

Enhancement of a software–hardware system for measuring volleyball players' speed indicators and evaluating its effectiveness in a pedagogical context

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Abstract

This study aims to evaluate the effectiveness of assessing agility in volleyball players by comparing traditional testing methods with computerized measurements, using student athletes as subjects. Methods: A comprehensive approach was employed, including analysis of scientific literature, pedagogical observation, exclusive interviews, traditional agility tests, and computerized measurement tools designed for precise speed assessment. Heart and respiratory rate were monitored, and statistical analyses were performed. Results: Modification of traditional tests, including "Running for 92 meters in the shape of spruce" and "Running 5 × 6 m, (30 m)" was performed, introducing a new running test named "Running in the shape of star" (certificate No. 005215). Following implementation, the running time improvements were notable: "Running in the spruce configuration" increased from 4.19 s to 9.25 s, "Running 5 × 6 m" from 4.78 s to 10.60 s, and "Star" from 3.35 s to 9.09 s. A computerized device was developed (certificate No. 005215), ensuring reliable data storage and comparison with traditional tests. Improvements were observed in "Running in the spruce configuration" (5.73%), "5 × 6 m running" (10.41%), and "Running in the shape of star" (7.25% left side, 7.42% right side). In the control group, these indicators are 1.51%, 2.73%, and 5.18%. Conclusion: The analysis of various sources has revealed a significant limitation in relying solely on stopwatch-based tests to assess the quality of speed characteristics in sports games. These tests, conducted without standardized conditions and procedures, are susceptible to subjective or mechanical influences such as stopwatch accuracy, the mental state of the participants, and the observers' knowledge and experience. Consequently, the objectivity and reliability of the results obtained through such methods are compromised. This discrepancy is evident in volleyball, where regulatory requirements established by experts for qualified players aged 18–20 for the "Running for 92 meters in the shape of spruce" test vary considerably (ranging from 23.4–24.0 to 25.0–25.9 s). Such inconsistencies have been observed in evaluations, current research, and survey results reviewed in the analysis.

Key words: running speed, running time, running distance, measuring technique, running to 92 meters in the shape of spruce, running in the shape of star

Introduction

The increasing global popularity of volleyball competitions underscores the need to achieve remarkable results year after year, intensifying the competition among teams. This trend underscores the need to enhance the efficacy of technical and tactical training in volley-ball, particularly focusing on improving aerobic–anaerobic performance. Such enhancements are crucial for sustaining peak performance during extended training sessions and competitions, requiring the adoption of novel methodological approaches for evaluation. Increasingly testing method in the planning give the reason for an better conditions to decide the annual planning (Popelka & Pivovarniček, 2018). So, it have to provide the kinds of functional tests for training.

The scientific literature confirms that the game's effectiveness in modern volleyball, including the effectiveness of technical and tactical movements performed along sharp trajectories, depends on players' speed. While current volleyball training methodologies integrate methods and tools to improve such skills, the technologies for their objective assessment remain underdeveloped. This involves performing many dynamic combinations, encompassing both active and passive movements, requiring intense efforts interspersed with phases of lower intensity (Borras et al., 2001). Agility in volleyball is characterized by the rapid change of movement direction, the ability to quickly start and stop actions (Little and Williams, 2005), and the capacity to

decelerate, accelerate, and change direction while maintaining optimal body control without compromising speed (Costello & Kreis, 1993).

Agility in volleyball is influenced by a range of motor skills, including balance, coordination, explosive strength, and flexibility (Young & Farrow, 2006). When discussing agility within the context of volleyball, it is crucial to consider not only the cognitive aspects involved in various tasks, such as sprinting or running in zigzag patterns but also the more difficult and unpredictable tasks inherent in sports games, like blocking an attack or reacting to a spike (Sheppard & Young, 2006). These actions require rapid body movement and the ability to quickly change direction, distinguishing agility from speed. Speed refers to the shortest time required for an object to cover a fixed distance, which is the same as velocity but without specifying the direction (Harman & Garhammer, 2008).

Control tests focused on the manifestations of motor skills demonstrated that athletes in the experimental group exhibited greater progress in the final test compared to their initial results (Young et al., 2002). Acceleration and deceleration are involved in changing direction movements, which are fundamental to agility performance. Therefore, acceleration and deceleration are specific qualities that require targeted training (Jeffreys, 2006). Change of direction performance is relatively independent of straight-line speed performance (Little et al., 2005; Young et al., 2001a). Agility in team sports encompasses changing direction, anticipating opponent movements, and reacting to specific game situations (Gamble, 2013). In the context of team sports, agility comprises not only change of direction abilities but also perception and decision-making. Similar to the multifaceted nature of speed expression, agility in team sports is multifactorial (Gamble, 2011). In volleyball, achieving peak performance entails mastering all motor qualities; proficiency in fundamental skills like passing and spiking must be complemented by speed, coordination, balance, strength, quickness, and agility.

Our study investigated whether specific training methods could enhance skills such as agility and speed. The experiment confirmed the hypothesis that physical exercises, motor games, and volleyball-specific drills contribute to developing motor qualities, resulting in stable skill acquisition. Control tests focused on motor skill manifestations revealed that athletes in the experimental group made more significant progress in the final test compared to their initial results (Alexandru Oprean, Alexandru-Rareș Puni, 2021). The sport of volleyball is an intermittent and non-inversion game characterized by short bursts of high-intensity movements interspersed with periods of lower activity (Muazu et al., 2019; Casal et al., 2016). Therefore, players must possess specific physical fitness attributes, including endurance, upper and lower body strength, speed, and power, aligning with the demands of other team-based sports (Abdullah et al., 2016; Hughes et al., 2012).

The use of machine learning in sporting activities has garnered considerable attention in recent years, particularly with the emergence of Industry (Richter et al., 2021). Machine learning, and to some extent deep learning, has been applied in various areas such as activity recognition, performance analysis, match outcome predictions, and injury prediction (Taha et al., 2018). Based on these considerations, developing a software-hardware complex for measuring the speed indicators of volleyball players was deemed necessary. This research was conducted in collaboration with colleagues. The software-hardware complex for measuring the speed indicators of volleyball players operates as follows. The measuring device must be connected to a personal computer upon launching the program. This connection is established by selecting the appropriate port from the drop-down menu and clicking the "Connect" button on the program's main window, as illustrated in Figure 1. Typically, only one port is listed after connecting the device to the computer. Therefore, users can select this port and click "Open" to establish the connection.

Material & methods

- 2.1. The software-hardware complex is specifically designed to measure the speed of volleyball athletes.
- 2.2. The operational protocol of the equipment includes:
 - An operating temperature range of 10–35°C.
 - Relative air humidity tolerance up to 98% at +25°C ambient temperature;
- 2.3. Technical information
 - 2.3.1. The software-hardware complex facilitates the display, measurement, and calculation of the following data:
 - Athlete information.
 - Type of exercise.
 - "Running in the shape of spruce" exercise duration.
 - "4 × 10 m running" exercise interval.
 - Total exercise completion time.
 - 2.3.2. The device is powered by 220 V alternating current with a tolerance of $\pm 10\%$ and a frequency of 50Hz.
 - 2.3.4. Power consumption is limited to a maximum of 10 W.
 - 2.3.5. General dimensions:
 - Operator remote control—220 × 145 × 70 mm;
 - Sensor—500 × 500 × 600 mm.
- 2.4. Device composition

Table 1 outlines the components comprising the device.

Table 1. Device components

Name	Designation	Quantity	Reminder
1	2	3	4
Personal computer (laptop)		1	Submitted by the customer
Control panel		1	
Sensor		7	
Bracket for the sensor		7	
Connection cable		7	
Technical description and instructions for use		1	

2.5. Technical device and operation principle

2.5.1. The software–hardware complex, named the "Volley-run" program, comprises a built-in personal computer and seven touch sensors.

2.5.2. Each sensor generates an output signal upon contact with a hand, transmitting the signal to the instructor's computer through a connecting cable.

2.5.3. Sensors are positioned at the height of 25 cm.

2.5.4. U1 TTP-223 touch sensor utilizes a supply voltage converter, control circuit, and sound signal.

2.5.5. The instructor's computer receives, processes, and stores measured data.

2.5.6. Signals from sensors are routed to the instructor's computer via XG1–XG7 connectors on the ARDUINO-UNO microprocessor device, utilizing a built-in power supply and a data transfer device.

2.5.7. HL1–HL7 LEDs indicate signal reception from sensors.

2.5.8. Software installed on the computer processes sensor signals, calculates parameters, and stores and presents exercise results.

2.6. Software

2.6.1. The "Volley-run" computer program facilitates exercises within the "Running in the shape of spruce" and "4 × 10 meters running" complexes. It enables complex control, exercise result recording, and storage in the built-in database.

2.6.2. Basic software requirements.

2.6.3. The program requires the following pre-installed components on the computer:

- Driver CH340G–USB-UART interface converter. The driver is available for downloading from the manufacturer's website: <http://www.wch.cn>

- Microsoft SQL Server Express LocalDB, a built-in database management system version 2016 or later.

This program can be downloaded from the developer's website: <http://microsoft.com>

2.6.4. Software Operation.

2.6.4.1. The main program window, depicted in Figure 1, features a table listing athletes and buttons for adding or removing athletes and managing connections.

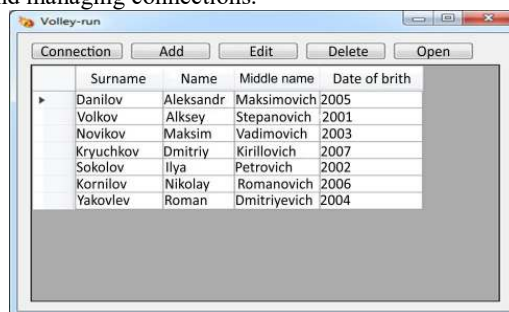


Fig. 1. The main window of the "Volley-run" program

2.6.4.2. Upon initiating the program, connecting the measuring device to a personal computer is imperative. To facilitate this, the connection window appears (Figure 2) upon clicking the "Connection" button on the program's main interface. This window features a drop-down menu listing available ports alongside buttons to refresh the list and open and close ports. Typically, most computers display only one port in the list after the device connection. Therefore, users should select this port and click "Open" to establish the connection.

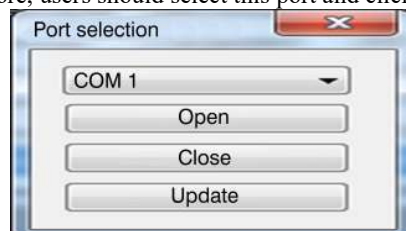


Fig. 2. Device connection window

2.6.4.3. The main program window includes a context menu (Figure 3)

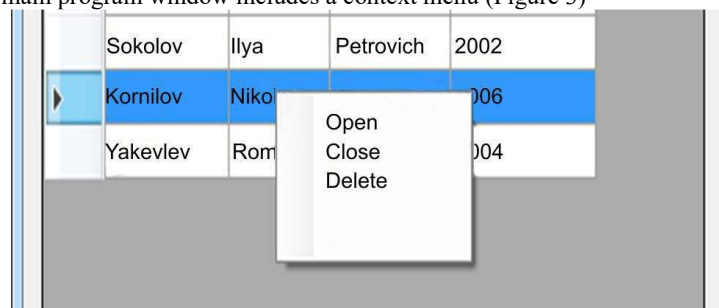


Fig. 3. Table context menu

2.6.4.4. Clicking the "Add" button in the main program window opens a window for adding a new athlete (Figure 4). This window includes text fields for entering the athlete's last name, first name, middle name, and year of birth. Upon clicking the "Add" button, the entered data are added to the main form table. Additionally, input can be submitted by pressing the "Enter" key.

2.6.4.5. If required, athlete data in the main window table can be modified. To do so, select the desired athlete and click the "Change" button or access the context menu for similar options. Additionally, athletes can be removed from the list by clicking the "Delete" button or through the table's context menu.

Note: Deleting an athlete will permanently erase the athlete's data and all associated results from the program's database. This action cannot be undone.



Fig. 4. "Addition of new athlete" window

2.6.4.6. Clicking the "Open" button opens a window presenting a list of test results corresponding to the selected athlete. This window is shown in Figure 5. This window can be accessed through the context menu or by double-clicking on the athlete in the table.

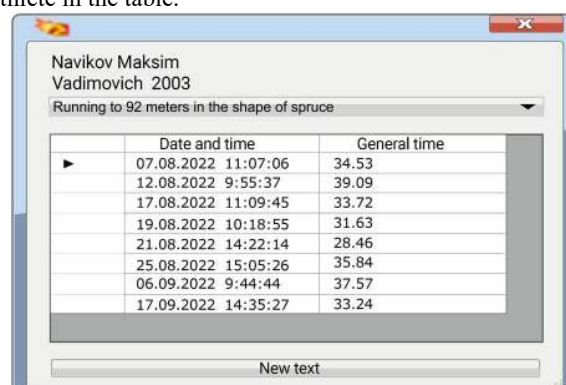


Fig. 5. A window with a list of tests

2.6.4.7. In the upper part of this window, the details of the selected athlete (such as name and surname) are displayed. Below, a dropdown menu presents a list of available exercise types. The menu has two options: "Running for 92 meters in the shape of spruce" and "Running for 30 meters". Further down, a table lists the results of previously completed tests for the selected exercise type. At the bottom of the window is a button labeled "New test."

To access detailed results from the previous test in the abovementioned list, simply double-click the left mouse button on any of the results displayed in the table. Alternatively, this can be done through the table's context menu containing the results list. Doing so will open a window (Figure 6). This window will display information about the athlete (name, surname, etc.), the date and time of the test, and a table showcasing the results from all four or six points, depending on the type of exercise.

Point number	Time
1	6.84
2	5.87
3	3.23
4	4.28
5	5.47
6	7.78
Total time	28.46

Fig. 6. Previous test results window

If necessary, a result can be removed from the table using the context menu with the results list.

Point number	Time
1	7.55
2	3.34
3	4.52

Figure 7. Results window

The "New test" button switches the program and device into training mode, prompting the opening of a tabular window for result recording (Figure 7). This table shows the point number and the measured time in seconds, with accuracy to the hundredth of a second. The table is filled out upon test completion, and the total time is calculated and recorded. To save the results in the built-in database, it is necessary to click the "Save" button. Then, the window will close automatically, and the results will be saved.

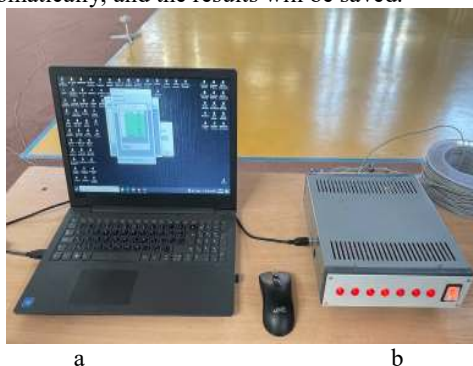


Fig. 8. Measuring equipment
a-notebook; b-equipment

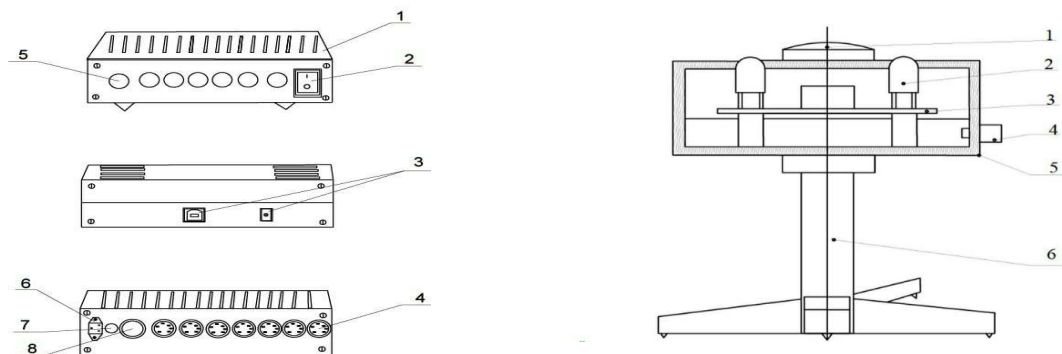


Fig. 9. Technological components of the equipment

Note: 1. Sensor. 2. Hardware on-off button. 3. Computer connection port. 4. Cable connection ports. 5. LED indicators. 6. Power outlet connection plug. 7. Fuse

Note: 1. Overview of the equipment. 2. Status indicator. 3. Device for recording signals. 4. Cable connection ports. 5. Standard equipment. 6. Stand

It is designed to autonomously and integrally determine the speed of each distance cycle recorded in (running 3×10 meters, 4×10 meters, and 5×6 meters) running tests, and it includes computer software and hardware designed to store results in memory. The computer pro-gram is operated by the researcher. There are sensors and warning lights that record running speed. Sensor posts to be positioned at the boundary of each running test cycle: 7 posts, each 25 cm tall. There are cables connecting the "sensors" to the computer (Figure 10).

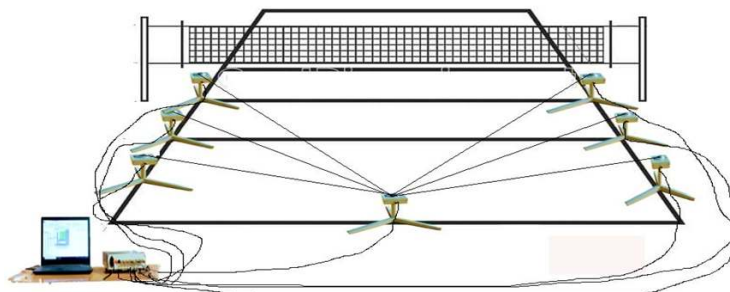


Fig. 10. Utilization of measuring equipment

Utilization of measuring equipment

1. The researcher's remote control connects the computer and sensors to the power grid. When the "Ready" mode is displayed on the monitor, it indicates the designated starting position for verification.
2. As soon as the signal-buzzer is given, the volleyball player performing the test must sprint along the sensor-equipped posts shown in the figure 9 and touch the sensor with his hand.
3. The running speed for each running cycle and the final test results are autonomously and integrally displayed on the monitor and stored in the computer's memory. The researcher then records the result.
4. Seven sensors attached to posts are positioned at specific points or field zones based on the parameters and specifications of each (running 3×10 meters, 4×10 meters, and 5×6 meters) running test.
5. Diagrams illustrating the layout, content, and distance measurements of running (running 3×10 meters, running 4×10 meters, and running 5×6 meters) tests are provided in Figures 10, 11, and 12.

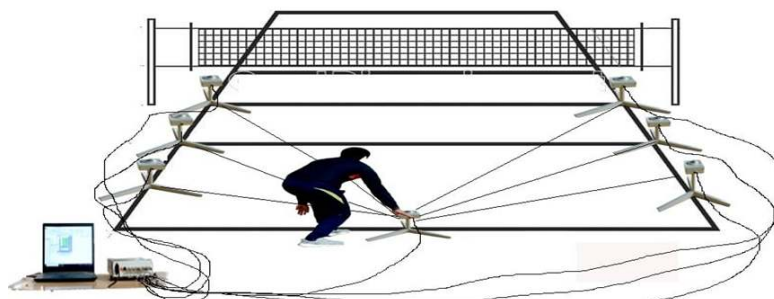


Fig. 11. Schematic diagram depicting the "Running for 92 meters in the shape of spruce" test, delineating both intermediate and full running distances

The "Running for 92 meters in the shape of spruce" test begins with the examinee pressing the sensor on the "start" post with one hand and awaiting the signal to initiate the test. Upon receiving the signal, the examinee touches the sensors positioned alternately on the right and left sides. Before approaching each sensor, the examinee must touch the sensor at the "start" again.

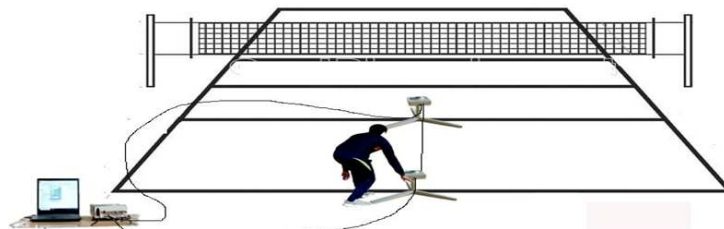


Fig 12. " 5×6 meters running" test (30 meters)

The " 5×6 meters running" test procedure is as follows. Two post sensors are positioned between the back line of the field and the offensive line (6 m), with the first post labeled "start" and the second labeled "finish." The examinee initiates the test by pressing the sensor next to the "start" post. Upon receiving the signal, the examinee completes five runs along the post sensors, ensuring the sensor is touched at each pass between the posts. The test concludes upon reaching the "finish" post.

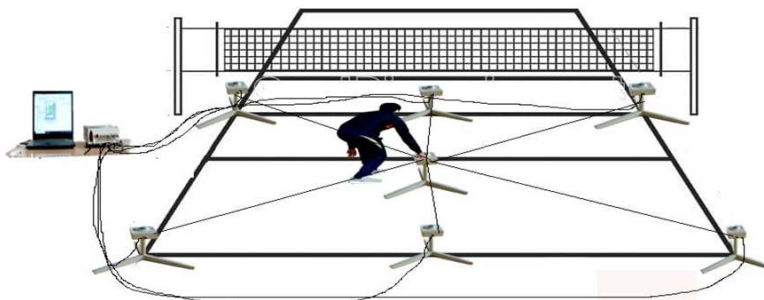


Fig. 13. The "Running test" arranged in a star configuration

The procedure for performing the "Running test" in a star configuration involves placing a "start" post at the center of the field within the six zones. Additional posts are positioned in zones 1–5 and in the middle of the rear line, totaling seven post sensors. The examinee must reach each zone's post sensor and touch it before returning. The test concludes back at the "start" position in zone six.

Note: The primary characteristic of all running tests conducted with electronic measuring equipment is the individual assessment of running speed towards each post sensor. At the end of the test, the total running speed is recorded on the monitor and stored in memory.

Results

Recent studies have revealed that the results of volleyball players proficient in "Running for 92 meters in the shape of spruce", "Running $5 \times 6 = 30$ meters", and "Running for 68.4 meters in the shape of spruce" tests fluctuate in terms of running speeds when assessed through traditional stopwatch methods. Initially, these results aligned closely with normative requirements established at the start of the 2021–2022 academic year. By mid-academic year (January 2022), there was a noticeable increase in running speed (by 3.81%, 5.94%, and 3.95%, respectively). However, by the end of the academic year, there was a decline in running speed (by 7.34%, 7.29%, and 11.2%, respectively). This decline suggests increased symptoms of exhaustion among the volleyball players who participated in the study by the end of the training year.

"Running for 92 meters in the shape of spruce" running test is frequently utilized in volleyball training. In this test, the participant must touch the filler balls positioned at intervals of 3 m along the sidelines, simulating receiving the ball before executing a free throw. Another test, the 5×6 -meters (30 meters) running test, involves starting behind the back line, touching it, and upon receiving a signal, sprinting to the offensive line 6 meters away and touching it. This sequence is repeated five times, with the participant touching the line with one hand each time. As previously noted, the frequency of players sprinting at maximum speed to various zones and positions on the volleyball court is increasing in contemporary volleyball competitions. Considering this growing trend, we have integrated the "Running in the shape of star" running test into volleyball training sessions (copyright certificate № 005215). This test entails running towards designated markers placed in strategic positions, as shown in Figure 8.

-Option 1: 6-2-6-3-6-4-6-5-6-1-6 zones.

-Option 2: 6-2-6-1-6-5-6-4-6-3-6-2 zones.

Test procedure: The examinee assumes the starting position behind the back line and touches a filler ball. Upon receiving the signal, he runs alternately through zones 6-2-6-3-6-4-6-5-6-1-6. In zone 6, substitutes positioned in the corners of zones 2, 4, 5, and 1 must touch the balls. The total distance covered is 68.4 m.

Several studies utilized these tests to assess the running speed in various directions among proficient volleyball players. The studies were conducted at the beginning of the academic year (September 4, 5, 6, 2022), in the middle of the academic year (January 4, 5, 6, 2022), and at the end of the academic year (June 28, 29, 30, 2022). Fifteen skilled volleyball players participated in the tests over three days during each phase ($n = 45$) (Table 2).

The obtained indicators were recorded as follows. In the running test covering a distance of 92 m, the average running time was 24.92 ± 2.73 s at the beginning of the training year, 23.97 ± 2.58 s in the middle of the training year, and 25.73 ± 2.68 s at the end of the training year (Table 2). The test results showed that the running speed of these volleyball players decreased by 0.6 s by the middle of the training year. However, by the end of the training year, the running speed increased by 0.8 s.

"Running for 92 meters in the shape of spruce" a and b: 0.95 s, 3.81%; $p > 0.05$ -b and v (see the note in Table 2) 1.76 s, 7.34%, $p < 0.01$;

Running 5×6 meters a and b: 0.52 s, 5.94%, $p < 0.01$ -b and v -0.60 s, 7.29%, $p < 0.001$;

"Running in the shape of star" a and b: 0.78 s, 3.95%, $p < 0.05$ -b and v -2.11 s, 11.2%, $p < 0.001$;

Initially, the running speed for the 5×6 meters running test was 8.75 ± 0.78 s. By the middle of the training year, it was 8.23 ± 0.71 s, a difference of 0.52 s. At the end of the training year, the running speed increased to 8.83 ± 0.71 s, a difference of 0.18 s.

Table 2. Results of assessing running speed in various directions among skilled volleyball players using conventional tests (n = 45)

Test	2021 September (a)		2022 January (b)		2022 June (c)		a and b			b and v		
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	RG%	t	p	RG%	t	p
"Running for 92 meters in the shape of spruce" (s)	24.92	2.73	23.97	2.58	25.73	2.68	3.81	1.70	>0.05	7.34	3.17	<0.01
Running 5 × 6- meters (30 meters) (s)	8.75	0.78	8.23	0.71	8.83	0.71	5.94	3.31	<0.01	7.29	4.01	<0.001
Running for 68.4 meters in the shape of star (s)	19.76	2.16	18.98	1.94	21.09	2.55	3.95	1.80	<0.05	11.12	4.42	<0.001

Note: The difference between the measurements was evaluated at the beginning and the middle of the 1st academic year (after 5 months). The difference between the measurements was evaluated at the beginning and the end of the 2nd academic year. a and b, b and v denote the relationship between indicators' growth rates and the reliability of indicators. RG represents relative growth. At the beginning of the training year, the time of running in the shape of star was 19.76 ± 2.16 s. By the middle of the training year, it was 18.98 ± 1.94 s, a decrease of 0.78 s. However, by the end of the training year, the running speed, according to this test, was 21.09 ± 2.55 s, an increase of 2.33 s. The decrease in running speed observed at the end of the training year, potentially attributed to the onset of fatigue symptoms, can be determined by examining the functional value of this load (Table 3).

Table 3. The running speed in various directions and its cardiorespiratory significance among skilled volleyball players at the beginning of the training year (2021, September) n = 45 $\bar{X} \pm \sigma$

Test	Beginning of research		RR	End of research		HCN	BN
	HCN (beats/s)	HOC (times/s)		HCN	BN	Relative value	
"Running for 92 meters in the shape of spruce" (s)	70.2 ± 3.05	14.8 ± 2.13	24.7 ± 2.51	115.7 ± 4.17	31.5 ± 4.23	45.5	16.7
Running 5 × 6- meters (30 meters) (s)	68.7 ± 2.57	14.5 ± 2.10	8.79 ± 1.02	109.3 ± 3.56	27.7 ± 3.45	40.6	13.2
Running for 68.4 meters in the shape of star (s)	69.7 ± 2.61	14.9 ± 2.13	18.8 ± 2.57	113.8 ± 3.73	29.5 ± 3.77	44.1	14.6
1000-meters running (min/s)	72.7 ± 3.13	15.3 ± 2.17	4.24 ± 0.34	157.8 ± 5.19	43.6 ± 3.32	85.1	28.3

Note: HCN - the number of heart contractions; BN - the number of breaths; RR - running results

At the beginning of the training year, the relative pulsometric value for running speed during the "Running test" among these volleyball players was 45.5 beats/min with a respiratory rate of 16.7 times/min. For the 5 × 6 m running test, the relative pulsometric value was 40.6 beats/min with a respiratory rate of 13.2 times/min. For the "star" running test, the pulsometric value was 44.1 beats/min with a respiratory rate of 14.6 times/min. By the end of the training period, these indicators changed to 48.3 beats/min and 19.1 times/min for the "Running test", 43.2 beats/min and 15.1 times/min for the 5 × 6 m test, and 46.8 beats/min and 16.3 times/min for the "star" running test. It is clear that the increase in these indicators, particularly the respiratory rates, suggests an increase in fatigue symptoms by the end of the training year. Thus, it is possible to attribute the decrease in running speed in alternating directions by the end of the training to increased fatigue levels.

Table 4. The preparatory phase of the training program aimed at enhancing running speed in changing directions in skilled volleyball players

Week	Upload	Norm	Repeat	Rest	Pulse
Monday	9-3-6-3-9 meters (30 meters) running.	3–4 times	2–4 series	30 s	145–155
Tuesday	5 × 6 meters (30 meters) running.	3–4 times	2–4 series	30 s	120–130
Wednesday	Running for 92 meters in the shape of spruce (s).	3–4 times	2–4 series	30 s	135–145
Thursday	Running for 68.4 meters in the shape of star (s).	3–4 times	2–4 series	30 s	145–155
Friday	9-3-6-3-9 meters (30 meters) running.	3–4 times	2–4 series	30 s	140–150
Saturday	Running for 92 meters in the shape of spruce (s).	3–4 times	2–4 series	30 s	135–145
Sunday	Travel to the mountain				

Objective: To increase overall physical fitness levels and develop volleyball-specific agility.

Task: During this phase, refine specific physical attributes and agility pertinent to volleyball.

Table 5. The program aimed at enhancing running speed in changing directions in skilled volleyball players during the competitive season

Week	Load	Norm	Repeat	Rest	Pulse
Monday	9-3-6-3-9 meters (30 meters) running. Running consecutively from zone 6 to zones 2-4 and imitating receiving the ball.	3-4 times	2-4 series	30 s	155-165
Tuesday	5 × 6 meters (30 meters) running. Running from the line of scrimmage to the 4th, 3rd, and 2nd zones in succession and performing a throw imitation	3-4 times	2-4 series	30 s	150-160
Wednesday	"Running for 92 meters in the shape of spruce" (s). Lateral running through the 4-3-2- and 2-3-4- zones in front of the net and imitating putting up a barrier.	3-4 times	2-4 series	30 s	155-165
Thursday	Running for 68.4 meters in the shape of star. Imitating the way of running, jumping, and putting the ball into the field. Between zones 2-3	3-4 times	2-4 series	30 s	160-170
Friday	9-3-6-3-9 meters (30 meters) running. 4-3-2 and 2-3-4 zones in front of the net, making lateral runs and blocking imitations	3-4 times	2-4 series	30 s	160-170
Saturday	"Running for 92 meters in the shape of spruce". Running consecutively from zone 6 to zones 2-4 and imitating receiving the ball	3-4 times	2-4 series	30 s	160-165
Sunday	Sauna				

Purpose: To maintain overall physical fitness parameters.

Task: During this phase, the objective is to prepare volleyball players for competitions from a functional standpoint while also developing specialized agility skills.

Table 6. Exercises designed to enhance agility and directional speed in skilled volleyball players and guidelines for their implementation

№	Exercise content	Norm	Repeat
1.	9-3-6-3-9 meters (30 meters) running.	3-4 times	2-4 series
2.	5 × 6 meters (30 meters) running.	3-4 times	2-4 series
3.	"Running for 92 meters in the shape of spruce".	3-4 times	2-4 series
4.	Running for 68.4 meters in the shape of star (s).	3-4 times	2-4 series
5.	Running consecutively from zone 6 to zones 2-4 and imitating receiving the ball	3-4 times	2-4 series
6.	Running consecutively from the offensive line to the 4th, 3rd, and 2nd zones, performing a shot imitation	3-4 times	2-4 series
7.	4-3-2 and 2-3-4 zones in front of the net, making lateral runs and blocking imitations	3-4 times	2-4 series
8.	Imitating the way of running, jumping, and entering the ball into the field. Imitating receiving the ball by falling on the chest in zones 2-3.	3-4 times	2-4 series
9.	Throwing the ball by jumping from zone 2, passing the ball into zone 4, and hitting from zone 3. Performance imitations	3-4 times	2-4 series

In volleyball training, it is advisable to incorporate various tools to enhance the efficiency of agility training and evaluation objectivity.

Exercises designed to enhance the speed of movement across the field.

Running exercises 1-4 involve touching balls placed in various zones (positions) with one hand; all exercises are timed like a competition. A 30-s break is given between sets, during which a deep breath is inhaled, and a sharp breath is exhaled. Given the subjective nature of tests assessing running speed in different directions, it is advisable to employ computerized measuring devices for objective and reliable evaluation.

The results of traditional tests, measured with a stopwatch, assessing the speed of running in various directions (determined using the "Running in the shape of spruce", "Running 5 × 6 meters," and "Running in the shape of star" running tests) among skilled volleyball players were documented in each consecutive study. These results aligned with normative requirements, indicating high running speeds. However, they exhibited significant variability in subsequent assessments. It was observed that the running speeds estimated using computerized measuring equipment were significantly lower than the standard requirements, revealing insufficient objectivity and reliability of results obtained using traditional stopwatch tests (Table 7). Table 7 shows that the running speed recorded for "Running in the shape of spruce" running decreased from 9.25% to 5.06% when determined by computerized measuring equipment compared to the traditional test results ($P < 0.001$ – $P < 0.01$). Similarly, the speed for the 5 × 6 meters running test decreased from 10.6% to 4.78%, and for the "Running in the shape of star" running test, it decreased from 9.09% to 3.35%. Figures 13, 14, and 15 illustrate the actual running speed results for these distances in graphical form.

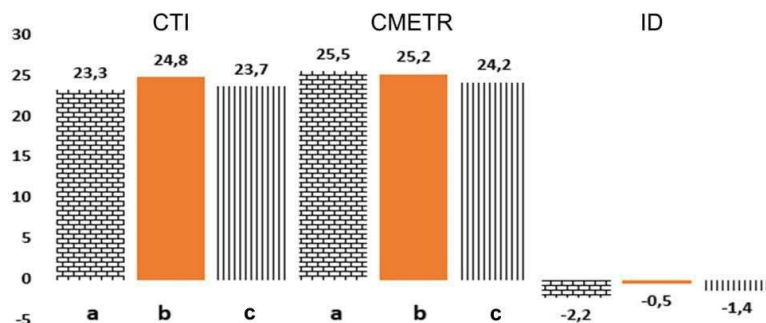


Fig. 13. Diagrams depicting the results of traditional stopwatch tests and assessments conducted with computerized measuring equipment for the "Running in the shape of spruce" running test among skilled volleyball players

Note: CTI-conventional test indicators; CMETR-indicators obtained using computerized measuring equipment: AT-a-June 1; AT-b-June 3; AT-v-June 6; CMETR-a-June 2; CMETR-b-June 4; CMETR-v-June 7; ID-difference between indicators

The "test-retest" studies showed that the "Running for 92 meters in the shape of spruce" running test yielded varying results in skilled volleyball players. When assessed using the traditional test, the recorded speeds were 23.3 ± 2.37 s on June 1, 2021, 24.8 ± 2.24 s on June 3, and 23.7 ± 2.17 s on June 6, with an average statistical indicator of 23.8 ± 2.29 s. Conversely, when the running speed was measured using CMETR, the recorded speeds were 25.5 ± 1.54 s on June 2, 25.2 ± 1.51 s on June 4, and 24.9 ± 1.48 s on June 7, with an average statistical indicator of 25.2 ± 1.18 s. Notably, the difference between the reciprocal indicators is consistently negative when evaluated with CMETR, indicating extended time: 2.2, 0.5, and 1.4 s, respectively.

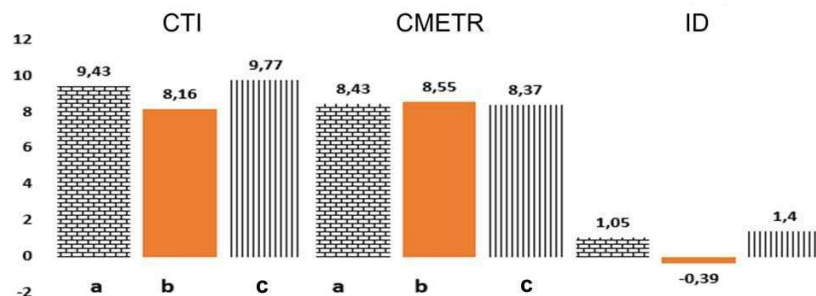


Fig. 14. Diagrams illustrating the results of speed assessment for 5×6 m running among proficient volleyball players using CTI and CMETR methodologies

Note: CTI-conventional test indicators; CMETR-indicators obtained using computerized measuring equipment: a-June 8; b-June 10; v-June 13; ID-difference between indicators

The traditional test results for 5×6 meters running speed were as follows: on the first day (June 8), 9.43 ± 1.19 s; on the second day (June 10), 8.16 ± 1.07 s; and on the third day (June 13), 9.77 ± 1.15 s. The average statistical indicator was 9.12 ± 3.14 s. Conversely, the CMETR recorded running speeds for the same distance were 8.43 ± 0.66 s on June 9, 8.55 ± 0.71 s on June 11, and 8.37 ± 0.58 s on June 14. Comparing the CMETR results to those of the traditional test, on the first day, there was a slight (positive) deviation of 1.05 s, while on the second day, the running speed increased by 0.39 to 8.45 ± 0.650 s.

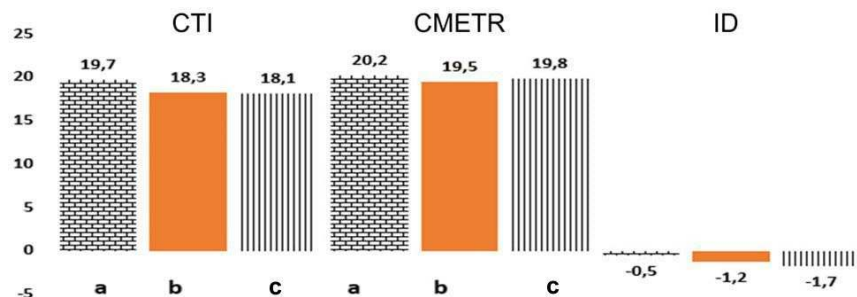


Fig. 15. Charts depicting the results of speed assessment for running in the shape of star in proficient volleyball players using both CTI and CMETR methodologies

Note: CTI-conventional test indicators; CMETR-indicators taken on computerized measuring equipment: a-June 15; b-June 17; v-June 20; ID-difference between indicators.

When evaluating the running speed in the shape of star using CTI, the recorded results were as follows: 19.7 ± 2.57 s on the first day (June 15), 18.3 ± 2.45 s on the second day (June 17), and 18.1 ± 2.62 s on the third day (June 20). In contrast, when assessed using CMETR, the running speed for the 68.4-m distance was 20.2 ± 1.56 s on the first day (June 16), 19.5 ± 1.52 s on the second day (June 18), and 19.8 ± 1.53 s on the third day (June 21). The relative differences between these indicators in relation to the CTI readings were -0.5 , -1.2 , and -1.7 s, respectively. The average statistical indicator was 19.8 ± 1.52 s.

The "Running in the shape of star" test was conducted daily on June 15–21.

Table 7. Results of the evaluation of running speed in different directions among skilled volleyball players utilizing traditional tests and computerized measuring equipment (n = 45)

Tests	Test–retest periods 2022	CTI		CMETR		ID %	t	P
		$\bar{X}$	σ	$\bar{X}$	σ			
Running in the shape of spruce (s). Total distance-92 m	June 1 and 2	23.36	2.37	25.52	2.49	9.25	4.22	<0.001
	June 3 and 4	24.80	2.24	25.84	2.21	4.19	2.22	<0.05
	June 6 and 7	23.70	2.17	24.9	1.48	5.06	3.06	<0.01
	$\bar{X}$	-	23.95	2.29	25.42	2.25	6.12	<0.01
5 × 6 meters running (s). Total distance-(30 m)	June 8 and 9	9.43	1.19	8.43	1.02	10.60	4.28	<0.001
	June 10 and 11	8.16	0.89	8.55	0.87	4.78	2.10	<0.05
	June 13 and 14	9.77	1.15	8.77	0.98	10.24	4.44	<0.001
	$\bar{X}$	-	9.12	0.98	8.58	0.87	5.88	<0.01
"Running in the shape of star" (s). Total distance-(68.4 m)	June 15 and 16	19.70	1.54	20.36	1.46	3.35	2.09	<0.05
	June 17 and 18	18.31	2.14	19.52	2.17	6.61	2.66	<0.01
	June 20 and 21	18.16	2.64	19.81	2.79	9.09	2.88	<0.01
	$\bar{X}$	-	18.72	2.55	19.90	2.62	6.27	<0.05

Note: CTI-conventional test indicators; CMETR-indicators obtained using computerized measuring equipment ID-difference between indicators; - studies were conducted at 8:00 am; -"Running in the shape of spruce" running test on June 1–7; 5 × 6 m running test on June 8–14;

The results revealed significant advantages in evaluating the speed of running in different directions using specialized tests (such as "Running in the shape of spruce", 5 × 6 meters, and "Running in the shape of star") with the aid of computerized measuring equipment. First, this equipment autonomously determines the running speed at each "sensor" in respective zones. Second, it allows for differentiated assessment of running speed along the right and left sides. Third, the recorded results are displayed on a computer monitor. Fourth, all data are stored in memory. Fifth, the equipment consistently delivers objective and reliable results. These capabilities are not attainable through traditional stopwatch-based tests.

Table 10. The speed of running from right to left along each zone in the shape of star among skilled volleyball players n = 45 ($\bar{X} \pm \sigma$) (at the beginning of the 2022–2023 academic year)

"Sensors"	Group	Before the experiment		After the experiment		ID %	t	P
		$\bar{X} \pm \sigma$	$\bar{X} \pm \sigma$	$\bar{X} \pm \sigma$	$\bar{X} \pm \sigma$			
Right side 10.8+15.0+20.2=46 m	EG	14.72	0.71	14.03	0.58	4.69	4.12	<0.001
	CG	15.83	0.74	15.46	0.64	2.34	2.07	<0.05
Left side 10.8+15.0+20.2 = 46 m	EG	10.73	0.75	9.97	0.61	7.08	4.31	<0.001
	CG	11.65	0.66	11.32	0.57	2.83	2.07	<0.05
General speed - $\bar{X}$	EG	25.45	1.52	23.95	1.24	5.89	4.19	<0.001
	CG	27.50	1.53	26.81	1.38	2.51	1.83	>0.05
"Sensors"	Group	Before the experiment		After the experiment		ID %	t	P
		$\bar{X} \pm \sigma$	$\bar{X} \pm \sigma$	$\bar{X} \pm \sigma$	$\bar{X} \pm \sigma$			
Right side 10.8+15.0+20.2=46 m	EG	14.72	0.71	14.03	0.58	4.69	4.12	<0.001
	CG	15.83	0.74	15.46	0.64	2.34	2.07	<0.05
Left side 10.8+15.0+20.2 = 46 m	EG	10.73	0.75	9.97	0.61	7.08	4.31	<0.001
	CG	11.65	0.66	11.32	0.57	2.83	2.07	<0.05
General speed - $\bar{X}$	EG	25.45	1.52	23.95	1.24	5.89	4.19	<0.001
	CG	27.50	1.53	26.81	1.38	2.51	1.83	>0.05

Note: Overall average statistical indicator of the speed of running in the shape of star (68.4 m)

The total speed of running the test distance (68.4 m) was 20.35 ± 1.62 s (to the left) and 20.81 ± 1.52 s (to the right). By the end of the experiment, the following results were obtained: from right to left, the speeds were 3.33 ± 0.19 , 3.12 ± 0.16 , 3.14 ± 0.16 , 2.70 ± 0.16 , 3.21 ± 0.16 , and 3.39 ± 0.20 s; from left to right, the speeds were 3.15 ± 0.15 , 3.32 ± 0.20 , 3.10 ± 0.17 , 3.31 ± 0.20 , 3.23 ± 0.19 , and 3.28 ± 0.21 s. The running time from

right to left was 18.89 ± 1.03 s, while from left to right, it was 19.39 ± 1.12 s. It is evident that in this test, the speeds of running from right to left to each "sensor" and the overall distance were lower than the speed of running in the opposite direction, indicating a handedness issue in the running test. However, addressing and rectifying such asymmetrical tendencies in volleyball training is crucial to ensure symmetrical running speeds in all directions.

Based on the evaluation of running speed in the "running" configuration across various directions with equipment assistance, the running speed significantly changed in the experimental group, which consistently performed the designated running exercises. Specifically, the "Running in the shape of spruce" speed decreased from 25.47 ± 1.47 to 24.01 ± 1.23 s by the experiment's end ($p < 0.001$), a decrease of 5.73%. Similarly, the speed for the 5×6 meters running decreased from 10.85 ± 1.07 to 9.72 ± 0.89 s ($p < 0.001$), a decrease of 10.41%. When examining the "star" running test, the speed from right to left decreased from 20.35 ± 1.48 to 18.84 ± 1.25 s ($p < 0.001$), a decrease of 7.42%. Conversely, the speed of running from left to right decreased from 20.83 ± 1.54 to 19.31 ± 1.36 s ($p < 0.001$), a reduction of 7.25%. In contrast, in the control group undergoing traditional training, the "Running in the shape of spruce" speed increased insignificantly from 25.76 ± 1.19 to 26.15 ± 1.06 s ($p > 0.1$), indicating a marginal increase of 1.91%. Similarly, the 5×6 meters running speed slightly decreased from 11.34 ± 0.86 to 11.03 ± 0.78 s ($p > 0.1$), equating to a decline of 2.73%. Regarding the "Running in the shape of star" running test, the speed of running from right to left decreased from 21.05 ± 2.06 to 19.97 ± 1.83 s ($p < 0.05$), a reduction of 5.18%. In contrast, the speed of running from left to right decreased from 22.05 ± 1.45 to 21.43 ± 1.32 s ($p > 0.05$), a reduction of 2.81%. Notably, the study group consistently undertaking the recommended running exercises showed a significant increase in running speed across all tests, as evidenced by reliable results.

Discussion

In volleyball, various types of speeds are typically encountered, with reaction speed being the most common (Castagna et al., 2009). Motor skills crucial to agility include balance, coordination, explosive strength, and flexibility (Young & Farrow, 2006). When discussing agility in volleyball, we consider not only the cognitive aspects involved in various tasks, such as sprinting starts and zigzag running, which differ from the more complex and unpredictable actions in sports games, like blocking an attack or reacting to a spike (Sheppard & Young, 2006). Agility in sports games is inherently tied to decision-making and anticipation in all processes (Horicka et al., 2014). In volleyball, various types of speed are commonly encountered, with reaction speed being the most prevalent (Castagna et al., 2009). These speeds often involve dynamic combinations, both active and passive, necessitating high-intensity effort alternated with lower intensity in other phases (Borras et al., 2001). Agility is described in various ways, often characterized as "the quick movement of the body in response to a stimulus" (Chelladurai) or as "the ability to rapidly change movement direction" and "the ability to start and stop quickly" (Little and Williams, 2005). When discussing agility in volleyball, it encompasses not only the cognitive components involved in tasks such as sprinting starts or zigzag running, which differ from the more complex and unpredictable actions in sports games like blocking an attack or reacting to a spike (Sheppard and Young, 2006). Agility movements encompass perceptual components such as decision-making and anticipation, which are integral to all processes occurring in sports games (Horicka et al., 2014). While speed and agility involve moving the body quickly, agility emphasizes the ability to change direction rapidly, a crucial aspect in sports games (Verchoshansky). In modern volleyball, achieving peak performance requires mastery of primary skills like passing and spiking and secondary motor qualities such as speed, coordination, balance, strength, and agility (Ioan et al., 2015). The following conclusions can be drawn based on the comparative analysis of scientific-methodical sources, expert opinions, current research findings, and pedagogical experience.

From the analyzed sources, it is evident that failure to adhere to standard conditions and procedures in assessing the quality of speed characteristic of sports, along with its constituent components, using tests reliant on a "stopwatch," can significantly compromise the reliability and objectivity of the results. Factors such as subjective bias, mechanical errors in timing, the athlete's mental state, and the evaluator's knowledge and experience can influence the outcomes obtained. Consequently, the original value of the results may be diminished, thereby limiting their objectivity and reliability. Thus, in volleyball practice, it is observed that normative requirements for tests like the "Running for 92 meters in the shape of spruce" among skilled 18–20-year-old players can vary significantly, as indicated by the wide range of results (e.g., 23.4–24.0; 24.68 ± 1.32 ; 25.0–25.9, etc.) established by experts. Similar variations were noted in the evaluation experience, current research findings, and survey results examined during our study.

In this study, significant results were observed regarding the running speed of qualified volleyball players in the "Running in the shape of spruce", the 5×6 meters running and the "Running in the shape of star". At the beginning of the academic year (September 2021), the recorded speeds were as follows: 24.92 ± 2.73 for the "Running in the shape of spruce", 8.75 ± 0.78 for the 5×6 meters running and 19.76 ± 2.16 for the "Running in the shape of star". However, by the middle of the academic year (January 2022), these speeds decreased to the following indicators: 23.97 ± 2.58 for the "Running in the shape of spruce", 8.23 ± 0.71 for the 5×6 meters running and 18.98 ± 1.94 for the "Running in the shape of star". At the end of the training period (June 2022),

the recorded indicators were as follows: 25.73 ± 2.68 for the "Running in the shape of spruce", 8.83 ± 0.71 for the 5×6 meters running, and 21.09 ± 2.55 for the "Running in the shape of star". This increase may be attributed to increased fatigue symptoms experienced by the volleyball players by the end of the training year. This inference is supported by the increased pulsometric (number of heart contractions) and respiratory (number of breaths) values during running activities at the end of the annual training.

Specifically, there was an increase in the number of heart contractions from 68.7 ± 2.57 to 70.3 ± 3.05 beats/min and an increase in the number of breaths from 14.5 ± 2.10 to 14.9 ± 2.13 times/minute, reflecting a rise from 2.77 ± 3.45 to 4.23 times/minute.

The findings from the current research identified another relevant and practical issue in volleyball practice: the assessment of running speed along alternating directions showed considerable differences between traditional stopwatch-based tests and computerized electronic measurement equipment, resulting in significantly different indicators. For instance, when evaluating shuttle running speed in the "Running in the shape of spruce" direction, the traditional test yielded an average time of 23.95 ± 2.29 s after three attempts. However, when assessed using electronic equipment, the result was 25.42 ± 2.25 s (objectivity and reliability, $p < 0.01$). Similarly, for the 5×6 m running, the traditional test recorded a speed of 9.12 ± 0.98 s, whereas the electronic measurement showed 8.77 ± 0.98 s (objectivity and reliability, $p < 0.01$). Furthermore, in the "Running in the shape of star", the traditional test produced a time of 18.72 ± 2.55 s, contrasting with 19.81 ± 2.79 s obtained through electronic measurement ($p < 0.05$). These findings underscore significant disparities in the running speed measurements across alternating directions between the two evaluation approaches.

During a 10-month pedagogical evaluation, it was observed that all qualified volleyball players performed the recommended experimental running exercises. During these activities, the speed of running in the "Running in the shape of spruce" was measured using sensors positioned along the right and left sidelines of the field at 3-m intervals. Remarkably, the recorded indicators exhibited significant differences. At the beginning of the experiment (September 5, 6, 7, 2022), the running speeds to each of the three "sensors" installed on the right side were measured as follows: -5.03 ± 0.11 , 5.40 ± 0.14 , and 4.12 ± 0.09 s, respectively. Conversely, on the left side "sensors," the recorded times were -3.09 ± 0.07 , 3.20 ± 0.05 , and 3.03 ± 0.03 s, respectively. On average, the total run time to the "sensors" on the right side was 14.25 ± 0.34 s, while on the left, it was 10.22 ± 0.15 s. The overall running time for the entire distance (92 m) averaged 24.47 ± 0.49 s. Studies conducted on September 6 and 7 yielded comparable results. However, by the end of the experiment (June 1, 2, 3, 2023), all examined indicators exhibited a consistent reduction trend. Notably, the speed of running the entire distance (92 m) averaged 24.01 ± 0.65 s, which is higher than the standard requirements.

It is worth mentioning that before the experiment, both the experimental and control groups demonstrated faster running speeds towards the "sensors" positioned on the right side, recording times of 14.72 ± 0.71 and 15.83 ± 0.74 s, respectively. In contrast, the running speed towards the left-side "sensors" was notably lower, averaging 10.73 ± 0.75 s for the experimental group and 11.65 ± 0.66 s for the control group. By the end of the experiment, considerable running speed reductions were observed on both the right and left sides. In the experimental group, the running speed on the right side decreased significantly from 14.03 ± 0.58 to 14.03 ± 0.58 s ($p < 0.001$), a decrease of 4.69%. Similarly, on the left side, the running speed decreased from 10.73 ± 0.75 to 9.97 ± 0.61 s ($p < 0.001$), a reduction of 7.08%. In the control group, consistent trends were noted, with the running speed on the right side decreasing from 15.83 ± 0.74 to 15.46 ± 0.64 s ($p < 0.05$), a reduction of 2.34%. Likewise, on the left side, the running speed decreased from 11.65 ± 0.66 to 11.32 ± 0.57 s ($p < 0.05$), indicating a reduction of 2.83%. The average "jump" running speed in the training group decreased from 25.45 ± 1.52 to 23.95 ± 1.24 s ($p < 0.001$), a reduction of 5.89%. In contrast, in the control group, the average "jump" running speed decreased from 27.50 ± 1.53 to 26.81 ± 1.38 s ($p > 0.05$), a reduction of 2.51%. These findings indicate that, in the experimental group, the running speed in the "Running in the shape of spruce" surpassed the standard requirements by a significant margin.

Before the experiment, the average speed of running five times between two "sensors" placed on the back and offensive lines of the field (6 m) for skilled volleyball players engaged in experimental training was as follows: 2.03 ± 0.09 , 2.08 ± 0.11 , 2.17 ± 0.14 , 2.34 ± 0.17 , and 2.23 ± 0.18 s. The speed of running the total distance ($5 \times 6 = 30$ m) averaged 10.86 ± 0.69 s. By the end of the experiment, these indicators were as follows: 1.47 ± 0.11 , 1.83 ± 0.08 , 1.97 ± 0.27 , 2.05 ± 0.12 , and 2.09 ± 0.12 s, with the overall average running time decreasing to 9.41 ± 0.70 s.

At the beginning of the experiment (September 12, 13, 14, 2022), the speed of running from right to left along the "sensors" positioned in zones -6-6-2-6-3-6-4-6-5-6-1-6 in the configuration of a "Running in the shape of star" (68.4 m), measured by the sensor installed at the midpoint of the back line, among skilled volleyball players undergoing experimental training, averaged the following values after three attempts: 3.53 ± 0.29 , 3.16 ± 0.27 , 3.67 ± 0.32 , 3.02 ± 0.18 , 3.35 ± 0.25 , and 3.62 ± 0.30 s. The speed of running the entire distance was recorded as 20.35 ± 1.62 s. According to the "sensors" placed in the zones, the speed of running from left to right was measured as follows: 3.48 ± 0.24 , 3.27 ± 0.23 , 3.57 ± 0.27 , 3.19 ± 0.22 , 3.44 ± 0.26 , and 3.85 ± 0.34 s, with the overall speed of running the total distance of 20.81 ± 1.52 s. Notably, the speed of running from left to right (considered the unfavorable side for the athletes) was observed to be comparatively more consistent. However,

by the end of the experiment (September 13, 14, 15, 2023), based on the abovementioned indicators of running speed, the following measurements were obtained: from right to left, the recorded speeds were 3.33 ± 0.19 , 3.12 ± 0.16 , 3.14 ± 0.16 , 2.70 ± 0.16 , 3.21 ± 0.16 , and 3.39 ± 0.20 s, with the total running speed averaging 18.89 ± 1.03 s. Conversely, from left to right, the speeds were 3.15 ± 0.15 , 3.32 ± 0.20 , 3.10 ± 0.17 , 3.31 ± 0.20 , 3.32 ± 0.19 , and 3.28 ± 0.21 s, with the average overall speed of 19.39 ± 1.12 s. These findings indicate that the time of running from right to left in the "Running in the shape of star" was shorter and that the time of running in both directions was significantly reduced by the end of the experiment.

Conclusions

The time of running the specified distances according to the utilized tests ("Running for 92 meters in the shape of spruce", 5×6 m running (30 m), "Running in the shape of star" 68.4 m) in the experimental group exhibited the following trends during the experiment: decreased from 25.47 ± 1.47 to 24.01 ± 1.23 s ($p < 0.001$) or 5.73% in the case of "Running in the shape of spruce"; decreased from 10.85 ± 1.07 to 9.72 ± 0.89 s ($p < 0.001$) or 10.41% for the 5×6 m run-ning; the speed of running from right to left in the "Running in the shape of star" configuration decreased from 20.35 ± 1.48 to 18.84 ± 1.29 s ($p < 0.001$) or 7.42%, while from left to right, it decreased from 20.08 ± 1.54 to 19.31 ± 1.36 s ($p < 0.001$) or 4.03%. Conversely, in the control group, the parameters exhibited different trends: increased from 25.76 ± 1.19 to 26.15 ± 1.06 s ($p > 0.1$), with a difference of 1.51% for "Running in the shape of spruce" running; decreased from 11.34 ± 0.86 to 11.03 ± 0.78 s ($p > 0.1$) or a reduction of 2.73% for the 5×6 m running; the speed of running from right to left in the "Running in the shape of star" decreased from 21.01 ± 2.06 to 19.97 ± 1.83 s ($p < 0.05$) or 5.18%, while from left to right, it decreased from 22.05 ± 1.45 to 21.43 ± 1.32 s ($p > 0.05$) or 2.81%. It is evident that in the experimental group, which performed the recommended running exercises, running speed was significantly in-creased across all tests assessed by electronic equipment by the end of the experiment. Such significant progress was not observed in the control group.

Conflicts of interest The authors declare that there are no conflicts of interest.

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