Acta of Bioengineering and Biomechanics
Vol. 26, No. 1, 2024

Original paper
DOI: 10.37190/ABB-02412-2024-03

Sensory equipment for monitoring and assessing the jumping ability of volleyball players

SOYIB TAJIBAEV*, AKRAM UMMATOV, SVETLANA ASHURKOVA, GANISHER ISMOILOV, SHOKHRUKH XOJIYEV, OYATKHON YOKUBOVA

Uzbek State University of Physical Education and Sport, Republic of Uzbekistan.

Purpose: The objective of this research was to develop a sensor device to control and evaluate the jumping ability of elite volleyball athletes and to test its efficacy in a pedagogical experiment. *Methods*: The study involved determining the pulsometric and respiratory parameters during test loads, indicative of the endurance and speed–strength aspects essential for volleyball performance. Additionally, the necessity for post-training and post-competition jump performance restoration via short-term relaxation exercises was identified. *Results*: Through the developed computer program, a method for storing maximal vertical jumps in computer memory was established. Furthermore, a technique was developed to determine the functional significance of maximum vertical jump performance among elite volleyball players. Notably, participants in the experimental group, who performed specialized exercises developed within the experimental framework, exhibited discernible progressive improvements compared to the control group participants. Before the experiment, the maximum number of jumps in the experimental group was 29.2 ± 2.73, with a jump time of 31.7 ± 3.08. *Conclusions*: The equipment developed for monitoring and assessing volleyball players' jumping ability has proven effective, warranting its incorporation into training regimens.

Key words: *computerized diagnostic equipment, vertical jumping, test construction, reproducibility, jump abilities, position differences*

1. Introduction

Volleyball is a popular team sport. It involves two teams of six players each, separated by a net. The objective is to score points by successfully hitting a ball over the net and landing it on the opponent's side of the court. Each team is allowed up to three touches before returning the ball over the net. The sport originated in 1895. It was conceived by William G. Morgan, a YMCA physical education director, who initially named it "Mintonette". It has since gained global popularity, being played at various levels, from recreational to professional, and has been an Olympic sport since 1964, with a beach version introduced in 1996. Notable game elements include jumps, blocks, agile positioning, and short, explosive movements [19]. Volleyball matches develop around a net typically set at heights of 243 cm for men and 224 cm for women [25]. Given the significance of jumping ability in volleyball, training in this aspect is crucial and warrants attention from the coaching staff [22], [25]. Professional volleyball players engage in approximately 60 jumps per hour, while female players average 78 jumps after introducing the new rally rule [11], [21]. Recognizing that the training process facilitates sport-specific adaptations conducive to competitive success [27], it is imperative for coaches and sports scientists to accurately quantify training-related variables. This allows for objectively monitoring how athletes adapt and respond to training

* Corresponding author: Soyib Tajibaev, Uzbek State University of Physical Education and Sport, Sportchilar str., 46/45 Chirchik, Republic of Uzbekistan. E-mail: soyibjontajibayev@gmail.com
Received: March 5th, 2024
Accepted for publication: May 14th, 2024

[6], [20]. A systematic assessment of training loads, fitness, and fatigue aids professionals in detecting beneficial changes in these variables and overall physical performance [24], [29].

Despite volleyball matches often lasting up to three hours, the sport is predominantly characterized as anaerobic, primarily reliant on phosphagen energy pathways to meet metabolic demands [19]. Effective coordination of the hip, knee and ankle joints is essential to formulate movement strategies that optimize dissipation, particularly in managing significant vertical forces [30]. As part of the screening process, physical performance tests are crucial in assessing the functional capacity of the athlete's upper extremities and are commonly utilized as indicators for performance enhancement or post-rehabilitation progress [5]. Various assessment methods, ranging from sophisticated electronic measurement devices (such as force platforms, contact mats or photocells) to widely employed field-testing techniques (such as the Sargent jump test or the Abalakov test), are used to evaluate vertical jump performance.

Various types of jumps, including squat jumps, are often employed in these evaluations. However, the individual tests' validity and reliability have not been extensively explored. Furthermore, volleyball-focused research has not addressed differences in jumping capacities based on player positions. We hypothesize that players' jumping performance will significantly vary across playing positions owing to systematic training and targeted game performance. Additionally, we anticipate that anthropometric measurements will differ across playing positions owing to selection processes. To address these gaps, this study employs two different approaches. First, the validity and reliability of the jumping tests are thoroughly examined in the first section of the study (see Statistical Analysis). Second, the study's second section aims to compare the anthropometric measurements and jumping tests (dependent variables) among volleyball players in various positions (independent variables) [28].

According to Ashby and Heegaard [1], jumping involves intricate motor coordination of upper and lower body segments, making it a fundamental human activity. The standing long jump (SLJ), or the broad jump, is a widely used test to assess lower limb explosive strength and power [9]. This test, requiring minimal equipment, provides a simple yet reliable measure of muscle power, with the jump distance as the test result. Measurement is taken from the take-off line to the landing mark of the heel or the closest point of contact to the take-off line upon landing [12]. Volleyball, characterized by dynamic and explosive movements such as frequent vertical jumps and fast displacements, requires continuous assessment of athletes' training and competition load to optimize performance [7]. Literature suggests that performance analysis significantly contributes to understanding performance-related factors [14].

Wearable technology has emerged as a leading method for measuring and monitoring loads during training sessions and competitive events [3]. A recent surge in wearable technology has expanded the array of instruments available to researchers and coaches, encompassing magnetometers, gyroscopes, and accelerometers [10]. These advancements have made sensors more affordable, compact and unobtrusive, enabling the athletes to compete without interference while data are being collected. Moreover, various attachment techniques are employed in sports research, with modern sensors affixed to various body areas such as the arms, waist and quadriceps using tapes, belts, and straps [8].

Most research published in the literature in this field has focused on jump parameters, particularly the frequency of jumps executed during gameplay [2]. For instance, Bahr et al. [2] discovered that athletes engaged in approximately 12 h of jumping within a two-hour play period, as measured by jump count. Despite this, there remains a notable gap in summarizing the various types of wearable measurement tools. However, recent reviews have highlighted the growing integration of wearable technologies in volleyball, particularly in performance and training contexts (e.g., software for video analysis or training). Given the significance of gathering data to inform coaches and researchers about prevalent variables and instrument types used in volleyball performance monitoring, evaluation, and prescription, this systematic review aims to fulfil that need. Drawing from this premise, the objective of this review is to comprehensively examine and consolidate existing research on the application of wearable technology in assessing and tracking volleyball players' physical performance. Additionally, it aims to provide insights for future investigations in this area. The aim of the research is to develop a sensor device aimed at controlling and evaluating the jumping ability of elite volleyball players, subsequently testing its effectiveness in a pedagogical experiment. Hypothesis: monitoring and evaluating volleyball players' jumping ability using state-of-the-art sensory technology yield more objective and accurate data than conventional techniques, enhancing the effectiveness of training plans and improving player performance.

2. Materials and methods

2.1. Method for using sensory equipment to control and evaluate the jumping ability of volleyball players

2.1.1. Device description

The setup is designed to assess the jumping ability of volleyball players. Utilizing this setup, the maximum number of vertical jumps is recorded through the touch panel of the touch block, which captures the palm touches from both hands. Positioned at a height of 40 cm from the outstretched arm for men and 30 cm for women, the touch sensor of the block is designed to record hand touches accurately. The device consists of a touch detection block, a rod, a clip, a pressure screw for height adjustment, a clamp for attachment to a volleyball rack, and a power supply (charger).

The touch detection unit includes two touch panels, LED indicators, a switch, a charger connector and a radio communication module unit connected to a computer. The touch panels (2 pieces) are specifically designed to detect simultaneous palm touches on the detection device during jumps, positioned on the front side of the device. These panels consist of a double-sided foil PCB measuring 168 × 188 mm etched with conductive copper pads measuring 158 × 178 mm. Additionally, the device is equipped with 4 LED indicators. Three LED indicators are positioned on the side of the device. They indicate the power status, the charger connection and the battery charging, and the wireless connection to the computer. Another green LED indicator is located on the detection block's bottom panel. This indicator lights up when the test subject has successfully touched both touch panels of the device simultaneously. The power switch, located on the side of the device, is used to turn the device's power on and off. The charger is connected to a socket connector, also located on the side of the device. It is intended for use with an external 5 V power supply (supplied with the device). The Bluetooth radio module block, enclosed in a plastic case measuring 45 × 40 × 50 mm, is positioned on the side of the touch block. Its purpose is to establish a wireless connection with a computer and transmit data seamlessly.

2.1.2. Preparing the device for operation

The device was prepared for the operation according to the following procedure:

1. Install the jumping performance diagnosis device onto a volleyball stand at the desired height.
2. Activate the device by toggling the switch located on its side panel.
3. Turn on the computer.
4. Utilize the operating system control panel tools to initiate a wireless Bluetooth connection with the device.
5. Open the computer program provided with the device.
6. Establish a connection between the program and the device through a virtual COM port. Select the appropriate COM port in the program and click the "Connect" button.
7. Once the connection is established, begin the examination or training session.

2.1.3. Operating procedure

Upon establishing a connection with the device, the program will start counting the successful touches by the test subject on both touch sensors. It will then display the number of touches in the program window on the computer screen.

The subject positions himself under the device to initiate an examination or training session. Upon command, he must execute the maximum number of jumps while simultaneously touching both touch sensors with his hands.

Upon a successful touch, the green LED touch indicator on the device's bottom panel illuminates, visually registering the touch for the test subject and the instructor. Simultaneously, the touch counter in the program increments by one.

After completing one test, another test can be conducted. To do this, the program's touch counter must be reset using the "Reset" button.

Upon completion of all tests, it is essential to power off the device. This involves disconnecting the connection to the virtual COM port in the program, closing the program and switching off the device using the power switch.

2.1.4. Device design

The device for evaluating jumping performance comprises the following structural components (Fig. 1): 1) touch detection block, 2) rod, 3) clip, 4) clamping screws (2 pieces), 5) clamp, 6) tension screws (4 pieces).

The rod with the touch detection block affixed to it using a clamp and tightening screws is mounted onto a volleyball rack. The touch detection block is adjusted to the preferred height. This adjustment involves loosening the clamping screws to allow the rod with the touch detection block to move in the holder. Once the desired height is set, the clamping screws are securely tightened to fix the rod in place.

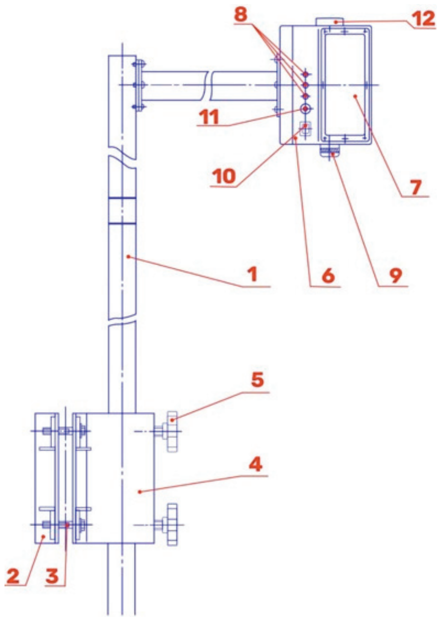

Fig. 1. Device for monitoring and evaluating the jumping performance of volleyball players. Note: 1 – rod, 2 – clamp, 3 – compression screw, 4 – clip, 5 – pressure screw, 6 – touch detection block, 7 – touchpad, 8 – LED indicators, 9 – touch indicator, 10 – power switch, 11 – female connector, 12 – radio communication module

2.1.5. Schematic diagram of the device

A schematic diagram of the touch detection block of the jumping performance diagnostic device is shown in Fig. 2.

The core component of the circuit diagram is the 8-bit microcontroller U1 ATMega8A (we can use throughout in the world), which is responsible for performing all the device's primary functions. Additionally, the device incorporates two touch panels, SR1 and SR2, a lithium-ion battery BAT1 model 18650, a charger driver U2 utilizing a TP4056 chip, a Bluetooth radio module U3 HC-06, and LED indicators D1, D2, D3, and D4.

The touch panels are constructed from double-sided foil PCB, measuring 168 × 188 mm. They operate on the principle that any conductive surface possesses electrical capacitance. The microcontroller continually measures this capacitance. To facilitate this, the sensors are linked to the power bus through 1.5 MΩ resistors R1 and R2 and connected to the microcontroller pins via 47 Ω resistors R7 and R8. Resistors R7 and R8 serve as basic protection for the microcontroller against static electricity.

Capacity assessment is conducted by measuring the time required to charge the touch panel to a logical one level. This is possible because the microcontroller pins have threshold properties. When a person touches the

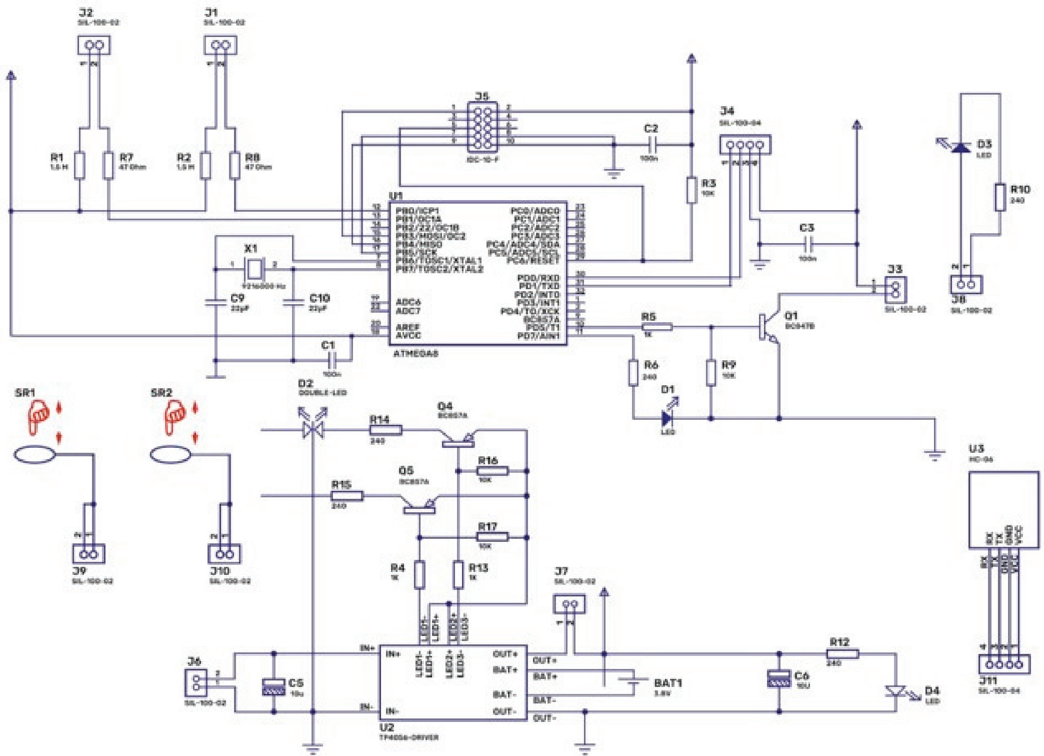

Fig. 2. Schematic diagram of the device

touch panel, its electrical capacitance changes, affecting the panel's charging duration. The microcontroller detects this change, thereby registering the touch of the sensor. A special feature of this device is that the microcontroller registers only simultaneous touches of two panels at once.

Upon registering such touches, the microcontroller activates the LED indicator D3, located on the bottom panel of the detection unit, through control transistor Q1. Furthermore, using the integrated universal USART transceiver with the connected Bluetooth HC-06 module, the microcontroller transmits data regarding the successful touch to the computer. Then, a specialized program on the computer records the count of successful touches.

The circuit is powered by an 18650 lithium-ion battery with a voltage of 3.8 V. The battery is charged through the programmable driver TP4056, which maintains the programmed charging current (approximately 1A) and voltage, thereby preventing overcharging and excessive discharge.

The jumping performance diagnostic device is equipped with a charger. This charger is connected to the touch block via the DS-025 connector on the side panel. The charging process is indicated by a two-color LED D2. During battery charging, LED D2 illuminates red. Upon completion of the charging process, the TP4056 driver transitions into standby mode and LED D2 glows red.

A key switch, KCD1-1, is provided on the side panel to activate the touch detection device. Upon powering on, the red LED D1 lights up on the detection unit, indicating the initialization of all systems. Then, the device tries to establish communication via the Bluetooth HC-06 radio module with the accompanying computer program. If the computer program is running and communication is successfully established, the blue LED D1 on the side panel of the touch detection device lights up.

In Figure 3, photographs of the experimental process involving volleyball players are shown.

2.2. Vertical jumps

Vertical jump assessment was performed using a jump mat [27]. During each assessment, participants positioned themselves on the jump mat with their feet shoulder-width apart and hands on their hips. They were instructed not to perform any preliminary steps before executing the vertical jump, although a brief downward quarter-squat movement was permitted before initiating the upward propulsion phase [13]. For each vertical jump attempt, participants were instructed to explosively propel themselves upward using both feet simultaneously and return to the initial stance upon landing on the jump mat. The jump mat determined the height of vertical jumps (in cm) by analyzing the flight time, which is the duration from the moment the feet left the mat until recontact upon landing. Each participant completed a single warm-up attempt followed by three formal trials of the vertical jump, with a one-minute rest interval between each trial. The highest vertical jump measurement recorded among the three trials was selected for further analysis [17].

3. Results

Among elite volleyball players, the development of physical performance components such as agility, jumping endurance, quickness and strength occurs slower

Fig. 3. Photographs of the experimental process

Table 1. Test results of elite volleyball players before the commencement of the general physical training cycle (July 2021)

No.	Tests	*n*	Min–max	Means ± SDs	Test execution rule
1	Vertical jump height (jump, cm)[1]	76	45–67	51.8 ± 4.22	The best result out of three jumps is recorded
2	The maximum number of jumps (jump performance, times)[2]	49	26–39	31.21 ± 5.17	43 cm from the top of the bag. Jumping to touch the detection block with both hands
3	9-3-6-3-9 m sprint (speed–power, s)	93	7.5–9.0	9.2 ± 1.02	Running to touch each of the transverse lines
4	Jumping and throwing a 2 kg ball from behind the head using both hands (explosive power, m)	61	9.0–12.0	11.4 ± 0.59	Medicine ball is thrown only in the air – without support

Test 1 is performed following the Abalakov method. Test 2 is performed using a computerized device based on a sensor signal.

Table 2. Dynamics of changes in training cycles of jumping and jumping endurance among elite volleyball players (Means ± SDs for the season 2021–2022)*

Tests / Preparation cycles	*n*	Vertical jump [cm]	Running vertical jump [cm]	Maximum number of vertical jumps [number]
General physical training cycle	36	51.8 ± 4.22	63.6 ± 4.13	31.2 ± 5.17
Special physical training cycle	33	53.6 ± 3.57	64.9 ± 4.27	33.5 ± 4.72
Pre-competition training cycle	35	55.3 ± 4.12	65.7 ± 4.31	34.8 ± 4.81
Competition cycles:	24	54.7 ± 3.84	64.5 ± 3.72	34.3 ± 4.14
After 1 round	23	52.5 ± 3.34	63.2 ± 3.45	33.2 ± 3.57
After 2 rounds	20	50.4 ± 4.13	61.8 ± 3.13	31.6 ± 4.02
After 3 rounds	24	49.3 ± 3.72	60.2 ± 3.07	30.2 ± 3.67
After 4 rounds	24	48.6 ± 3.79	59.6 ± 2.95	29.7 ± 3.43

* The players of "Orient" (Tashkent, Uzbekistan) and "Almalik Mountain Metallurgical Combine (AMMC)" (Almalik, Uzbekistan) teams participated in the study.

compared to the model, and standard requirements set in international volleyball practice. For instance, participants in our study exhibited a jumping height of 51.8 ± 4.22 cm, jumping endurance measured by the maximum number of jumps at 31.21 ± 5.17 times, and throwing the ball with a jump to achieve maximum distance recorded at 11.4 ± 0.59 times (Table 1).

Notably, these indicators progressively improved during the initial three stages of the annual training process (general physical training, special physical training, and pre-competition training). However, these indicators declined by the end of the competition cycles (Tables 2, 3, and 4). This decline, particularly observed in the leading clubs and the national team of Uzbekistan, underscores two key points. First, the efficacy of the physical exercises employed during the preparatory cycles may be insufficient. Second, the decline in jumping endurance and the quality of quickness and strength towards the end of the competition cycles suggests inadequate utilization of means to restore work capacity between training sessions and competitive games.

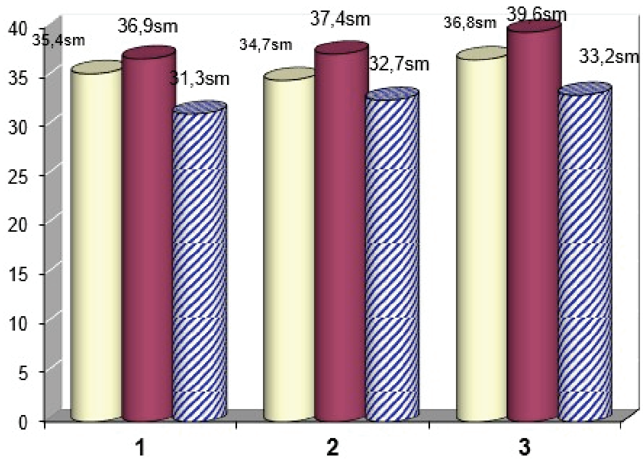

Fig. 4. Dynamics of changes in jumping performance (maximum number of jumps) among volleyball players from clubs and the Uzbekistan national team across different training cycles.
At the beginning of Season 1,
before the 2nd competition cycle,
and at the end of the 3rd competition cycle,
– "Orient" team, – "AMMC" team,
– Uzbekistan national team

Table 3. Dynamics of changes in jumping performance and its functional value among elite volleyball players (Means ± SDs, *n* = 43) during training cycles (season 2022–2023)

Tests / Preparation cycles	Maximum number of jumps before the test		Maximum number of jumps test result		Maximum number of jumps after the test		Maximum number of jumps functional value of the result	
	HRC beats/min	breathing frequency times/min	number	time	HRC beats/min	breathing frequency times/min	HRC beats/min	breathing frequency times/min
General physical training cycle	67.4 ± 3.14	11.5 ± 0.42	31.3 ± 3.12	27.1 ± 2.07	149.6 ± 5.82	33.8 ± 3.72	82.2	22.3
Special physical training cycle	68.9 ± 3.16	12.7 ± 0.59	31.9 ± 2.91	28.6 ± 2.17	152.3 ± 5.92	35.2 ± 3.84	83.4	22.5
Before the pre-competition training cycle	70.3 ± 4.67	13.4 ± 0.61	29.5 ± 2.63	30.2 ± 1.19	147.3 ± 4.73	34.6 ± 3.61	77.0	21.2
After the pre-competition training cycle	71.2 ± 3.54	13.9 ± 0.65	27.2 ± 2.15	31.2 ± 1.71	151.6 ± 4.94	36.2 ± 3.66	80.4	22.3
After the competition cycles (2 Cup competitions and 4 rounds)	74.7 ± 5.12	15.2 ± 1.03	25.7 ± 2.01	33.4 ± 2.02	155.9 ± 5.12	39.8 ± 2.98	81.2	27.6

GPT – general physical training, SPT – special physical training, PC – pre-competition cycle, FCH – heart contraction frequency, BR – breathing rate.

Table 4. Dynamics of changes in jump endurance during the pedagogical experiment across training cycles in the CG and EG (Means ± SDs)

Tests / Preparation cycles		Group	Jump endurance – 43 cm The maximum number of jumps	
			number	time [sec]
Before the experiment – before the training cycles begin (July 2022)		CG EG	30.4 ± 3.05 29.2 ± 2.73	32.3 ± 2.16 31.7 ± 3.08
In the middle of the practice season – before the start of competition cycles (October 2022)		CG EG	31.3 ± 3.12 33.5 ± 2.64	32.7 ± 2.14 31.9 ± 1.88
After practice – at the end of competition cycles (May 2023)		CG EG	28.3 ± 2.97 36.8 ± 3.04	34.6 ± 2.23 33.5 ± 2.72
The difference between the indicators before and after the experiment		CG EG	−2.1 +7.6	−2.3 −1.8
Reliability of pre- and post-test scores	*t*	CG EG	1.84 7.1	2.77 1.66
	p	CG EG	$p > 0.05$ $p < 0.05$	$p < 0.05$ $p > 0.05$

The change of the "Orient" team's jumping performance (maximum number of jumps) in different training cycles was 35.4 times at the beginning of the season, decreased to 34.7 times before the competition cycles, and increased to 36.8 times at the end of the competition cycles (Fig. 4). In the "AMMC" team, 36.9 times at the beginning of the season, decreased to 37.4 times before the competition cycles, and increased to 39.6 times at the end of the competition cycles. In the national team of Uzbekistan, it increased to 31.3 times at the beginning of the season, to 32.7 times before the competition cycles, and to 33.2 times at the end of the competition cycles.

The dynamics of indicators representing jumping performance (number and time of maximum jumps, their functional value) was observed in these volleyball players based on the results obtained before and after training and testing. This trend was particularly noticeable during the intervals between the first–second and third–fourth rounds of the competition cycles.

Based on the abovementioned results and conclusions, it is evident that the actual indicators representing the qualities of agility, jumping endurance, quickness, and strength in the elite volleyball players who participated in the study were significantly lower than the established model and normative criteria. Furthermore, these indicators and their functional value declined across training cycles, competition rounds, and individual training sessions. Such observations suggest that the annual training programs employed by these volleyball players were not tailored to their actual physical and functional indicators. Moreover, these results indicate a lack of emphasis in the training program on effectively utilizing exercises targeting functional organs and restoring work capacity.

While the Brazilian national team and other elite teams integrate preventative techniques into their on-field training routines, prevention methods still require enhancements [15]. Given the limited data availability, it is imperative to maintain preventive measures and training regimens as proactive strategies to reduce athlete complaints and injuries.

The results of the 10-month pedagogical experiment revealed that the control group (CG) participants, who adhered to traditional training methods throughout the experiment, exhibited agility, jumping endurance and quickness–strength qualities below the established model and normative criteria. Specifically, the standing and running jump heights were 56.5 ± 3.41 and 59.8 ± 4.32 cm, respectively. Throughout the experiment, from before the competition cycles to the end of the experiment (at the end of the competition cycles), a partial increase in these indicators was observed, with a growth difference of only 1.9 and 2.9 cm, respectively ($p > 0.05$). Conversely, the experimental group (EG) participants, who consistently incorporated the recommended experimental exercises into microcycles aligned with the developed training program, exhibited substantial improvements in standing and running jump heights. The increase amounted to 5.9 and 7.1 cm, respectively (Fig. 5).

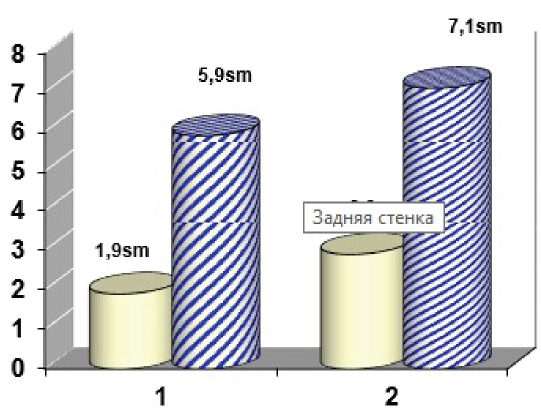

Fig. 5. The difference in growth rates between the CG and EG at the end of the experiment.
1 – jump height from 1st place, 2 – running and jumping height, – control group results, – experimental group results

Because it is difficult to find a CG with identical training and performance levels as the EG, conducting experimental studies in team sports presents significant challenges [18], [24]. To address this issue, the stability of the measure was demonstrated using test–retest reliability measures, which were reported as the intraclass correlation coefficient (ICC), aligning with findings from other studies [18]. It is worth emphasizing that these challenges should not diminish the necessity and importance of such research endeavors [23], especially in the context of young female volleyball field players, where information regarding seasonal variations is lacking.

Maintaining high-level jumping endurance throughout long-term training, competitive matches, and competition cycles without compromising standing and running jump height is crucial for ensuring the effectiveness of jumping performance, particularly in attack shots and blocking. The results showed that, in the CG, the jumping endurance – measured as the maximum number of jumps to the high-hanging detection block or approximately 43 cm from the point of extension of the arms – was initially recorded at 30.4 ± 3.05 times before the experiment. The maximum jump time was 32.3 ± 2.16 s (Table 4). Thus, each jump took more than 1 s to perform. Before the competition cycles (i.e., after 4 months), these indicators slightly increased to 31.3 ± 3.12 times and 32.7 ± 2.14 s, respectively. However, by the end of the experiment (after 10 months), the number of jumps in this group sharply declined, accompanied by significantly longer jump times. This indicates an increased prevalence of fatigue symptoms among volleyball players in the CG, likely influenced by the applied loads.

The coefficient of variation (CV) for the typical error of the estimate (TEE) was 7.8% (90% CL 7.0–8.9%). A strong correlation was observed between the VERTEC and VERT devices ($r = 0.75$; 90% CL 0.68–0.81). While the standardized TEE indicated a modest effect size (ES) for both raw (0.65) and CV (0.66) estimates, the raw TEE measured 5.3 cm (90% CL 4.8–6.0 cm).

The least significant change in the attack jump for the VERT device was 6.8 cm (9.9%). For both the VERTEC and VERT devices, the mean ± SD block jump performances were 53.7 ± 6.1 and 58.5 ± 5.7 cm, respectively. The TEE was 7.9% (90% CL 7.1–8.9%) as a CV. The raw TEE measured 4.0 cm (90% CL 3.6–4.5 cm), and Pearson's correlation value was very high at $r = 0.75$ (90% CL 0.67–0.81). The study's criteria (ruler) and practical (VERT) devices recorded scores of 70.9 and 53.7 cm and 76.3 and 58.5 cm, respectively. Additionally, the block jump performance in this research was 23.3% lower than the attack jump performance, similar to findings by Sattler et al. [25], who reported a 22.0% difference. These findings suggest that elite volleyball players frequently exhibit comparable variations in their AJ and BJ performances [4].

Moreover, during the experiment, the indicators recorded for the EG participants, who performed special exercises within the experimental program framework, exhibited a progressive trend distinct from that observed in the CG. For example, before the experiment, the EG demonstrated a maximum jump frequency of 29.2 ± 2.73 times and a jump duration of 31.7 ± 3.08 s.

By the middle of the experiment, these parameters increased to 33.5 ± 2.64 times for maximum jumps and 31.9 ± 1.88 s for jump duration. Towards the end of the experiment, the maximum number of jumps increased to 36.8 ± 3.04 times, and the jump duration showed a positive trend compared to the CG metrics, with a jump time of 33.5 ± 2.72 s. Notably, the CG exhibited a decrease in the number of jumps (2.1 times less) and jump time (2.3 s less), indicating a decline in jump endurance.

In modern competitive volleyball, the most repetitive element is the jumping technique. Inadequate jumping endurance or high functional load can compromise coordination, technical precision, and tactical effectiveness, decreasing efficiency. The results showed that while the initial jumping endurance indicators among participating volleyball players were not exceptionally high, their functional value was significant. Specifically, in the CG, the initial maximum number of jumps was 30.5 ± 3.09 times, with a heart rate of 66.3 ± 3.09 beats/min and a respiratory rate of 13.8 ± 1.12 times/min. Following the test load, these indicators increased to 132.4 ± 4.21 beats/min and 37.2 ± 2.69 times/min, respectively (Table 5). Consequently, the pulsometric value for maximum jump load reached 66.1 beats/min, with a respiratory value of 23.4 times/min. Conversely, in the EG, the initial maximum number of jumps was 29.7 ± 3.02 times, with a pulsometric value of 68.0 beats/min and a respiratory value of 34.4 times/min.

Just before the beginning of the competition cycles, the number of jumps in the CG increased to 32.9 ± 3.34 times, corresponding to its pulsometric value (67.3 beats/min) and respiratory rate (24.2 times/min). Conversely, during the experiment, these parameters showed progressive improvement in the EG participants, who underwent specialized, experimentally designed training regimens. In EG, the number of jumps increased to 35.6 ± 3.53 times, with a pulsometric value of 63.3 beats/min and a respiratory rate of 19.0 times/min.

In volleyball, the ability to reach the ball in time and execute game techniques depends on movement speed. Sustaining this speed throughout prolonged training and competition depends on speed–power endurance and its functional significance. The fluctuating indicators observed in the EG and CG groups regarding jumping endurance and its functional value were also influenced by these speed–strength factors. Consequently, the conventional training regimen in CG cannot foster the essential components of volleyball-specific physical performance, such as agility, jumping endurance, quickness–strength attributes, and their functional significance, in a progressive manner.

However, during the 10-month pedagogical experiment, all metrics displayed progressive trends in the EG participants, who adhered to the prescribed exercises

Table 5. Dynamics of changes in jump endurance and its functional value in the CG and EG during the pedagogical experiment across various training cycles (Means ± SDs)

Tests / Preparation cycles	Before the test		Maximum jump test – result	After the test		Functional value of the test result	
	HRC beats/min	breathing frequency times/min		HRC beats/min	BF times/min	HRC beats/min	BF times/min
Before the experiment – before the training cycles begin (July 2022)	66.3 ± 3.09 67.7 ± 3.12	13.8 ± 1.12 14.4 ± 1.19	30.5 ± 3.09 29.7 ± 3.02	132.4 ± 4.21 135.7 ± 4.28	37.2 ± 2.69 36.8 ± 2.55	66.1 68.0	23.4 34.4
In the middle of the practice season – before the start of competition cycles (October 2022)	71.5 ± 4.07 65.4 ± 3.08	15.2 ± 1.21 14.5 ± 1.13	32.9 ± 3.34 35.6 ± 3.53	138.8 ± 4.31 128.7 ± 2.97	39.4 ± 2.83 33.5 ± 2.14	67.3 63.3	24.2 19.0
After the experiment – at the end of the competition cycles (May 2023)	73.6 ± 4.12 67.2 ± 3.01	14.7 ± 1.17 12.6 ± 1.03	29.4 ± 2.75 36.9 ± 3.15	139.9 ± 4.37 126.7 ± 2.48	39.8 ± 2.73 31.6 ± 2.05	66.3 59.5	25.1 19.0
The difference between the indicators before and after the experiment	−7.3 +0.5	−0.9 +1.8	−1.1 +7.2	−7.5 +9.0	−2.6 +5.2	–	–

Above – indicators related to the CG, below – indicators related to the EG.

and training sessions outlined in the developed program. Consequently, these exercises and training sessions are highly effective.

4. Discussion

Previous studies suggest that physical work ability, encompassing the problems of developing physical qualities, is crucial in maintaining the effectiveness of technical and tactical actions during long-term training regimens, competitive cycles, and diverse game scenarios in sports like volleyball. Some scientific–methodical perspectives have been proposed, shedding light on developing such abilities and attributes. Furthermore, the fundamental components of physical work ability, pivotal for technical and tactical skills, notably in optimizing the efficacy of jumping techniques, along with the strategies and techniques for fostering traits like agility, jumping endurance and quickness–strength across different training phases, underscore the need for innovative measures that provide objective insights. It has been observed that the evaluation challenges based on tools and technological methodologies lack a substantive scientific discourse. This observed gap underscores the importance of the chosen topic, which has significant scientific and practical relevance.

To determine the actual jump-and-reach height, participants performed two types of vertical jumps – the countermovement (CM) jump and the drop jump (DJ) – utilizing a Vertec device adjacent to the force platform. Each jump was measured twice, with a 0.5–1.0 min rest interval between each jump. The Vertec apparatus evaluated the height in a plantar flexed stance, deducting one-hand reach height to determine the best trial, characterized by jump height. Following the protocol outlined by Newton et al., the height of the DJ box remained consistent at 30 cm for all subjects.

Based on the model and normative standards set for professional volleyball players, the actual indicators of essential physical performance components – agility, jump endurance, and quickness–strength – in elite volleyball players were 2.7–4.4%. The indicators were 4.3–7.5% and 6.3–6.5% at a lower level. It is noteworthy that leading up to the competition cycles within the annual training regimen, these initial indicators improved among the participating volleyball players: jumping increased by 9.3–9.7%, jump endurance by 8.9%, and speed–strength by 10.7–11.12%. However, by the conclusion of the competition cycle, these indicators were 11.6%, 10.7–11.3% and 11.2–12.5%, respectively. This scenario reflects the volleyball players incompletely developed physical work capacity and how competition demands exacerbate fatigue symptoms, diminishing their already limited physical capabilities. It is possible that the dynamics of such regressive indicators may not adversely affect the degree of technical–tactical proficiency.

Hennessy and Kilty [16] identified a correlation between sprinting performance and various jump tests, including the CM, DJ, and bounding jump. They revealed that 63% of sprinting performance was accounted for by both the CM and DJ tests, with the DJ test alone explaining 55% of the relationship. However, in contrast to their findings, this study indicates that CM factors alone account for 34% of the variance in agility performance, as opposed to DJ variables.

In our assessment, jumping endurance (jumping ability) measured using a computerized device based on sensory signals was initially recorded at 30.4 ± 3.05 times for the maximum number of jumps and 32.3 ± 2.16 s for jump time in the CG before the experiment (at the beginning of the season). In the EG, these parameters were slightly lower at 29.2 ± 2.73 times and 31.7 ± 3.08 s, respectively. By the middle of the experiment (before the competition cycles), the EG exhibited higher values than the CG. By the end of the experiment, the number of jumps increased by 7.6 times in the EG, with the jump time increasing by 1.8 s. In contrast, in the CG, the number of jumps decreased by 2.1 times, and the jump time increased by 2.3 s. Thus, it is evident that the traditional training methods employed in the CG lacked the efficacy to rapidly enhance jump endurance. Conversely, the experimental jump exercises and movement games utilized in the EG demonstrated effectiveness in this aspect.

Although the test results representing speed and quickness–power were initially similar in both groups before the experiment, they were considerably lower than the model and normative indicators established for professional volleyball players. Notably, the initial indicators recorded in the EG quickly improved by the end of the experiment. For instance, the speed of running the distance of 9-3-6-3-9 m decreased from 8.7 ± 0.11 to 7.3 ± 0.05 s, while the speed–strength decreased from 26.5 ± 2.81 to 23.7 ± 2.16 s. Additionally, the performance in jumping and throwing a 2 kg ball from behind the head with both hands to the maximum distance (speed–power) increased from 10.3 ± 1.03 to 13.9 ± 1.1 m, reaching the level of indicators set for elite volleyball players. This result indicates the effectiveness of the experimental exercises developed and utilized in the EG. Such progressive directional changes were not observed in the CG.

5. Conclusions

Traditional training programs implemented in elite volleyball players, including club and national teams, often fail to adequately develop the essential components of physical performance crucial for the efficacy of technical and tactical actions in modern volleyball, such as agility, jumping endurance, and quickness–strength qualities. Moreover, extensive observations, examination of foreign practices, and the outcomes of ongoing research on elite volleyball players, coupled with the training regimens devised and employed in the EG to cultivate agility, jumping endurance, and speed-power qualities, have been pedagogically proven to be highly effective.

Acknowledgements

The authors would like to thank the Design Bureau of the Academy of Sciences of the Republic of Uzbekistan, coaches and volleyball players for took part in the search research, and Falcon Scientific Editing (https://falconediting.com) for proofreading the English language in this paper.

References

[1] ASHBY B.M., HEEGAARD J.H., *Role of arm motion in the standing long jump*, Journal of Biomech., 2002, 35, 12, 1631–1637.

[2] BAHR M.A., BAHR R., *Jump Frequency May Contribute to Risk of Jumper's Knee: A Study of Interindividual and Sex Differences in a Total of 11,943 Jumps Video Recorded during Training and Matches in Young Elite Volleyball Players*, Br. J. Sports Med., 2014, 48, 1322–1326.

[3] BARTLETT J.D., O'CONNOR F., PITCHFORD N., TORRES-RONDA L., ROBBERTSON S.J., *Relationships Between Internal and External Training Load in Team-Sport Athletes: Evidence for an Individualized Approach*, Int. J. Sports Physiol. Perform., 2017, 12, 230–234.

[4] BORGES T., MOREIRA A., BACCHI R. et al., *Validation of the VERT wearable jump monitor device in elite youth volleyball players*, Biol. Sport., 2017, 34, 3, 239–242.

[5] BORMS D., COOLS A., *Upper-Extremity Functional Performance Tests: Reference Values for Overhead Athletes*, Int. J. Sports Med., 2018, 39, 6, 433–441.

[6] BORRENSEN J., LAMBERT M.I., *The quantification of training load, the training response and the effect on performance*, Sports Med., 2009, 39, 9, 779–795.

[7] BOURDON P.C., CARDINALE M., MURRAY A., GASTIN P., KELLMANN M., VARLEY M.C. et al., *Monitoring Athlete Training Loads: Consensus Statement*, Int. J. Sports Physiol. Perform., 2017, 12, S2-161–S2-170.

[8] CAMOMILLA V., BERGAMINE E., FANTOZZI S., VANNOZZI G., *Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review*, Sensors, 2018, 18, 873.

[9] CVELC D., PEJOVIC T., OSTOLC S., *Assessment of physical fitness in children and adolescents*, Physical Education and Sport, 2013, 11, 2, 135–145.

[10] DAML F., MACDONALD K., HUNT M.A., TAUNTON J., SCOTT A., *Using the VERT wearable device to monitor jumping loads in elite volleyball athletes*, PLoS ONE, 2021, 16, 1, e0245299.

[11] ESPER A., *Cantidad y tipos de saltos que realizan las jugadoras de voleibol en un partido*, Lecturas: Educación física y deportes, 2003, 58, 21–30.

[12] ESPINOSA-SANCHEZ M., *A standing long jump study in preadolescents aged 9–13*, Journal of Sport and Health Research, 2017, 9, 2, 233–246.

[13] FARROW A.C., GONZALES J.U., AGU-UDEMBA C.C., SOBOLEWSKI E.J., THOMPSON B.J., PALMER T.B., *Effects of age on vertical jump performance and muscle morphology characteristics in females*, J. Sports Med. Phys. Fitness, 2020, 60, 8, 1081–1088.

[14] FORTE D., ALTAVILLA G., *Preliminary Correlation between Anthropometric and Performance Data in Volleyball about the Transition Period*. J. Phys. Educ. Sport, 2018, 18, 1994–1998.

[15] GOUTTEBARGE V., VAN SLUIS M., VERHAGEN E., ZWERVER J., *The prevention of musculoskeletal injuries in volleyball: the systematic development of an intervention and its feasibility*, Inj. Epidemiol., 2017, 4, 1, 25.

[16] HENNESSY L., KILTY J., *Relationship of the stretch-shortening cycle to sprint performance in trained female athletes*, J. Strength Cond. Res., 2001, 15, 326–331.

[17] IZQUIERDO M., GOROSTIAGA E., GARRUES M., ANTON A., LARRION J., HAEKKINEN K., *Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men*, Acta Physiol. Scand., 1999, 167, 57–68.

[18] KRAEMER W.J., *The body of knowledge: Use and professionalism*, Strength Cond. J., 2005, 27, 33–35.

[19] KÜNSTLINGER U., LUDWIG H.G., STEGEMANN J., *Metabolic changes during volleyball matches*, Int. J. Sports Med., 1987, 8, 5, 315–322.

[20] LAMBERT M.I., BORRESEN J., *A theoretical basis of monitoring fatigue: A practical approach for coaches*, Int. J. Sports Sci. Coach., 2006, 1, 4, 371–387.

[21] LIAN Ø., ENGEBRETSEN L., ØVREBØ R.V., BAHR R., *Characteristics of the leg extensors in male volleyball players with jumper's knee*, Am. J. Sports Med., 1996, 24, 3, 380–385.

[22] LIDOR R., ZIV G., *Physical and physiological attributes of female's volleyball players – A review*, J. Strength Cond. Res., 2010, 24, 1963–1973.

[23] MARQUES M.C., VAN DEN TILLAAR R., VESCOVI J.D., GONZALEZ-BADILLO J.J., *Changes in strength and power performance in elite senior female professional volleyball players during the in season: A case study*, J. Strength Cond. Res., 2008, 22, 1147–1155.

[24] ROBSON-ANSLEY P.J., GLEESON M., ANSLEY L., *Fatigue management in the preparation of Olympic athletes*, J. Sports Sci., 2009, 27, 13, 1409–1420.

[25] SATTLER T., SEKULIC D., HADZIC V., ULJEVIC O., DERVISEVIC E., *Vertical jumping tests in volleyball: Reliability, validity, and playing-position specifics*, J. Strength Cond. Res., 2012, 26, 6, 1532–1538.

[26] SINGH H., KIM D., KIM E., BEMBEN M.G., ANDERSON M., SEO D.-I. et al., *Jump test performance and sarcopenia status in*

men and women, 55 to 75 years of age, J. Geriatr. Phys. Ther., 2014, 37, 2, 76–82.
[27] SMITH D.J. *A framework for understanding the training process leading to elite performance*, Sports Med. [Review], 2003, 33, 15, 1103–1126.
[28] TINE S., DAMIR S., VEDRAN., OGNJEN U., EDVIN D. *Vertical jumping tests in volleyball: reliability, validity, and playing-position specifics*, The Journal of Strength and Conditioning Research, 2011, 1532–1533.
[29] WALLACE L.K., SLATTERY K.M., COUTTS A.J., *A comparison of methods for quantifying training load: relationships between modelled and actual training responses*, Eur. J. Appl. Physiol., 2014, 114, 1, 11–20.
[30] YEOW C.H., LEE P.V., GOH J.C., *An investigation of lower extremity energy dissipation strategies during single-leg and double-leg landing based on sagittal and frontal plane biomechanics*, Hum. Mov. Sci., 2011, 30, 3, 624–635.