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Balance disorders caused by running and jumping occurring in young basketball players

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Purpose: Body balance, as one of the coordination abilities,is a desirable variable for basketball players as regards the necessity of efficient responses in constantly changing situations on a basketball court. The aim of this study was to check whether physical activity in the form of running and jumping influences variables characterizing the process of keeping body balance of a basketball player in the standing position. Methods: The research was conducted on 11 young basketball players. The measurements were taken with a Kistler force plate. Apart from commonly registered COP displacements, an additional variable describing the process of keeping body balance by a basketball player was ankle joint stiffness on the basis of which an "Index of Balance–Stiffness" (IB-S) was created. Results: Statistically significant differences were obtained for the maximum COP displacements and ankle joint stiffness between measurements of balance in the standing position before and after the employed movement tasks whereas there were no statistically significant differences for the aforementioned variables describing the process of keeping balance between measurements after running and after jumping. Conclusions: The research results indicate that the employed movement activities brought about significant changes in the process of keeping balance of basketball player in the standing position which, after the run performed, remain on a similar level to the series of jumps being performed. The authors attempted to establish an index based on the stiffness which yields a possibility to perceive each basketball player as an individual person in the process of keeping balance.

Key words: *equilibrium, vertical jump, shuttle run, stiffness*

1. Introduction

Basketball is a team game which is characterized by movements natural for humans (e.g., running, jumping), special movements related to the specific nature of the game (e.g., basketball shots) and combined movements (e.g., dribbling on the run). Basketball players who are on a high sporting level are expected to display a high level of motor coordination because scoring points in a basketball game is relatively difficult due to the actions of opponents, running time, effect of fatigue and the detailed rules and regulations of the game etc. Additionally, players need to be in control not only over their body, but simultaneously over the ball, too. One of the coordinating abilities of humans is balance. The process of keeping balance in the standing position may be disrupted by effects of physical activity occurring during the game. Any possible disorders in keeping balance expressed by deteriorating the variables describing the basketball player's balance in the standing position shall be negatively manifested in the control of body positioning in game situations and in this way the activity of scoring points shall be hindered [2]. The upright position of the human body is subject to constant balance disruptions. This is caused by, e.g., the action of the heart or breathing [11]. The body remains in balance if the disruptions do not exceed critical values and displacements of the centre of gravity oscillate within a safe, constant range [4]. Basketball training improves the level of balance, especially referring to standing on one lower limb. This is related to the development of this sport because while being

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on the court a player spends the majority of the time on one of the limbs [7]. Surenkok et al. [21] and Truszczyńska et al. [22] emphasize that the body balance variable is particularly significant in players who suffered from different lower limb injuries and were in the past subject to rehabilitation. The decrease in the ability to maintain balance may also result from fatigue, thus a coach should wisely use the abilities of his players since a loss of balance may lead to injuries and can also influence the final score [6], [9].

Significant balance disturbances may consequently hinder the performance of the particular tasks on the court by a basketball player [2]. However, running and jumping constitute sorts of movements that are typical basketball player's activities during the game. Hence, the aim of our study was to check whether physical activity in the form of running and jumping has an impact on the variables characterizing the process of keeping body balance by a basketball player in the standing position. Any potential significantly greater disturbances in the process of keeping balance in the standing position after the employed movement tasks in comparison with the variables describing body balance before these tasks were employed shall constitute important information about the necessity to focus attention on exercises that improve the ability to keep balance in the training process by coaches. Another question is whether the potential disorders caused by these types of activity shall differ from one another? The results obtained may be valuable for coaches, since due to the process of constant changes occurring on the basketball court, the appropriate level of balance enables a player to react faster and does not require player's posture correction. As a consequence, a player may change position instantly from running to the defensive position or start a fast break after a rebound. This is particularly significant when we take into consideration the fact that basketball constantly evolves which shortens the time of a single action and consequently increases the speed of the game, a number of changes from the attack to the defense (and vice-versa) as well as a number of jumps [15], [20].

2. Materials and methods

Research was conducted on a group of 11 cadet players who trained basketball at the WKK Wrocław club. All the research measurements were conducted in the course of one day in the certified Laboratory of Biomechanical Analysis (Quality Management Certificate ISO 9001:2009), University School of Physical Education in Wrocław. Table 1 presents a detailed description of a research group (measurements were taken with the subjects wearing the sports shoes in which they train every day). The research was approved by the Senate Committee for the Ethics of Scientific Research at University School of Physical Education in Wrocław.

Table 1. Characteristic of a study group

n	Body height (cm)	Body mass (kg)	Age (years)	Training experience (years)
11	187.3 ± 9.3	74.9 ± 10.5	15 ± 0.5	4.7 ± 2.1

Ground reaction forces during a jump and measurements describing the process of keeping balance in the standing position were measured with a Swiss Kistler force plate model 9281B1 connected directly with a Kistler amplifier model 9863A which was further connected through an analogous & digital converter to a computer. In order to avoid displacements, the plate was fixed to the ground. The first activity examined was maintaining balance without any disturbances. The subject's task was to maintain the body in the 'still' position while standing first on both legs then only on the right leg and finally only on the left leg, with each of the three measurements lasting 60 seconds. Then, the subject performed 10 minute shuttle run (on a distance of 10 meters) which was followed by additional balance measurements, identical to those performed in the standing position as above. The run was conducted at a moderate pace with circa 10 sections a minute. Following the measurements of balance in the standing position after the run, there was a break (5–10 minutes) until the subject reached a rest heart rate value. Later, the subjects performed a series of ten vertical jumps preceded by quick flexion of the lower limbs and arm swing (countermovement jumps – CMJ). The subject stood on the plate in a straight position and performed CMJ to the maximum height. The subject had to land on the plate. Each jump was followed by a twenty second interval, which was assumed as a time based on the mean frequency of jumps in the match conditions [15], [20]. The subject was reminded to perform a two-foot take-off and amortization while landing. After performing ten jumps, a series of measurements of balance in the standing position were taken again in an identical way as the two previous ones.

BioWare® software was used during the research experiment. Ground reaction forces were sampled at a frequency of 240 Hz in jumps' time and the displacements of centre of pressure (COP) with torques acting on the vertical axis passing through that centre during balance measurements were registered. The height of each jump was determined on the basis of the following equation

$$h_s = \frac{1}{8} g t_l^2 ,$$

where h_s means jump height, t_l flying phase time, and g acceleration due to gravity.

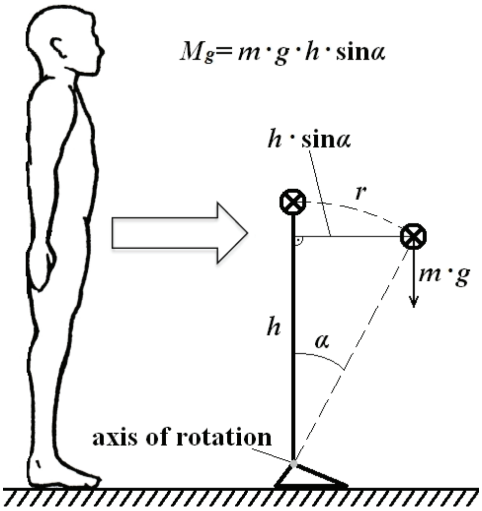

Fig. 1. A model of an examined subject during the measurements, M_g stands for torque precipitating the body out of balance

An additional variable applied to describe the level of balance in the standing position used by the authors was stiffness in ankle joints. This variable was used to establish an index of balance IB-S. As presented in Fig. 1, subjects were treated as inverted pendulums whose rotational axis was at the height of the ankle joints [25]. Displacements from the balance position causes plotting in a given plane by the point of the overall centre of mass (COM) an arc$r$ of radius h and the centre of rotational axis. Value h was computed on the following basis: 56.5% of body height minus the distance from the ground to the lateral malleolus fibula [4]. Knowing the values of r and h it is possible to compute angle α made by the subject during the off-balance: $\alpha = \frac{r}{h}$ or $\alpha_{\max} = \frac{r_{\max}}{h}$.

On the basis of the torque (M) observed during the displacements of COP recorded by the plate which impinged on a subject, it was possible to compute the rotational stiffness (ankle joint stiffness – k_s) of the system described above

$$k_s = \frac{M}{\propto} .$$

Body shall remain in balance if ankle joint stiffness (k_s) is at east slightly higher than the critical stiffness of the system (k_c). When the stiffness value becomes lower or equal, the body loses its standing position if a subject fails to perform a suitable movement. Critical stiffness of the system is individual and constant for particular subject and it does not depend on the plane. It is computed on the basis of the following equation [3]

$$k_c = m \cdot g \cdot h \cdot \frac{\sin\alpha}{\alpha} \left[\mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}^2} \cdot \mathrm{m} \frac{1}{\mathrm{rad}} \right] \approx m \cdot g \cdot h \left[\frac{\mathrm{Nm}}{\mathrm{rad}} \right],$$

where m constitutes a subject's body mass, and g acceleration due to gravity. In the equation, a simplification was made resulting from the fact that in the case of small angles α, the value sin α equals to a numerical value of α angle expressed in radians $\left(\frac{\sin\alpha}{\alpha} \left[\frac{1}{\mathrm{rad}} \right] = 1 \left[\frac{1}{\mathrm{rad}} \right] \right)$. On the basis of the two aforementioned stiffness variables, IB-S (Index of Balance–Stiffness) was created which constitutes a difference in stiffness in ankle joints (k_s) and critical stiffness of a particular person (k_c)

$$\text{IB-S} = k_s - k_c .$$

The Wilcoxon matched-pairs test was applied in order to evaluate the differences observed between the individual balance measurements. The test was used due to the lack of normal distribution in all the values examined. The Spearman Rank Correlation coefficient was applied to examine the relationship between the particular variables, and it was used for the same reasons. The value of $\alpha = 0.05$ was accepted as the level of significance.

3. Results

The mean values of balance measurements taken in the standing position before running and a series of jumps are presented in Table 2. Mean variable values collected during the six successive balance measurements in the standing position for the sagittal plane (3 measurements after a 10 minute run and 3 after 10 jumps) are presented in Table 3 (front–back displacements). Table 4 presents the frontal plane (side displacements).

A statistical analysis of the results computed for the maximum COP displacements and the ankle joint stiffness variable in both planes by each of the three supporting surfaces revealed statistically significant differences between the measurements of balance in

Table 2. Mean values ±SD of maximum displacements of COP (r_{max}), torques operating during these displacements (M_{max}), ankle joint stiffness (k_s) and critical stiffness (k_c) before activities disturbing the balance

	Sagittal plane			Frontal plane		
	Both lower limbs	Right lower limb	Left lower limb	Both lower limbs	Right lower limb	Left lower limb
r_{max} (mm)	19.4 ± 2.7	61.8 ± 19.0	56.7 ± 12.1	10.5 ± 2.1	45.5 ± 6.2	39.7 ± 5.5
M_{max} (Nm)	14.4 ± 2.4	45.6 ± 10.9	41 ± 7.1	7.5 ± 1.6	33.7 ± 8.6	28.3 ± 7.5
k_s (Nm/rad)	690 ± 23	715 ± 51	696 ± 28	686 ± 22	709 ± 59	685 ± 22
k_c (Nm/rad)	678 ± 94.5					

Table 3. Mean values ±SD of maximum displacements of COP (r_{max}), torques observed during theses displacements (M_{max}), ankle joint stiffness (k_s) and critical stiffness (k_c) in sagittal plane

	Both lower limbs after running	Right lower limb after running	Left lower limb after running	Both lower limbs after jumps	Right lower limb after jumps	Left lower limb after jumps
r_{max} (mm)	39.6 ± 7.4	84.5 ± 30.4	76 ± 23.5	42.1 ± 16.3	85.9 ± 43.8	79.7 ± 23.7
M_{max} (Nm)	29.3 ± 3.4	68.3 ± 27.8	59.5 ± 23.3	32 ± 13	66.3 ± 35.8	59 ± 20
k_s (Nm/rad)	727 ± 129	741 ± 143	743 ± 128	726 ± 132	754 ± 141	728 ± 127
k_c (Nm/rad)	678 ± 94.5					

Table 4. Mean values ±SD of maximum displacements of COP (r_{max}), torques observed during these displacements (M_{max}), ankle joint stiffness (k_s) and critical stiffness (k_c) in frontal plane

	Both lower limbs after running	Right lower limb after running	Left lower limb after running	Both lower limbs after jumps	Right lower limb after jumps	Left lower limb after jumps
r_{max} (mm)	21.6 ± 10.2	50.9 ± 10.1	45 ± 9.7	25 ± 6.5	45.8 ± 6.7	45.1 ± 6.2
M_{max} (Nm)	15.9 ± 6.5	41.2 ± 10.3	34.6 ± 8.1	18.8 ± 5.6	35.9 ± 7.5	32.9 ± 7
k_s (Nm/rad)	729 ± 129	757 ± 135	730.± 139	726 ± 132	754 ± 141	725 ± 125
k_c (Nm/rad)	678 ± 94.5					

the standing position before the disturbances and after running. The situation was identical with reference to the same variables describing balance in the standing position between the measurements before the disturbances and after jumping (except for the maximum COP displacements in balance measurements for the right limb in the frontal plane where the difference was statistically insignificant). On the other hand, there were not any statistically significant differences between the values of the maximum COP displacements and ankle joint stiffness between the balance measurements after running and jumping in both planes by each of the three supporting surfaces. The values of ankle joint stiffness presented in Tables 2, 3 and 4 show that this variable does not depend on the maximum COP displacements and a mean value in a group examined changes slightly depending on the plane being examined, supporting surface size or a factor that causes disorder. The values of the balance index IB-S oscillated in the range (0–191.2). Higher values suggest a better ability to maintain balance in the research conditions and a faster return to balance after its disturbance. There were no statistically significant correlations between IB-S and COP.

After the performance of 10 jumps, mean values for the variables achieved by the players were as follows: jump height: 0.37 ± 0.02 m, maximum take-off force: 1901 ± 313 N, maximum ground reaction force in the landing phase: 3555 ± 843 N.

4. Discussion

Statistically significant differences for the variables describing balance in the standing position before and after the disorders (running and a series of jumps) prove that the applied movement activities constitute significant disturbances in the process of keeping balance by humans in the standing position. Changes of the variables describing balance after the performed run are on a similar level to the performed series of jumps. Therefore, a basketball player during the game performs complicated coordinative movements at a lower balance level than in the standing position (without any previous disturbances) which additionally hinders the performance of these movement tasks. Coaches ought to take this fact into account in the training process by the employment of exercises in the conditions similar to real game conditions when the level of basketball player's balance in the standing position is disturbed [6]. For example, the improvement of the basketball shot efficiency ought to include the performance of a feint before a shot.

The influence of physical effort in the standing position was confirmed by the relatively high maximum values of COP displacements obtained by a basketball player after running and jumping. A basketball player needs to be prepared for quick changes of direction of movement resulting from constant changes of situations on the basketball court which may cause habitual body balancing between the successive movement activities during transitional periods. In extreme cases, the mean values of maximum COP displacements obtained during the research were four times higher than in groups researched by Kuczyński [10] performing the task without prior disturbances. Results accepted as being in the norm for the standing position are not higher than 40 mm for both planes [10].

The maximum values of the landing force obtained by the subjects being examined during the landing phase were on average nearly twice as high as the maximum take-off force. This was an indicator of the so called 'hard landing' which results in the considerable increase of the impact force. Hence, the lower limbs are influenced by a much greater load than in the case of amortized landing. The level of keeping balance in the standing position is disturbed under the influence of an effort and while the effort increases, the disturbance also grows. Consequently, in the face of an increased load that a movement system has to carry during hard landing, these disturbances may become greater. Thus, during training more emphasis ought to be placed on improving landing techniques by, for example, plyometric training that not only increases the level of strength, power and velocity, but also the level of balance [1]. Similar results were obtained in the case of a group of young female basketball players [24]. However, it needs to be emphasized that the subjects examined were at the age of cadet players who have not practiced for a long time, thus their results may change in the course of further training. This refers to both balance and jumping variables. Basketball players, in comparison with other sports, exhibit a higher level of balance [7].This refers to top class players in the first place, who in extreme cases reach similar values of the maximum COP displacements with open and closed eyes [17]. The positive influence of balance on sport results was also observed in different sports, not only in the case of basketball. An increase in the results of, inter alia, vertical jump, agility and velocity was observed [8]. However, a comparison of the results obtained by different researchers on balance is difficult due to the different research methods applied, not only with the use of laboratory equipment but also motor tests [18]. According to some researchers, basketball players happen to obtain worse results than athletes practicing other sports. As was observed by Bressel et al. [5], the results of the ability of static balance measurements in female basketball players were worse than those obtained by gymnasts, while in reference to the ability of "dynamic balance" measurements, these results were lower than those obtained by female football players. Research carried out on a stabilometer revealed that balance of young Japanese football players standing on one lower limb was better than in the case of basketball players of a similar age [14].

The ability to maintain balance is an individual feature which depends on our body structure and training [13], [19]. Since basketball players are statistically tall and lean, it can be presumed that this ability may not be favorable in this regard. The values of COP displacements of the study group of players describe only the result, not the reason for such a situation [10], [16]. As proposed by the authors, an index of balance computed on the basis of stiffness in ankle joints and critical stiffness presents an individual approach to each player's balance. A COP displacements by 1 cm would cause various disturbances in the case of a 2-meter-tall center than in another team member, e.g., a playmaker. Therefore, due to considerable differences observed between the players on one team, it is particularly significant to take into account their body height and mass. Hence, the displacements of subject's COP is not as significant as the fact whether the player is able to maintain balance in a given position. It is therefore beneficial when IB-S obtains the highest possible value. That is why the player obtains good results if the value he reaches is higher than the mean value of the researched group amounting to 30 (the value of the difference of stiffness parameters higher than 30 Nm/rad). The lack of statistically significant correlations between IB-S and COP enables one to arrive at another approach to the process of keeping balance. Through an analysis of the stiffness variable we obtain another type of information about this process when compared to commonly registered COP displacements. The authors deliberately used the concept which they named as "index of balance IB-S" to describe the result of difference of ankle joint stiffness and critical stiffness in order to avoid methodological chaos as the concept of stiffness is already used to describe (not always correctly) other human body variables [12], [23].

5. Conclusions

1. A significant increase was observed in relation to values of the maximum COP displacements and the ankle joint stiffness describing body balance in the standing position after running and after performing a series of jumps in comparison with their values in balance measurements in the standing position without disturbances. This proves that the employed movement activities significantly disturb the basketball player's balance and may result in low efficiency of the basketball player during the game.
2. A series of countermovement jumps significantly disrupts the level of keeping balance by the player in the standing position to a similar degree as the effort caused by running.
3. The group examined revealed that in extreme cases COP displacements in the sagittal plane were almost two times greater than in the frontal plane. Statistically this did not result in different levels of player's ankle joints stiffness for both planes.
4. The stiffness in the subjects examined during balance measurements is individualized as it includes body height and mass in relation to commonly measured displacements of COP. The authors suggest using an index of balance IB-S to evaluate the abilities to maintain balance in basketball players and focusing attention on this skill during the training process.

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