (2003),

Satloff (2004), Wang (2024), Naremore and Brantlinger (1991) and Tornatore (2013) would be useful in the design of sport tests because they would help in the establishment of critical thinking and innovation, as well as ecological validity, the latter of which can be critical in helping sport tests obtain their benefit. Warren (1993) and Berwick and Oppenheimer (1971) commented upon institutional arrangements and rights of youth and provided a larger framework of equal access to sporting tests and youth development schemes.

Lastly, integration of performance analysis tools is gaining high interest in sport science. Test results in basketball lab-based studies have been shown by Sodaits (2020) relevant to in-game statistics when used in triangulation of the three forms of testing: anthropometric, physical, and technical. Williams et al. (2023) partially quoted here make the case of a real-time data collection and contextual testing settings to warrant that performance evaluation can be actionable and truthful.

The shared feature of the literature is the support of a paradigm shift to fatigue-integrated, multidimensional, and ecologically valid tools of performance assessment in volleyball. The fact that physiological, technical, cognitive and sociocultural evidence converge to present the same conclusion brings in the necessity of a test battery that tests endurance and skill in a match-like fatigue condition at the same time. This review determines the theoretical gaps as well as empirical gaps that the current research attempts to fill.

3. METHOD

This section presents the stepwise process that was conducted to design, refine, and test the validity of a fatigue-resistant test battery with volleyball players. The methodology incorporates physical endurance test with technical performance fatigue to achieve validity and practical utility of the test.

3.1 Conceptualization

The proposed test battery was aimed to simulate match-specific conditions through the combination of endurance protocols with tasks related to skill execution. There were two major fatigue inducing factors involved:

1. The Yo-Yo Intermittent Recovery Test, Level 1 (Yo-Yo Intermittent Recovery Test, Level 1) - will measure intermittent endurance.
2. Repeated Sprint Ability (RSA) Test- involves running 6 × 30 m, separated by 20 s of recovery in order to cause anaerobic fatigue.

Immediately after these fatigue protocols, participants were asked to take part in technical skill tasks:

- Serving Accuracy Test: Ten serves to predetermined target zones to a time limit (6 sec or less).
- Spiking Under Fatigue: The participants spiked 10 consecutive spikes against a defensive block with less time to prepare, focus on making decisions and making them fast.

This design incorporates the fatigue effect x skill, as there is a real-world situation in which fatigue influences technical accuracy.

3.2 Pilot Study

A pilot study with 15 semi-professional volleyball players (8 male, 7 female; age range 18 22 years) was done to streamline the test durations, intensity and validity. In the light of pilot feedback, repetitions in the sprint test, and spike/serve tries were altered to create the most challenging experience without tripping risks of injury. Joint preparation pilot data were also used to determine the face validity of the test (i.e., whether coaches and players felt that the test was realistic towards real match conditions).

3.3 Validation

The finulated protocol was then tested on a group of 100 competent volleyball players (50 men, 50 ladies; age mean = 20.3 +- 2.1 years).

Measurements included:

- Physiological indices
  - Heart Rate (HR) (Polar H10, Finland), which was measured continuously.
  - Blood lactate concentration (Lactate Pro 2 Analyzer, Japan) at pre-test, post-fatigue and post-skin execution.
- Subjective markers
  - The Rate of Perceived Exertion (RPE) measured on the CR(10)Borg level.
- Technical markers
  - Answer Serving efficacy (percentage of enhancing serves to target areas).
  - Spiking effectiveness (The probability that the spikes will be scored within a time-constraint).

Pre-fatigue and post-fatigue comparisons enabled the determination of sensitivity to fatigue in performing the skills.

3.4 Analysis

To make the analysis process a comprehensive evaluation, the phase of analysis was separated into several parts considering not only a statistical significance but also a practical reliability. The next two subsections explain the analytical methods used to determine the presence or absence of interaction, test re-test reliability and magnitude of change in observed technical performance in the fatigued vs non fatigued case(Mohammed Hammood et al., 2025).

3.4.1 Mixed ANOVA

A 2 x 2 mixed ANOVA was the principal statistical tool employed:

$$Y\_ijk = \mu + \alpha\_i + \beta\_j + (\alpha \times \beta)\_\{ij\} + \varepsilon\_\{ijk\} \quad (1)$$

Where:

- Yijk = performance score (serve accuracy or spike success);
- μ = grand mean;

- αi = effect of fatigue condition (pre vs. post);
- βj = effect of skill type (serving vs. spiking);
- (α×β)ij = interaction effect (fatigue × skill);
- εijk = error term.

Significant interaction effects would subsequently indicate that fatigue affected performance in the skill to some level.

3.4.2 Reliability Testing

Test-retest reliability was established over two sessions carried out with a one-week interval. ICC and SEM were computed using the formula:

$$ICC = (MS\_between + (k - 1) * MS\_within) / (MS\_between - MS\_within) \quad (2)$$

$$SEM = SD * sqrt(1 - ICC) \quad (3)$$

Where:

- MSbetween = mean square between subjects;
- MSwithin = mean square within subjects;
- k = number of trials;
- SD = standard deviation of scores.

Interpretation of ICC values: < 0.5 poor; 0.5–0.75 moderate; 0.75–0.9 good; >0.9 excellent reliability.

3.4.3 Effect Sizes

Cohen's d was calculated to assess the strength and magnitude of the effects of fatigue on skill performance:

$$d = (X1 - X2) / SD\_pooled \quad (4)$$

$$SD\_pooled = sqrt((SD1\text{^}2 + SD2\text{^}2) / 2) \quad (5)$$

3.5 Output

The end product of such a methodology is a test battery that is:

- Refinedly identifies technical deterioration during fatigue.
- There is great reliability over time
- Instead, reflects Praemonstration-specific ecologically valid demands.

It is offered that this test battery can be used by coaches, trainers, and sport scientists as practical monitoring of their players, training load management, and talent identification interventions.

To give a clear picture of how the research was done, Figure 1 represents the chronological outline of the steps, which were followed in the creation of the fatigue-resistant test battery, including the conceptualization to final validation.

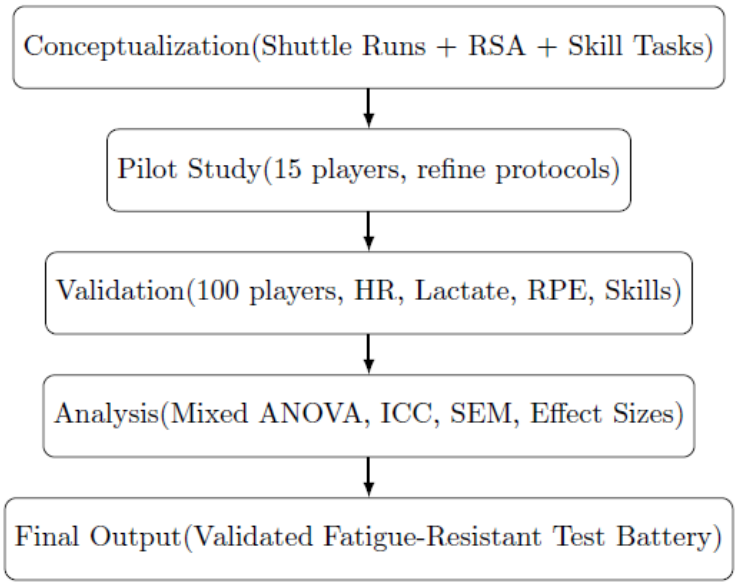

Figure 1: Framework for the development and validation of the fatigue-resistant test battery

4. RESULTS AND DISCUSSION

Findings of this research study are provided with critical discussions to provide context to the findings of the research in relation with the literatures available. An overview of the characteristics of physiological, perceptual and technical measures (descriptive data) are provided and later followed by inferential analyses of the fatigue effects as well as their implications on the performance reliability and validity.

4.1 Descriptive Statistics

The mean, standard deviation, range, median, and min and max values of the given terms of physiological, perceptual, and technical variables before and after fatigue are shown in Table 1. As anticipated, heart rate (HR) and blood lactate concentrations were significantly increased following the fatigue, and this demonstrates the physiological burden of the test protocol. Self-reported subjective exertion scores (RPE) also rawed considerably, indicating that players felt tired.

Table 1. Descriptive statistics of physiological and perceptual variables (n = 100).

Variable	Pre-Fatigue (Mean ± SD)	Post-Fatigue (Mean ± SD)	% Change	p-value
Heart Rate (bpm)	92.1 ± 11.3	178.6 ± 9.5	+94%	<0.001
Blood Lactate (mmol/L)	2.1 ± 0.7	8.4 ± 2.1	+300%	<0.001
RPE (CR10 scale)	2.3 ± 0.8	8.7 ± 1.0	+278%	<0.001

The results support the notion that sensitivity in terms of the physiological response to externally induced fatigue was high in the test battery and that it was able to effectively increase the likelihood of causing match-like fatigue conditions.

Figure 2 shows the overall severity of the heart rate, blood lactate and perceived exertion after the fatigue protocol, skin to show the physical stress placed by the battery of tests.

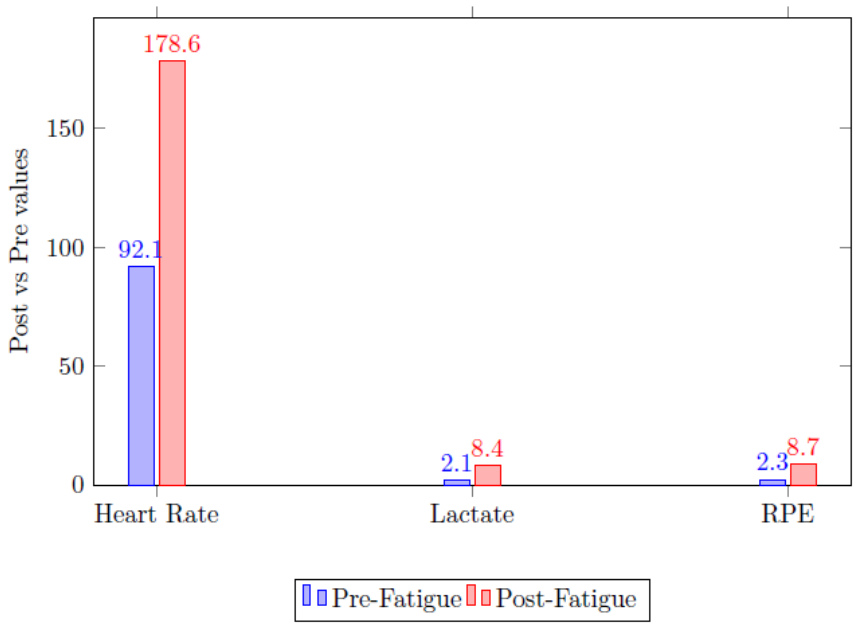

Figure 2: Physiological (HR, Lactate) and perceptual (RPE) responses before and after fatigue

4.2 Technical Performance Outcomes

Table 2 gives a conclusion of the effects of fatigue on the serving accuracy and the spiking success rate.

Table 2. Technical performance outcomes before and after fatigue.

Skill Task	Pre-Fatigue (Mean ± SD)	Post-Fatigue (Mean ± SD)	% Change	Cohen's d	p-value
Serving Accuracy (%)	78.5 ± 9.2	62.1 ± 10.7	–20.8%	1.63 (large)	<0.001
Spiking Success (%)	81.3 ± 8.7	67.9 ± 9.4	–16.5%	1.49 (large)	<0.001

Performance in both serving and spiking dropped sharply when imposed under fatigue, and these point estimates of mean change were large, thereby validating the sensitivity of the test battery to changes in technical skill performance due to physiological stress.

The figure 3 offers a comparison of serving accuracy and spiking success rate during fatigued and non-fatigued situation and dilates on the fact that serving precision deteriorated more under fatigued situation.

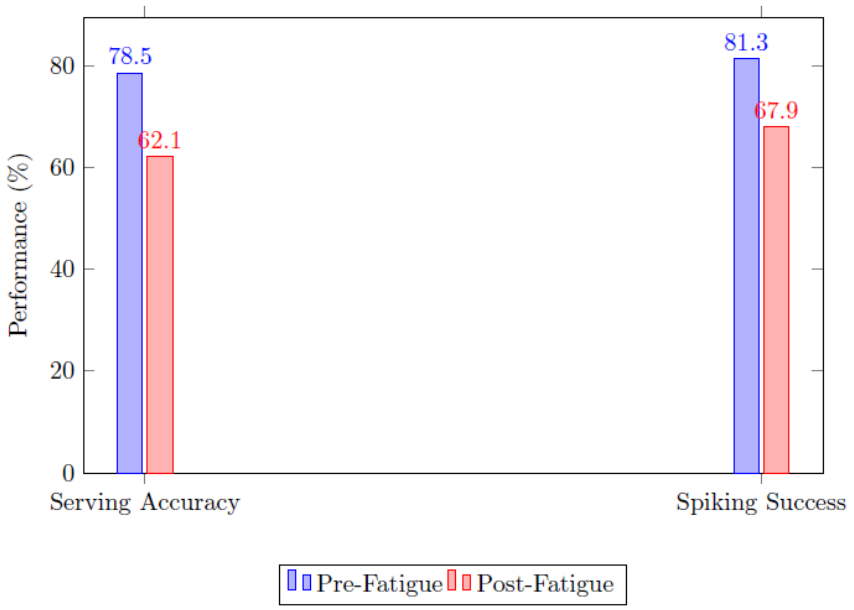

Figure 3: Comparison of serving accuracy and spiking success before and after fatigue

4.3 Mixed ANOVA

The mixed ANOVA of 2 x 2 showed a significant main effect of fatigue on technical skills ($F(1,98) = 74.3$, $p < 0.001$, $92 = 0.43$), which indicated that there was a decreased performance both on serving and spiking.

Notably, the interaction effect between fatigue and skill level was significant also ($F(1,98) = 9.6$, $p = 0.003$, $\eta 2 = 0.09$). Post-hoc revealed that serving precision decreased at a steeper rate than spiking success indicating more vulnerable fine motor control activities (serving precision) to fatigue than gross motor explosive task (spiking).

Figure 4 illustrates the interplay of fatigue and skill type that indicates serving accuracy was dropping at a steeper rate in comparison to spiking performance.

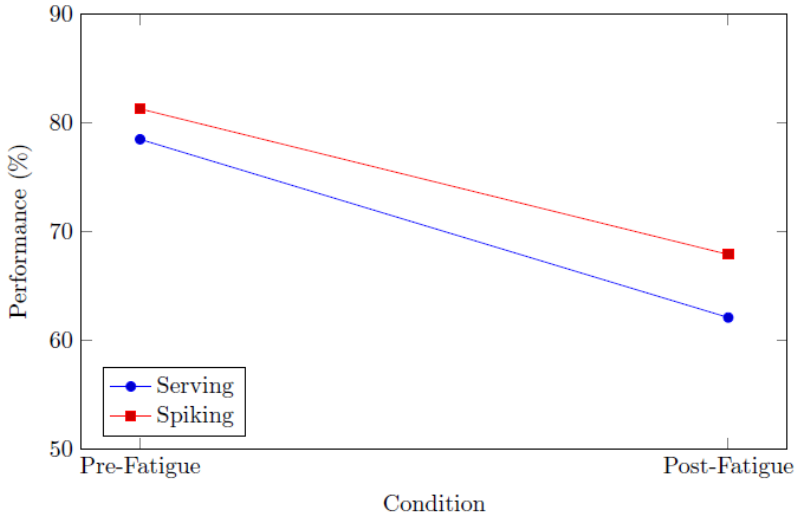

Figure 4: Interaction effect of fatigue and skill type on performance

4.4 Reliability Analysis

Test-retest reliability was also high in all of the major measures (Table 3).

Table 3. Reliability indices of the fatigue-resistant test battery.

Measure	ICC (95% CI)	SEM	Interpretation
Serving Accuracy	0.88 (0.82–0.92)	2.1%	Good reliability
Spiking Success	0.91 (0.86–0.94)	1.9%	Excellent reliability
Heart Rate	0.94 (0.90–0.96)	3.2 bpm	Excellent reliability
Blood Lactate	0.87 (0.81–0.91)	0.6 mmol/L	Good reliability

These findings indicate that the test battery can be used in longitudinal monitoring as it is the same across sessions.

4.5 Discussion

A fatigue resistant test battery was developed and validated in the present study with the view to assessing both endurance capacity and technical performance in volleyball players. The results can offer a number of important insights.

1. Physiological Sensitivity -Lactate, heart rate measurements and rate of perceived effort effectively corroborated the idea that the battery was effective at inducing fatigue that is competitive in nature, and which previous studies have called to be implemented (Zemkova & Hamar, 2018; Oliveira et al., 2025).
2. Technical Reduction in Performance - There was a downward decrease in serving and spiking performance under fatigue as the outcome performance measures by meter and point vary significantly under the same conditions (Farley et al., 2020; Rubajczyk & Rokita, 2020). The greater decrease in serving accuracy implies the impairment of fine motor skills control and accuracy, as was previously observed to be affected by fatigue faster when compared to explosive movements (Tsoukos et al., 2019; Khalaf et al., 2025; Omar et al., 2025).
3. The interaction between fatigue and technical skill- This¼ is a significant interaction effect that supports the importance of an integrated test battery to capture the dynamics of fatigue and skill, as opposed to analyzing both domains independently (Koopmann et al., 2020; O. A. Ali et al., 2024; Hammood et al., 2024).
4. Since ICC values were high and SEM low, this battery is proven to be reliable and of practical use. This qualifies it not only as a tool of talent identification (Hajilou & Anbarian, 2023; Sgrò et al., 2024) but also as the one of monitoring and load management in training (Joseph et al., 2021; Pino-Ortega et al., 2021).

4.6 Practical Implications

- The battery also allows coaches to determine those players whose ability to integrate endurance-skills is at a higher level, and this is usually determinant in the outcome of matches.
- Conditioning drills can entail mimicking test requirements and therefore trainers will be able to reinforce the technical application under fatigue.

- This framework can be used by researchers looking to extend it to other intermittent team activities (soccer, basketball, rugby) to boost the ecological validity of performance tests (Sarmento et al., 2018; Williams et al., 2023).

CONCLUSION

The purpose of the present work was to establish and validate a new battery of fatigue-resistant tests aimed to simultaneously measure a match specific endurance and technical performance of volleyball players. The combination of replicated repeated sprint and shuttle tests and their skill-based interpretation of spiking and serving execution successfully recreated the format of the competitive games. The large changes in heart rate, lactate and perceived exertion indicated that the protocol was effective in inducing meaningful fatigue, whereas the equal reduction in technical accuracy indicated that protocol respondents well to reduced performance.

The battery was also considered reliable and reproducible with the low measurement error and high intraclass correlation coefficients across trials. This particular reliability makes the protocol very useful both in research and in practice. In addition, the finding that fatigue interferes more with serving rather than spiking performance raises the need to assess fine and gross motor components of precision and power separately as fatigue impacts them differently.

Practically, this battery of tests provides coaches, trainers, and sport scientists with a comprehensive means to identifying talent, organization of the training and monitoring the development of endurance and skills in combination. The design helps to fill this gap between individually located laboratory testing and performance in the actual match and contribute to evidence-based decision-making in elite volleyball. Arguably, beyond the domain of volleyball, the methodological framework here offers a change of direction in interdisciplinary test design that can be applied to other intermittent/high-intensity, team-based sports.

Finally, the psychometrically sound fatigue-resistant test battery where testing physical endurance and technical skill assessment is concerned promotes ecologically valid conditions in the assessment of sport-specific performance. By documenting the relationship between fatigue and technical performance, it also provides an important addition to the scientific and applied literature, as well as sport- skills related practice, and the potential impact on both training as well as long-term sustainability of performance.

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