Development of a Repeated-Effort Test for Elite Men’s Volleyball


Purpose: The authors conducted a study to develop a repeated-effort test for international men’s volleyball. The test involved jumping and movement activity that was specific to volleyball, using durations and rest periods that replicated the demands of a match. Methods: A time–motion analysis was performed on a national team and development national team during international matches to determine the demands of competition and thereby form the basis of the rationale in designing the repeated-effort test. An evaluation of the test for reliability and validity in discriminating between elite and sub-elite players was performed. Results: The test jump height and movement-speed test parameters were highly reliable, with findings of high intraclass correlations (ICCs) and low typical errors of measurement (TE; ICC .93 to .95 and %TE 0.54 to 2.44). The national team’s ideal and actual jump height and ideal and actual speeds, mean ± SD, were 336.88 ± 8.31 cm, 329.91 ± 6.70 cm, 6.83 ± 0.34 s, and 7.14 ± 0.34 s, respectively. The development national team’s ideal and actual jump heights and ideal and actual speeds were 330.88 ± 9.09 cm, 323.80 ± 7.74 cm, 7.41 ± 0.56 s, and 7.66 ± 0.56 s, respectively. Probabilities of differences between groups for ideal jump, actual jump, ideal time, and actual time were 82%, 95%, 92%, and 96%, respectively, with a Cohen effect-size statistic supporting large magnitudes (0.69, 0.84, 1.34, and 1.13, respectively). Conclusion: The results of this study demonstrate that the developed test offers a reliable and valid method of assessing repeated-effort ability in volleyball players.

Key Words: spike jump, speed, fatigue, reliability, validity

Volleyball appears to be characterized by frequent short bouts of high-intensity exercise, followed by periods of low-intensity exercise and brief rest periods. The high-intensity bouts of exercise with relatively short recovery periods, coupled with the total duration of the match (~90 minutes), would suggest that volleyball players require well-developed creatine phosphate and glycolytic metabolic pathways, as well as reasonably well-developed aerobic capabilities. Based on testing results and observation of match conditions, considerable demands are also placed on the
neuromuscular system during the various sprints, dives, jumps, and multidirectional court movements that occur repeatedly during competition. As a result, it could be logically assumed that volleyball players require well-developed speed and muscle power along with the ability to perform these repeated maximal efforts with limited recovery for the duration of the match.

Physiological assessment of volleyball players has typically involved estimates of speed (5- to 10-m sprint), muscle power (vertical jump and spike jump), and maximal aerobic power (multistage fitness test). The specificity of the multistage fitness test, however (whereby athletes are required to shuttle back and forth along a 20-m distance), in relation to volleyball is questionable. Although aerobic metabolism is likely of some relevance in volleyball to replenish energy stores used in characteristically anaerobic efforts, a staged aerobic-power test appears very dissimilar to competition performance demands. In addition, it has been shown that measures of maximal aerobic power such as the 20-m multistage shuttle run do not discriminate between successful and less successful volleyball players at the high-performance and elite level. This suggests that physiological factors other than, or in addition to, maximal aerobic power contribute to success in volleyball at higher levels of playing proficiency.

Currently there is no test of repeated-effort ability for the sport of volleyball. Moreover, time–motion analysis (TMA) of international volleyball competition is also lacking. The volleyball TMA studies that have been published have generally been performed on competition before several rule changes (in 1999), which include player-substitution rules and a major change from service scoring to rally-point scoring. In addition, some previous TMA studies were performed on matches in which a single-ball system was used, and other studies have not specified whether a single-ball or “3-ball” rotation was used, which would presumably alter the rest periods between rallies. Elite international competition involves the use of a 3-ball rotation.

With this in mind, the purpose of this study was to perform a TMA on elite international men’s volleyball competition in order to develop and evaluate a repeated-effort test for the sport. The development of a game-specific repeated-effort test would provide objective evidence on the specific strengths and weaknesses of the athletes to allow individualization of coaching programs while also providing a useful method of monitoring the development and progress of these athletes.

This study was conducted as 2 experiments. First, we performed a TMA on men’s international volleyball matches to establish a valid testing methodology from which to base the experimental portion of the study. Based on the TMA, we conducted a second study to evaluate the repeated-effort test.

**Experiment 1: Time-Motion Analysis**

**Methods**

To address ecological-validity considerations, the test was developed based on 4 components, with each component providing essential insight into an appropriate test design and methodology. The first component involved a TMA of international men’s volleyball to obtain data on rally length, rest between rallies and games, and the type and frequency of activities that took place in the rallies. The second
component involved assessing blocking duties in international men’s volleyball, specifically to approximate the height and penetration of a block required at this level. The third component involved consulting with 4 expert coaches in international men’s volleyball to evaluate and refine the movements, requirements, and instructions used in the test. The fourth component involved a pilot study with several development-national-team players to evaluate the movements, requirements, efficacy of instructions, and physiological response to the test for comparison with training and competition data for this group. This 4-component process was necessary to confirm that the test design satisfied validity considerations.

Time–motion analysis of international volleyball matches was performed to obtain an accurate estimate of the repeated-effort demands of the sport. Two separate analyses were performed. The first involved a review of 8 matches from the men’s competition of the 2004 Olympic Games, and the second involved a review of 8 matches from a development national team (U23) competing in international competition. Information recorded included details of rally times, rest between rallies, rest between sets and matches, and all activities performed in the frontcourt (spikes, spike jumps, blocks, block jumps, and jump sets).

Data taken from the 2 separate analyses were nearly identical, with no absolute (or statistically significant, \( P > .05 \)) differences between elite-international and development-national-team competition demands in terms of minimum and mean rally length, rest period, and activity levels (spikes, spike jumps, blocks, block jumps, and jump sets). As such, data from the 16 matches were pooled.

**Results**

Figure 1 illustrates the range of rally durations and their typical occurrence, as well as the range of rest durations and their typical occurrence. It was determined that 76.6% of rallies lasted 12 seconds or less, and the average rally time was approximately 11 seconds. The range of durations, however, included rallies as short as 3 seconds (ace service) and as long as 40 seconds. In addition, 44% of rest periods between rallies were 12 seconds or less, with the average rest time being 14 seconds. Rest periods were observed to be as short as 4 seconds and as long as 38 seconds (contested call or time-out).

Table 1 outlines the range of the frontcourt activities of spike jumps, block jumps, and jump sets observed in a set from the matches analyzed in the TMA. In a rally, while in the frontcourt, setting and attacking players performed on average a minimum of 1 jumping movement. Frontcourt players performed as many as 4 block jumps and 3 spike jumps, which also included considerable lateral movements across the 9-m volleyball court. Depending on the individual’s playing position (setter, middle, or outside) this movement could occur in the form of a jump set, block, spike, or spike jump (fake). Although blocking duties are performed by all players in the front row, middles were typically involved in most blocking efforts.
Figure 1 — Distribution of (A) rally times and (B) rest between rallies in elite men’s volleyball competition.
Experiment 2: Repeated-Effort Test

Subjects

Sixteen male volleyball players (mean ± SD age, height, and mass of 23.7 ± 2.0 years, 200.5 ± 7.9 cm, and 90.1 ± 9.8 kg) participated in this study. All players were scholarship holders in the Australian Institute of Sport volleyball program and were competing at national-team (n = 8) or development-national-team (n = 8) level in volleyball. The national team and development national team did not differ significantly (P < .05) in regard to height or mass. All participants received a clear explanation of the study, including the risks and benefits of participation. Testing was in accordance with and approved by institutional ethics, and written consent for testing was obtained in the athletes’ scholarship holder’s agreements.

Methods

A volleyball repeated-effort test encompassing spiking, blocking, and lateral movements was developed to mimic the physical demands of frontcourt play in volleyball. We thought that because frontcourt play generally involves the most activities (jumping and lateral movement), the test should reflect these demands. We decided that to assess the most extreme demands of volleyball play, the test should include repetitions that reflected the typical rally time and involve rest periods that reflected the most extreme demands of international play. Based on the finding that 76.6% of rallies were 12 seconds or less in length, the repetitions of the developed test involved a sequence of activities lasting ~12 to 15 seconds. Given that the longest rally time was 40 seconds in duration, and that many typical rallies of ~12 seconds tend to occur in “clusters” of activity that are separated by short rest periods (4 to 6 seconds), 4 repetitions of the developed test were performed to reflect these extreme demands. Each repetition commenced on a 20-second interval to allow approximately 4 to 8 seconds of rest between repetitions, depending on the speed with which athletes executed each repetition.

The TMA (experiment 1) illustrated that while in the frontcourt, setting and attacking players performed, on average, a minimum of 1 jumping movement and that this could be in the form of a jump set, block, spike, or spike jump (fake). On occasion, however, it was observed that players performed as many as 4 block jumps and 3 spike jumps, which also included considerable lateral movements across the 9-m volleyball court. Because the test design was aimed at evaluating the most extreme demands of international play, the designed test incorporated repetitions of 2 spike jumps and 4 block jumps, with both left and right lateral-direction changes in the frontcourt (Figure 2).
As Figure 2 illustrates, 2 spike jumps were measured, using a Yardstick® vertical-jump apparatus (Swift Performance Equipment, Lismore, Australia), with the timing of movements measured via a dual-beam timing-light system (Swift Performance Equipment). The timing of the specific movement was separated from the jumping task. In other words, the timing as measured by the timing lights was the movement-speed performance measure and represented a portion of the
total repetition time (which was fixed for all subjects as a 20-second interval). The block jumps were performed on a specially designed apparatus that was adjustable for height and position, and this portion was included. The apparatus, which was 2 m wide, was placed on the opposite side of the net from the player being tested. Two volleyballs were secured to 2 separate supports mounted on an aluminum beam and supported by a tripod. Based on pilot testing and video observations of international play, the apparatus was placed so that the bottom of the ball was 15 cm above the top of the net (258 cm high) and the side of the ball nearest the athlete was placed 15 cm into the opposing court. To correctly execute a block, the athletes were required to perform a block jump and place both hands on the ball without contacting the net.

Before the commencement of testing, we discussed the proposed test with a panel of 4 expert volleyball coaches to gain feedback on the specificity of the test and its relevance. During pilot testing, 8 developmental volleyball players also completed the test to provide feedback on its specificity from a player’s perspective. In addition, heart-rate responses were recorded and blood lactate concentration analyzed (3 minutes after completion of the test) to compare with typical values observed in competition and training in this group, as well as observations from previous studies.1,5,6 In the pilot study, during the performance of the test, heart rates ranged from ~110 to 195 beats/min (rapidly rising from the onset of the testing protocol), with a mean maximum of 186 ± 12 beats/min. Blood lactate concentrations 3 minutes after completion of the test were 8.1 ± 2.2 mmol/L. It was observed that the physiological responses were highly similar to those observed in competition and simulated competition (training drills) in the group, as well as responses recorded in previous research.1,5,6 We therefore concluded that from a physiological-response perspective, the test demands appeared to be ecologically valid. As a result of this and the positive feedback from the coaches and athletes, only minor modifications were made to the test.

Players were familiarized with all testing procedures before beginning the study. After a thorough explanation of the test procedures, the familiarization session and all testing sessions began with the subjects’ typical volleyball match-specific warm-up. After this, 1 or 2 trials of 1 repetition were performed at a submaximal intensity, after which feedback was provided to the subjects to ensure clarity of instructions and adherence to the test protocol. The subjects then performed 1 maximal repetition of the test at full intensity. After 5 minutes of rest, the subjects then performed the actual test battery, which included 4 repetitions of the test. The measured performance outcomes of each of the 4 repetitions included 2 spike-jump scores (cm) and lateral movement time (seconds). During pilot testing, the first spike-jump measurement and the first movement times were superior to all other repetitions. As a result, the first spike jump and the movement time in the first repetition were used as the ideal-jump and ideal-time scores. The mean of all spike jumps recorded (total of 8) and the mean of all movement times recorded (total of 4) across the 4 repetitions were used as the actual-jump and actual-time scores. In addition, the performance decrements for the jump and speed variables were calculated as the percentage difference between the ideal and actual scores. Errors were recorded if the blocking task was not performed correctly (eg, 1 hand touching or hand on net).
Reliability and Validity

Twelve athletes performed the test on 2 occasions, 2 days apart, to determine the reliability of the test. The validity of the repeated-effort test to discriminate among players of different playing ability was evaluated by testing volleyball players on the national team (n = 8) and development national team (n = 8). We thought that the test would offer a valid assessment of repeated-effort ability if performance criteria in this test improved with increases in playing level.

Statistical Analysis

The test–retest reliability of the repeated-effort test was evaluated using intraclass correlation coefficients (ICC)\(^{10}\) and the typical error of measurement (TE).\(^{11}\) For the frequency data of blocking errors, the raw data were converted to the square root before ICC and TE were calculated. Differences between playing levels were evaluated by comparing the true difference in performance with the minimum clinically important difference and Cohen’s effect-size statistic. The minimum clinically important difference was defined as the smallest worthwhile difference deemed to be practically significant to the average athlete. The minimum clinically important differences for jump height and movement time were calculated as 1.88 cm and 0.10 second, respectively. The probabilities that the true difference in performance were negative, trivial, or positive were expressed as percentages, reflecting the following descriptors: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possibly; 75% to 95%, likely; 95% to 99%, very likely; and >99%, almost certainly.\(^{12,13}\) Cohen’s effect-size statistics reflected the following descriptors: >0.5, large; 0.1 to 0.3, moderate; and <0.1, small.

Results

The reliability data of the spike-jump, movement-time, and fatigue variables during the repeated-effort test are presented in Table 2. The test and retest measurements of spike-jump height and movement time proved to be reliable (ICC .93 to .96, %TE 0.55 to 2.40), but with large %TE scores observed for net and blocking errors (ICC .57, %TE 22.08).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Reliability Values for the Repeated-Effort Test*</th>
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<tbody>
<tr>
<td></td>
<td>Day 1 scores</td>
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<tr>
<td>Actual time (s)</td>
<td>7.43 ± 0.6</td>
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<tr>
<td>Ideal time (s)</td>
<td>7.15 ± 0.6</td>
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<tr>
<td>Actual jump (cm)</td>
<td>327.76 ± 8.6</td>
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<tr>
<td>Ideal jump (cm)</td>
<td>334.25 ± 10.3</td>
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<tr>
<td>Errors</td>
<td>2.82 ± 2.3</td>
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<tr>
<td>% Jump decrement</td>
<td>1.97 ± 0.9</td>
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<tr>
<td>% Time decrement</td>
<td>3.94 ± 2.3</td>
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</tbody>
</table>

*TE indicates typical error; %TE, relative typical error; and ICC, intraclass correlation. N = 12.
The ideal- and actual-jump and ideal- and actual-speed scores of the national team were 336.88 ± 8.31 cm, 329.91 ± 6.70 cm, 6.83 ± 0.34 seconds, and 7.14 ± 0.34 seconds, respectively. For the development national team, they were 330.88 ± 9.09 cm, 323.80 ± 7.74 cm, 7.41 ± 0.56 seconds, and 7.66 ± 0.56 seconds. The repeated-effort test was valid in discriminating between elite players and players on the development national team, with a high probability that the spike-jump and movement-time results of elite players were superior to developmental players. Probabilities of differences between groups for ideal jump, actual jump, ideal time, and actual time were 82%, 95%, 92%, and 96%, respectively, with Cohen’s effect-

![Figure 3](image)

Figure 3 — (a) Ideal and actual jump height and (b) ideal and actual time for the national team (n = 8) and the development national team (n = 8), mean ± SD. All measures depicted had large (>0.50) effect-size differences between groups.
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size statistics supporting large magnitudes (0.69, 0.84, 1.34, and 1.13 respectively). The probability of differences between groups for net and blocking errors was 72%, with a Cohen’s effect-size statistic of 0.64. The differences between the groups on the jump and speed variables are illustrated in Figures 3 and 4.

Discussion

In the current study we developed a repeated-effort test for international men’s volleyball. The test involved jumping and movement activity specific to volleyball, with duration and rest periods that replicated a portion of the most extreme
demands of a match. The results of this study demonstrate that the developed test offers a reliable and valid method of assessing repeated-effort ability in volleyball players.

Construct validity was assessed by evaluating the performances of 2 closely matched performance groups: a national team preparing for the world championships and a development national team whose primary focus was to prepare for eventual inclusion on the national team. The results of this evaluation establish criterion validity of this test, in that the national team’s performances were superior to the development national team’s results for all variables considered in the test, as demonstrated by large effect-size statistical differences (0.69 to 1.13) for the speed and jump variables.

Test–retest reliability for the repeated-effort test was evaluated with athletes from both the development national team and the national team. Although reliability measures should be considered population specific, the relatively low TE scores for the jump and movement variables found in this study suggest good sensitivity of this test for tracking training-induced changes in performance. The poor test–retest reliability (ICC .57, %TE 22.08) for measurements of technical-skill errors (ie, net and blocking errors) suggests that although the physiological responses to repeated-effort activity in volleyball are highly reproducible, the skill response to the induced fatigue is less reliable. Therefore, larger relative changes would have to be observed for us to be confident that a real change had occurred in the performance of the athletes.

Studies of repeated-sprint ability have typically calculated a percentage decrement between ideal and actual sprint times (percentage performance difference between first and average score), but we have been somewhat discouraged by high TE scores in this calculation. In the present investigation, we used 5 major variables to evaluate the reliability and criterion validity: ideal jump, actual jump, ideal time, actual time, and errors. Because the “actual” score for both spike jumps and movement time takes into consideration all the efforts performed, this score reflects the fatigue resistance of the athlete. This enables practitioners to evaluate athletes based on their “ideal” and “actual” scores as a measure of fatigue resistance.

It is interesting that when the reliability of the percentage decrement of time and jump variables was calculated after data collection in the current investigation, very high TE scores were observed, which is in agreement with previous findings using this calculation. Furthermore, it was found that within each group, the fastest athletes on the movement-time test and the highest jumpers demonstrated the largest percentage decrement when expressed in relative terms. When expressed in absolute terms, however, these superior athletes’ scores can be interpreted differently. In other words, when absolute ideal and actual scores are observed, the superiority of higher-performing athletes is clearly demonstrated, despite a higher percentage decrement (Table 3, Figure 4).

Examining the ideal-time and ideal-jump results of the repeated-effort test provides practitioners insight into the movement speed and jumping ability of volleyball athletes. By comparing the actual time and ideal time, an athlete’s fatigue resistance can then be observed. Finally, examining the frequency, type, and progression (over each repetition) of errors provides practitioners insight into the movement and jumping technique of athletes, as well as the influence of their progressing fatigue on technique.
In conclusion, in this study we developed and evaluated a repeated-effort test for volleyball. The test involved jumping and movement activities typical of volleyball and used durations, repetitions, and rest periods that simulated a portion of the most extreme demands of international men’s volleyball. The results of this study demonstrate that the developed test offers a reliable and valid method of assessing repeated-effort ability in elite volleyball players.

**Practical Applications**

We suggest that at a high-performance or elite level of competition, for intermittent-activity sports such as volleyball, sport scientists should consider using or developing repeated-effort tests, perhaps in addition to or instead of steady-state or incremental maximum-endurance testing.

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**References**


