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Objective Measurement Method for Assessing Plank Test Among Female Basketball Players

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Abstract

Trunk muscle strength plays a crucial role in the sport-specific movements of basketball players. While the plank test is widely used to assess trunk muscle endurance, its lack of standardization limits its effectiveness in high-performance environments. The study aimed to establish objective criteria for determining when the plank position was no longer maintained and introduced a new variable, postural error (PE). This study involved 23 (age = 15.22 years, weight = 66.3 kg, height = 174 cm) healthy female basketball players from the Hungarian U16 first league. Using optical motion capture, the thoracic kyphosis (TK) and lumbar lordosis (LL) were monitored during the test. The cutting point (CP) was determined based on four mathematical formulas and the estimation of two independent experts. PE was determined based on the area under the curves, which characterizes the magnitude of displacements until the endpoint. According to the difference between the expert-estimated and the calculated CP, the initial angles were calculated as the average of the first 15 seconds, and the CP was set at a ±25° deviation. Additionally, PE was introduced to assess the strategy of maintaining the plank posture, revealing differences in performance even among participants with similar CP times. The present study introduces a new method for determining the test's objective starting angle endpoint and introduces a new variable, PE, to characterize trunk stability, distinguishing between different execution strategies. The findings suggest that this approach provides a more reliable and objective way to assess trunk muscle endurance and core stability.

Keywords

plank test, trunk muscle endurance, core stability, basketball, spine curves

1 Introduction

Nowadays, continuous physical testing of basketball players has become a standard practice in elite sports. The systematic testing of athletes helps reduce the risk of injuries, optimize training loads, monitor athletes' current physical condition, and assist in talent identification [1–3]. The importance of assessing trunk muscle strength is widely acknowledged in the literature [1–5], as its development is essential for enhancing sport-specific performance, particularly in basketball [5].

Despite these facts, only a few standardized, objective tests for measuring trunk muscle endurance and core stability provide meaningful insights for athletes [1–5]. While many tests are commonly used in rehabilitation, their direct application in elite sports is often limited, as athletic movements typically require higher intensity and task-specific activation of trunk muscles compared to activities of daily living [1].

One of the most used trunk muscle endurance tests among athletes is the plank test [6–8], which is an easy-to-perform test that asses the endurance of static trunk muscle strength under field conditions [9]. Several studies among basketball players have found a significant correlation between plank test results [10] and other physical ability tests such as agility, jumping, and throwing ability [3, 11], suggesting that a strong performance on the plank test indicates better physical conditions in basketball players. Moreover, in order to improve basketball performance, Luo et al. [11] suggest the use of the plank test for developing trunk muscle strength in basketball players.

Although the plank test is widely used to test and assess athletes, and studies demonstrate its relationship with athletic performance, the test lacks standardization [10–14], particularly in defining its execution and the objective

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criteria for determining its start and end points [2, 3, 15]. Imai and Kaneoka [3] measured the duration of the plank test until a five-centimeter displacement deviation of the hip, while other studies terminated the measurement when there was repeated large displacement of the body [2]. Additionally, some research defined the end of the test as the moment when the participant voluntarily stops or can no longer maintain the starting position [15].

In Gál-Pottyondy et al. [16], an experimental protocol was developed to enhance the usability of the plank test. Changes in sagittal spinal alignment and muscle activation in response to fatigue were objectively evaluated using a motion capture system and electromyography (EMG) [16]. It was found that thoracic kyphosis (TK) significantly increased from the first to the last 10 sec of the plank test, while lumbar lordosis (LL) values showed inconsistent results depending on whether the raised or lowered hips responded to fatigue [16].

The aim of the present research is to develop an objective evaluation method for the plank test. Although the plank test is considered a static exercise, due to the complexity of the plank position, the muscles and muscle groups involved work together, sometimes alternating, sometimes simultaneously to maintain the posture. As a result, the position is not fully held in a completely static manner. This follows from the test is more appropriate for evaluating the combined endurance of the muscle groups involved in the plank position rather than assessing the strength of individual trunk muscles in isolation.

To ensure the comparability of the test results, a set of objective criteria was defined based on the requirement of maintaining a static posture, i.e., keeping the body still. Firstly, we hypothesized that by examining spinal kinematics, the initial angles and endpoint (cutting point (CP), where the static posture, as a fundamental requirement, is no longer maintained) of the plank test could be objectively determined based on the changes in the TK and LL angles. Our second aim was not only to establish an objective method for determining the endpoint of the test but also to analyze the execution technique. Therefore, it was hypothesized that a new variable, the summarized deviation from the initial angle, could effectively characterize the execution of the plank test.

2 Material and methods

2.1 Participant

Twenty-three female basketball players (age = 15.22 years, weight = 66.3 kg, height = 174 cm) from the Hungarian U16 first league participated in this study. The inclusion criteria required that players must have a valid sports medical clearance and, according to their and the coach's declaration, must not be injured. All players, coaches, and parents were fully informed verbally and in writing about the research protocol, requirements, potential benefits, and risks. Each of the participants was familiar with and had previously performed the plank test. Written consent was obtained from all participants before the experiment began, which was conducted in accordance with the Declaration of Helsinki. The study also received institutional approval from the Ethics Committee of the Hungarian University of Sport Sciences (TE-KEB/17/2021).

2.2 Measuring the angles of the spine curve

An OptiTrack© [17] based motion capture system recorded the spatial positions of the markers at a sampling frequency of 120 Hz. This measuring system has an accuracy of sub-millimeter (mean 3D error: 0.478 mm) [18]. Retroreflective markers were affixed to the participant's body to assess the angles of spinal curves and capture the spine's shape. Following the recommendations of Takács et al. [19], markers were placed using special adhesive discs designed to skin electrodes over the spinous processes of ten specific vertebrae: C6, T1, T4, T6, T8, T10, T12, L2, L4, and L5 (Fig. 1) [19]. Whenever possible, markers were placed on free skin surfaces to minimize artifacts from skin movement. During data processing, the positions of the markers were smoothed using a low-pass filter with a cutoff frequency of 6 Hz, and the data were resampled at 20 Hz. In addition, the last 5 sec of the recordings were excluded to eliminate potential positioning distortional movements at the end of the measurement. The spinal shape was determined by applying a recently validated method [20], which involved fitting a spatial spline curve to ten markers by minimizing the squared error. Then, the angles of TK and LL were calculated as the angles formed by the tangents of the spline at T1 and T12 and T12 and L5, respectively [20].

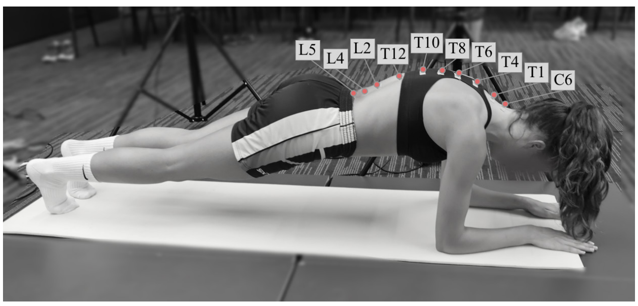

Fig. 1 Measurement setup

2.3 Experimental procedures

Participants were instructed to assume a prone plank position, and data collection started once the athletes achieved the correct posture. The pre-test instructions were the following:

1. beginning in the plank position;
2. lying face down with forearms and toes in contact with the ground, ensuring that the elbows were directly under the shoulders with the forearms facing forward;
3. maintaining a straight body line with the neck, mid-back, sacrum, knees, and ankles aligned;
4. holding the position for as long as the participant could.

No further instructions were given during data collection, even if the posture deviated from the correct form. The placement of the markers and the execution of the test protocol were carried out by the same human kinesiologist.

2.4 The evaluation of the LL and TK curves

In the analysis of the time curves of LL and TK angles, our primary goal was to initiate objective criteria for determining the CP, considering the initial position of the participant and the magnitude of the corrective changes during the test. To determine the initial angle, averaging a minimum of the first 10 sec was considered sufficient, as this time frame is adequate to smooth out any potential large fluctuations caused by initial positioning. Given that the study focused on elite athletes, a 15-sec averaging period was also considered appropriate, as it was assumed they could sustain the plank position for an extended duration. Accordingly, the initial angle was determined by calculating the root means square (RMS) value of the given angle recorded during both the first 10 and 15 sec. Maintaining a static position requires the range of spinal angles to remain within a specified boundary from the initial angle. Consequently, the objective endpoint of the measurement could be identified by monitoring the initial angle and the maximum deviation as a boundary. If the participant does not exceed the prescribed boundary value at any point during the measurement, CP corresponds to the total measured duration. Initially, the endpoints were assessed by two experts based on their subjective evaluation of the time curves for TK and LL angles for each participant. Afterwards, the indicated values were compared to four mathematically defined CPs:

1. the initial angles were determined as average of the first 10 sec, and the cutting point was marked at a ±25° deviation;
2. the initial angles were determined as the average of the first 10 sec, and the cutting point was marked at a ±30° deviation;
3. the initial angles were determined as the average of the first 15 sec, and the cutting point was marked at a ±25° deviation;
4. the initial angles were determined as the average of the first 15 sec, and the cutting point was marked at a ±30° deviation.

The visualization of these threshold values is shown in Fig. 2 using the measurement of Participant No. 25. Fig. 2 (a) shows the fitted sine curves between the initial (t = 1 s) and end ($t = T_{cut}$, time until CP) position at t = 10 s and t = 15 s. On the other hand, Fig. 2 (b) represents the marked deviations (±25° and ±30°) parallel to the starting position.

Alongside defining the cutting point, a new qualitative measure, postural error (PE), was introduced to characterize the movements and strategies between the starting position and the cut-off time. PE was calculated as the integral of the absolute difference between the constant

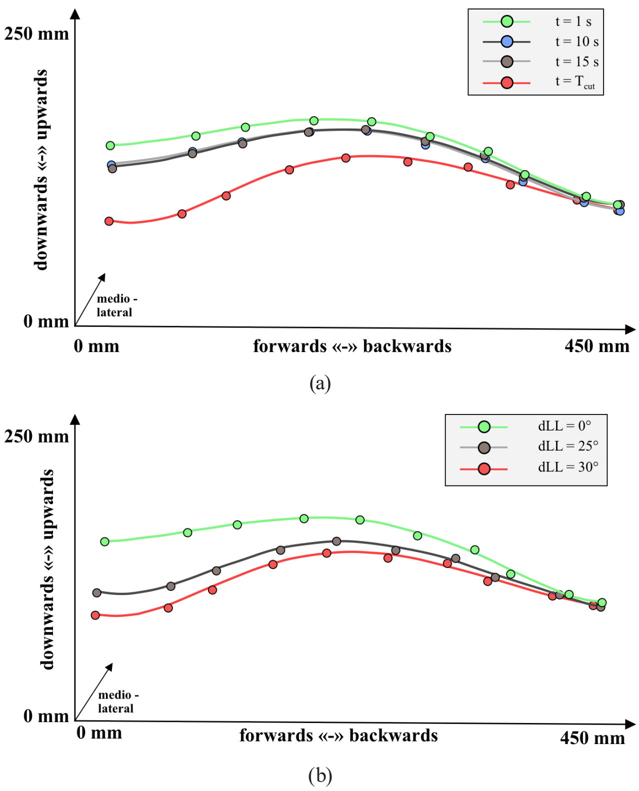

Fig. 2 Visualization of the effect of (a) time interval for the initial angel calculation and (b) max. angular change values used to determine CP on the spinal shape

line representing the theoretically held initial angle (LL_0) and the computed LL values divided by T_{cut}.

$$\mathrm{PE} = \frac{1}{T_{cut}} \int_{0}^{T_{cut}} \left| LL_0 - LL \right| dt$$

The PE value quantifies the time-normalized cumulative error from the initial angle, with its theoretical maximum defined by the allowed deviation. Note that this variable allows for differentiation in performance between two individuals with the same T_{cut} time.

The two variables underwent normality testing and exhibited slightly non-normal distributions. Consequently, their correlation was assessed using Spearman's rank correlation.

3 Results

Based on the percentage difference between the expert CP and the CP calculated using various mathematical formulas, the third calculation method was applied, where the initial angle is determined as the average of the first 15 sec, and the CP occurs at the time moment of a ±25° deviation (Table 1). In the case of applying the third method, there was a difference more significant than 3% between the expert-estimated CP and the CP calculated by the method in only 4 cases (Table 1).

As participants were not specifically instructed to maintain a fixed head position, the intensive head movement resulted in a significant distortion in the TK angle during the measurement (example, see in Fig. 3). Consequently, this study prioritized LL angle values for determining CP. For measurements where expert-determined CP values differed substantially from those calculated using Method (3), the graphical representation revealed that the monotonic increase in LL reached the threshold more quickly than the expert would stop it based on its subjective experience. As examples, the measurements of participants S16 and S17 can be seen in Fig. 4. This highlights the method's ability to objectively characterize CP despite initial discrepancies.

The PE variable effectively characterized the strategy chosen by the participant while holding the plank posture. Specifically, it showed whether the participant slowly but steadily adjusted after deviating from the initial LL values or eventually correcting and returning to the starting position. On the other hand, the PE variable allowed us to distinguish between participants who achieved similar time until CP. In Fig. 5, all the calculated PE values are shown in the scales at the bottom in increasing order. Some representative examples are also illustrated in Fig. 5 to demonstrate the different execution techniques.

Table 1 The percentage difference between the expert CP and the CP was calculated using various mathematical formulas

ID	Method (1) diff. (%)	Method (2) diff. (%)	Method (3) diff. (%)	Method (4) diff. (%)
S01	0.89	5.82*	0.89	5.82*
S02	0.04	1.27	0.13	12.97*
S06	11.73*	2.56	2.56	1.71
S08	0.04	0.76	0.04	2.08
S09	0.10	0.10	0.10	0.10
S11	0.07	0.07	0.07	0.07
S13	0.03	0.03	0.03	0.03
S14	0.08	0.08	0.08	0.08
S15	0.36	6.24*	0.29	6.39*
S16	30.83*	26.52*	26.70*	24.62*
S17	0.16	0.16	0.16	0.16
S18	0.07	1.16	0.04	1.16
S19	10.11*	5.77*	10.07*	5.65*
S20	0.17	0.24	0.17	0.24
S21	0.15	0.41	0.07	0.50
S22	0.63	3.57*	0.57	3.67*
S23	4.05*	2.17	2.81	1.62
S24	7.03*	5.76*	6.32*	0.17
S25	0.25	1.14	0.17	1.14
S26	1.26	0.69	1.20	0.63
S27	0.18	3.17*	0.08	3.17*
S28	11.66*	10.30*	11.41*	9.46*
S30	0.88	0.45	0.83	0.21
3% < ∑diff.	6	8	4	8

* 3%< differences, Method (1): the initial angles were determined as the average of the first 10 sec, and the cutting point was marked at a ±25° deviation; Method (2): the initial angles were determined as the average of the first 10 sec, and the cutting point was marked at a ±30° deviation; Method (3): the initial angles were determined as the average of the first 15 sec, and the cutting point was marked at a ±25° deviation; Method (4): the initial angles were determined as the average of the first 15 sec, and the cutting point was marked at a ±30° deviation.

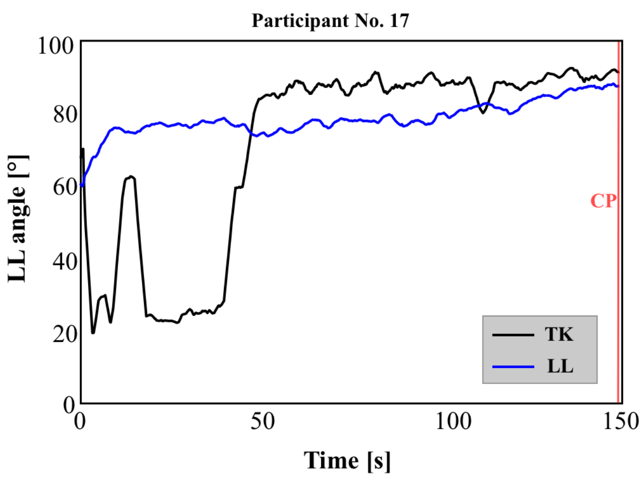

Fig. 3 Role of the head movement in the starting

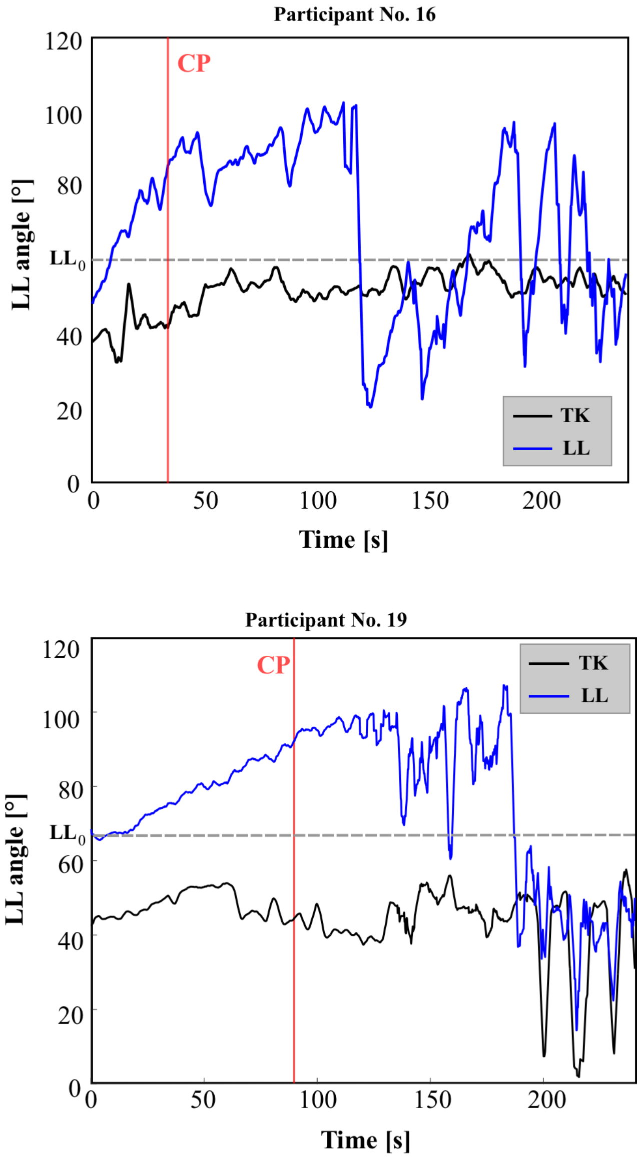

Fig. 4 Indicative example of measurement with significantly lower CP

According to the Anderson-Darling normality test the two calculated variables can be considered normally distributed. Hence, the Pearson rank correlation revealed no significant correlation (r = 0.082) between the two variables, supporting their independent use as complementary measures to characterize the plank test.

4 Discussion

Although testing and measuring trunk strength is essential in the assessment of basketball players' physical condition, there are few standardized, objective, and easily executable trunk strength tests suitable for testing athletes [21]. There are dynamometer protocols for the isolated and validated assessment of trunk muscle strength and endurance [22–24], which are useful for athletes. However, not every club has access to these devices, and they cannot be quickly performed on the sidelines, even during training sessions. The plank test is a simple field test to perform [5]; however, its drawback is that it needs to be more objective, and there needs to be more consistency in the literature regarding the determination of the test's endpoint [2, 3, 15]. The aim of the study was to establish objective criteria for determining when the static plank position was no longer maintained, using the OptiTrack motion capture system, in order to later validate image processing with a low-cost, markerless camera system. Firstly, we hypothesized that an optical-based motion capture system could be used to objectify the test, making it repeatable and comparable.

By applying motion capture technique, the movement of the spine during the test can be graphically represented through the calculation of the TK and LL angles. Using Method (3) – which defines the initial angle as the average of the first 15 sec and marks the CP at a ±25° deviation – the endpoint of the test can be objectively determined, providing a standardized measure of how long the participant was able to maintain the plank position under the same conditions. Considering all the aforementioned mathematical methods for CP, Method (3) proved to be the most consistent with the expert-determined values, with only four cases showing a difference greater than 3%. After a separate examination of these four cases, we concluded that the CP calculated by the method was acceptable, as the experts had not considered that the participants continuously and significantly changed their body position from the very first time point (Fig. 4).

Due to the potential for significant movements at the beginning caused primarily by the head, it is crucial to provide clear and specific instructions to the participants. In both the literature [3, 6, 25, 26] and in the present study, the primary directive was to hold the plank position for as long as possible, even if this resulted in larger movements to sustain the posture. In the case of using our newly developed measurement method, we recommend the instruction: "Hold the plank position as still as possible for as long as you can!". This encourages the participant to focus primarily on maintaining stillness during the test and secondarily on the duration. Although the method is sufficiently robust to handle steadiness during the test, it is recommended to stop the measurement and remind the participant to remain still if visible movements occur at the start. Then, the test

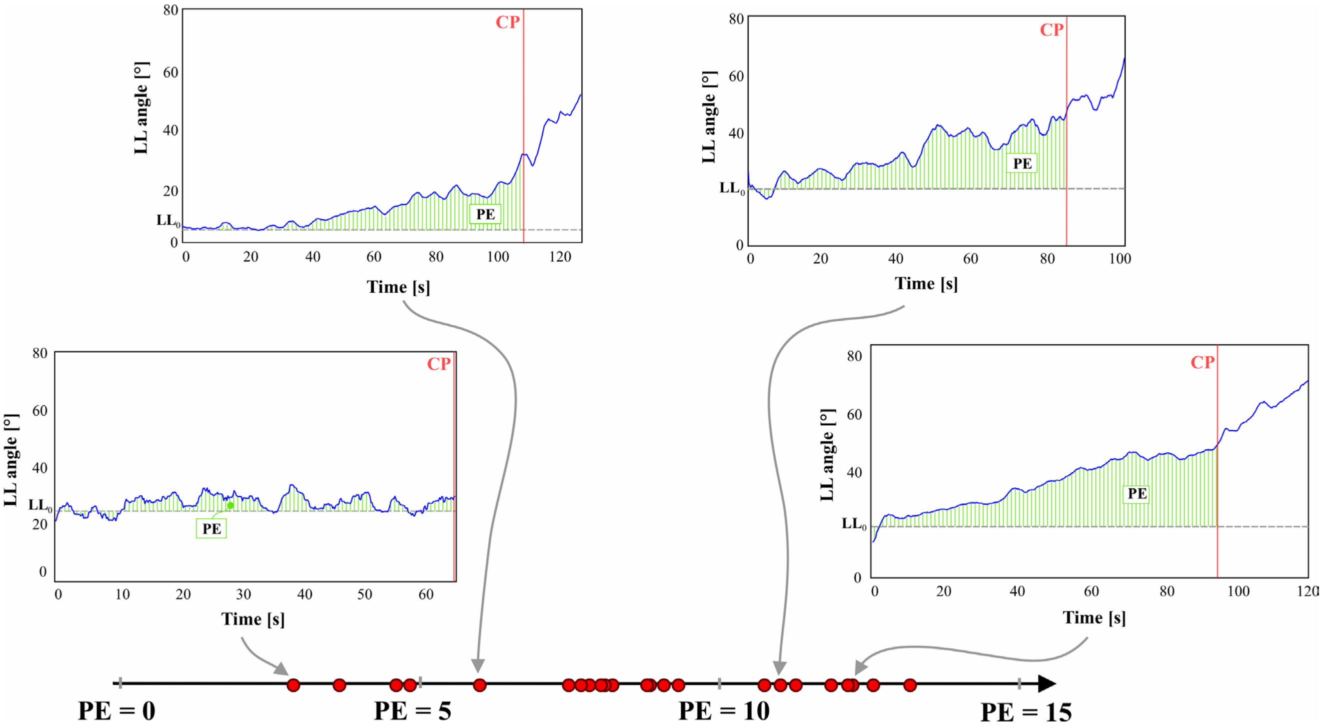

Fig. 5 PE values and its explanation for different strategies

can be repeated, eliminating the possibility of poor results caused by inattention or lack of discipline.

Secondly, as it can be seen, the CP allows us to assess athletes under the same conditions, so we deemed it necessary to introduce a new indicator that adds nuance to the purely time-based evaluation. Several strategies for maintaining the static plank position were observed based on the LL curves. It was hypothesized that a new variable, which can be calculated based on the curves, allows us to characterize the execution of the plank test.

Before reaching the CP, we can distinguish between two types of curves:

- The test participant's LL angle continuously changes in one direction and does not return to the starting position. PE is typically higher and tends to the theoretical maximum value (Fig. 5, the subplot at the bottom right).
- After a slight deviation from the starting position, the participant returns to the initial position or a state close to it. PE is smaller, close to 0 (Fig. 5, the subplot at top left).

In the latter case, the conscious corrections, meaning that participants perform the exercise with active attention, which is a fundamental condition for dynamic balance and trunk stability [27]. Therefore, in the case of the plank test, we consider the second method of execution to indicate better trunk stability, which is indicated by a lower PE value.

The newly developed measure, PE, is suitable for characterizing the static execution of the test, thus providing another perspective for objectively assessing the plank test. This variable allows not only the endurance but also the proper technique to be characterized. Therefore, it can be a convenient measure to know how correctly the test was executed or used as an additional ascent in the case when participants have the same measured time (T_{cut}) and shade lights on the arisen differences in the evaluation of the test.

Based on the present research, it can be concluded that the plank test duration can be objectively determined using our methods based on optical-based motion analysis, and the newly developed PE measure for the overall error is suitable for characterizing core stability.

5 Limitation

Following prior instructions from the literature, the test did not emphasize the importance of head immobility, so in the present study, we could only consider the LL angle values when determining the CP.

We conducted our research exclusively on female basketball players, so the method we present is only applicable to female athletes.

6 Conclusion

This study addresses the need for more standardization in the plank test, a widely used assessment of trunk muscle endurance in athletes, by introducing an objective method to evaluate its duration and effectiveness. The changes in TK and LL angles during the test were analyzed using an optical-based motion capture system to determine when the static posture is no longer maintained, referred to as the CP. A new variable, PE, is introduced to quantify core stability and analyze the execution of the test. The findings suggest that the plank test can be objectively assessed by applying a mathematical formula for determining CP and using PE to evaluate core stability. Additionally, the motivation for this research was to develop an easy-to-use, reliable, long-term alternative to the traditional plank test. By this method, trunk muscle endurance can be quantitatively assessed, improving the plank test's reliability and comparability in the field of elite sports application. The new variable (PE) and the evaluation method offer an alternative for the potential use of markerless, low-cost systems in the future.

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