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Compensatory action of the index and middle finger in the kinematic chain of a basketball shot

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Performing effective actions requires the basketball player to balance factors such as motor variability, error minimalization and a complex sequence of coordination to determine the best action. *Purpose*: The aim of the study was to differentiate the strength of the muscles of the index and middle fingers when performing a basketball shot. *Materials and methods*: Study group consisted of 122 male college basketball league students. The study included psychophysiological tests to determine indices of individual and typological characteristics of higher nervous activity, proprioceptive sensitivity tests of the fingers of the leading hand and field tests to assess participants' shooting skills. The touch-based finger pressure sensing system measured the different levels of pressure exerted by the participants' main index and middle finger during grasping. *Results*: For both the middle and index finger, the highest correlation with shot efficiency was found for a 120 g load g ($p < 0.01$ for 2PS; 2PS40 suc; FT; 3PSO and 3.5 mS). Furthermore, high reproducibility of proprioceptive sensitivity of the index and middle finger of the leading hand was found in basketball players. *Conclusions*: The research indicates that it is possible to organize compensatory behavior between joints on the basis of proprioception, with the last compensatory movements of the kinematic chain being performed by the fingers of the hand. The demonstrated high proprioceptive sensitivity of the index and middle finger of the leading hand in basketball players at a weekly interval may indicate ability to maintain high repeatability of movements controlled by these fingers.

Key words: *proprioceptive feedback, basketball, accuracy, index finger, middle finger*

1. Introduction

The high complexity of competitive activity in basketball places high demands on all aspects of an athlete's preparation. Under conditions of fierce competition in non-standard situations with a shortage of time and space, the player must reliably and effectively solve constantly arising technical and tactical problems [3], [13], [14], [29], [37]. Therefore, in addition to physical preparedness and training, and working capacity, a high psychophysiological state and strong coordination abilities, technical and tactical skills, and psychological and stress resistance are necessary [1], [5], [26].

For sporting success in basketball, the ability of players to make an effective throw in order to score points is of great importance. In the process of sports training, basketball players perform many hours of throwing exercises to optimize effectiveness. Performing effective action requires the basketball player to balance factors such as motor variation, minimizing errors and a complex sequence of co-ordination to determine best action. Both the free shots and the

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3-point shots are important as they require different speeds, forces and levels of energy transfer from the lower limbs to the shooter's shoulder.

Projection studies have shown that the variation in the angle of the proximal-distal joint of the kinematic chain does not adversely affect the execution of the shot [4], [27], [30]. At the same time, it was found that the success of a free throw is determined, at least in part, by the player's ability to sense the position of the distal joints of the upper limb performing the throw. From the point of view of motor control, this suggests that basketball players may organize compensatory behavior between the joints of the free-throws hand on the basis of proprioception. From a practical point of view, this points to new training techniques that should improve the efficiency of free throws. Researchers indicate a high correlation between the success rate of free throws and the sense of wrist position, and a moderate correlation between the success rate of free throws and the sense of position in the elbow joint. In both cases, the top scorers also had the best proprioceptive scores [34].

Coordination variability near a slowdown may indicate that participants are seeing the difference between their movement and the desired slowdown, and are dynamically correct. This suggests that individuals select a desired release state and dynamically adapt to achieve it, rather than simply repeating the desired movement [24].

The preferred speed and angle of the shot, in the opinion of qualified basketball players, is varied and remains the subject of discussion. Early research proposed a minimum release rate to minimize energy expenditure [8], [20]. The role of sensorimotor noise in unnecessary tasks and its proportionality to force and speed has been widely recognized [6], [25] and has led to speculation that shooting strategies using minimum release rates are favored by slowing down dependent on engine noise, resulting in greater traffic consistency [19], [35].

Analysis of the technique of shooting the ball into the basket with one hand has demonstrated that the ball is released when the lower extremities are fully straightened, and that the guiding movement of the ball is performed mainly from the index finger of the shooting hand [37]. In turn, the thumb and middle fingers allow the basketball player to hold the ball without letting it slide off the shooting hand. The index finger of the leading hand which determines the fly path of the ball should be located at the medium of the distance between the thumb and the small finger [3], [29]. A study monitoring the dynamic pressure of the fingers and palms during a basketball shot confirmed the observations regarding the distribution of finger strength the moment a shot is taken with players using their index finger to control the direction and strength of the throw [14]. During the period of lifting the ball above the head, the pressure of the fingers of the leading hand on the ball is evenly distributed. Nonetheless, at the time of the release of the ball, basketball player uses the index finger to control the direction and force of shooting the ball into the basket [14], [26]. However, although Oks et al. [26], determined the biomechanical indicators of the wrist and fingers at the time of shoot however, they did not study the reproduction of the specified muscle efforts of the fingers. In the current literature, there is a lack of data regarding the strength contribution of each individual finger when performing a shot with the leading hand. Several studies have examined hand dynamometry indicators, such as the size of the hands and fingers [5], [16]. A group of specialists [26] has developed a wireless system (Smart Basketball Glove – SBG; Riga Technical University, Latvia) for the analysis and training of shots in basketball, the use of which enables one to determine the kinematic and dynamic characteristics of the movement of the wrist and fingers during the throw. Currently there is no literature to suggest that the index finger is the leading finger when a shot is made in basketball, while the middle finger simply assists to make a successful shot towards the ring. However, based on coaches' and players' anecdotal reports when teaching the appropriate technique of the basketball shot, some express preference on one of the respective fingers for releasing the ball from the palm. Consequently, for an effective throw, a clear distinction of the contribution of the index and middle fingers is necessary.

Based on the aforementioned information, the aim of this study was to determine the compensatory action of the index and middle finger in the kinematic chain of the basketball shot and its relation to shooting skills.

2. Materials and methods

2.1. Participants

The study was conducted on a group of 122 male university students. The average mean of students participating in experimental studies was: age of 20 ± 1.58 years, body mass of 81.5 ± 3.15 kg and body height of 199.5 ± 6.54 cm (Table 1). At the time of the study, according to the clinical examination, the students were healthy. Also, written consent was obtained from the athletes before participation in the research.

All participants were informed about the study procedures, benefits, risks and their obligations before signing informed consent. They were also informed that they could cease participation at any point, without any consequences.

Table 1. Characteristics of basketball players participating in experimental studies

Statistical Indicator	Age [years]	Experience [years]	Body height [cm]	Body mass [kg]
Experimental group (n = 122)				
Average mean	20	5	199.5	81.5
Standard deviation	1.58	0.36	6.54	3.15
Variation coefficient [%]	7.90	7.20	3.28	3.86

2.2. Data collection

The study included psychophysiological testing to determine the indicators of the individual and typological properties of higher nervous activity proprioceptive sensitivity testing of the fingers of the leading hand and field testing to assess the shooting skills of the participants. Procedures followed the ethical standards of the Declaration of Helsinki. Approval of ethics issued by the Federal State Scientific Institution Yakut Scientific Center of Complex Medical Problems on 2020.

2.3. Shooting skill tests

The order of trials was set and communicated to competitors prior to the start of the test. Each trial was preceded by a warm-up and the next trial began after a full rest break.

Two point shots (2PS) test

The participant performed a series of ten two-point shots from predetermined spots around the three-second limit area (TSLA). Five spots on each side were selected (Fig. 1a). The spots 1 and 10 were placed in a straight line from the center of the rim, right and left onto the TSL A line. The points 1–5 and 6–10 were placed with 101 cm between them. Players performed the shots without a time limit. One of the teammates passed the ball after each shot. The test commenced from the right side. Only successful shots were recorded.

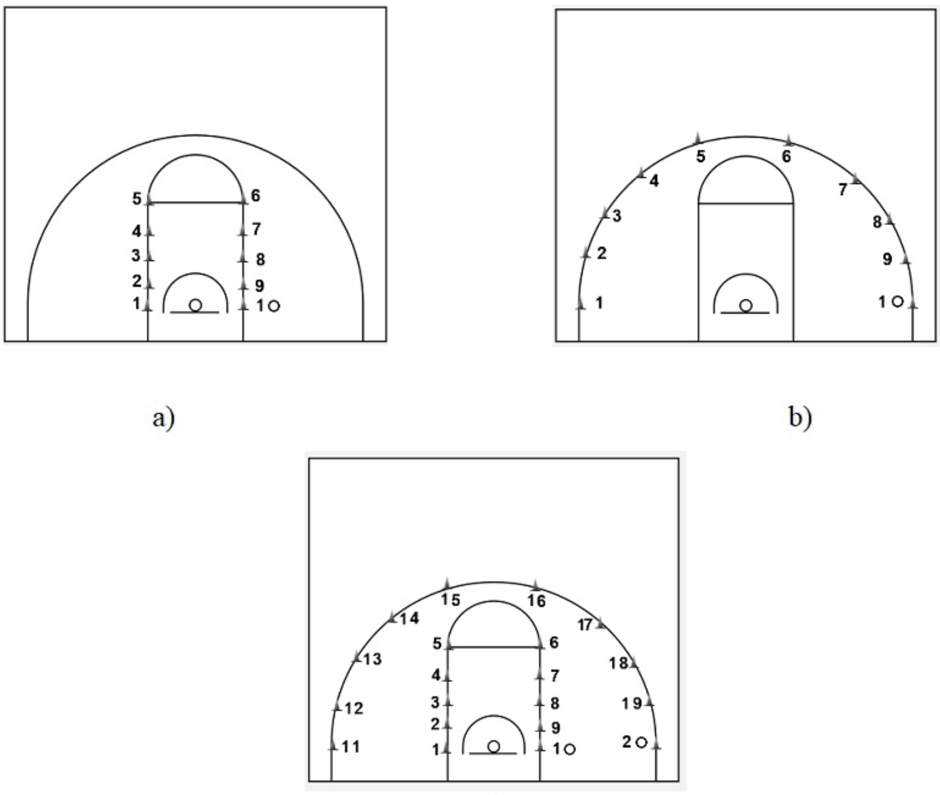

Fig. 1. Places where shots are taken as a function of their point values

Two point shots in 40 s test (2PS40)

Similarly as in the previous test, the participants performed the throws from the same set points but without assistance and with a time limit of 40 s. At the command of the investigator, the participant commenced to make throws into the ring. Regardless of whether the throw was successful or not, it was necessary to catch the ball following the throw, progress to the next point and perform the next throw. If the participant managed to achieve all ten points and the time was still not completed, the participant continued the test by commencing again from the first point. The variables recorded were the shots made and the number of successful shots.

Free-Throws test (FT)

The participant performed ten free-throws, with the ball served to him by a teammate. The test was performed without a time limit. Only successful shots were recorded.

Three-point shot (3PS) test

The test was carried out along the entire three-point arc (TPA), without stepping on the arc or crossing it, commencing from the right side of the ring, performed in such a way that all ten points for shots were evenly distributed throughout the arc (Fig.1b). The number of throws was ten. The spots 1 and 10 were placed in a straight line from the center of the rim, right and left onto the TPA line. The spots 1–5 and 6–10 were separated by a 232 cm distance in between. After each throw, the ball was passed to the participant by a teammate. There was no time limit. Only successful shots were recorded.

Three point shot with an opponent test (3PSO)

Players performed ten throws on the ring with a jump shot in front of an opponent. The test was performed in pairs along the line of the three-point arc. The athlete moved along the points of the three-point line (starting from the right side of the ring, moving gradually to the left). The obstruction was provided by a teammate standing in front of him with his hands raised. The participant tried to perform a maximum in height jump shot. Following either a rebound from the shield or a successful throw the ball passed on to the participant by a teammate. As in the previous test, only successful throws were recorded.

Two and three point shot in 3.5 minutes from deferent spots test (3.5 mS)

Making throws (40 throws) from the set spots in 3.5 min. Twenty spots were set as in tests 2PS40 and 3PSO. The test commenced with the shots made from the perimeter of the three-second zone as shown in Fig. 1c. The participant had to complete 40 shots in a time period of 3.5 min. Testing was conducted without a partner. Only successful shots were recorded.

2.4. Proprioceptive sensitivity test

The test used to determine proprioceptive sensitivity was based on the reproduction of given muscular efforts by the index and middle fingers of the participant's leading hand. The Finger Tactile Pressure Sensing System (Finger TPS, USA Medical Tactile, inc.) designed to measure the pressure exerted on objects by human hands while gripping was used for the assessment. The following proprietary test protocol was used. The athlete sat on a chair with the forearm of the leading arm placed on an elevated surface (Table) in front of him, bent at the elbow joint (joint angle at 90°), with the palm of the hand facing upwards. The athlete was wearing the "glove" of the pressure sensing system and held a tennis ball (diameter of 6.7 ± 0.16 cm) in his palm. The system uses highly sensitive capacitive pressure sensors wirelessly connected via Bluetooth to a computer running software to quantify the forces applied by a person's fingers.

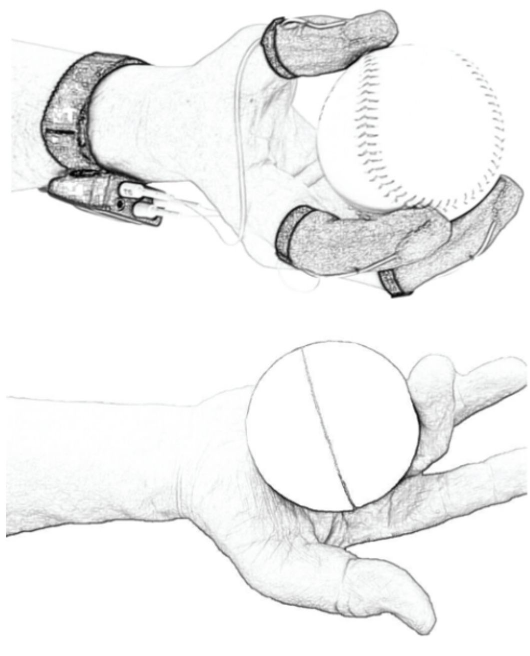

Fig. 2. The Finger Tactile Pressure Sensing System (Finger TPS, USA Medical Tactile, Inc.)

Before testing, two trial attempts were conducted. During the trial attempts, the athlete had to apply force by "squeezing" the ball either with the index or the middle finger (Fig. 2), with their eyes open, and the investigator provided feedback regarding the amount of applied force. Following the trial attempts, the participants were asked to close their eyes and "squeeze" three times, at a set effort, with the index or the middle finger. Feedback about the force applied by the participant was provided after the third attempt was completed. The participant had to complete three attempts at the following set resistances: 60, 80, 100, 120, and 150 g. The rest interval between each resistance was one minute.

For each given resistance, the mean value of the three attempts was determined as well as the average percentage of muscle effort reproduction error (PMERE). Initially, the participants performed the procedure with the index finger (all ten preset values from 60 to 150 g) and then, the same procedure was repeated with the middle finger. To determine the reliability of the procedure, the test was repeated after seven days.

2.5. Statistical analysis

Statistical analysis for this study was performed with the use of Statistical Packages for the Social Science (SPSS) version 21.0 (IBM Corporation, Somers, NY, USA). After assessing the normality of the data with the use of the Kolmogorov–Smirnov test, the means and standard deviations were calculated for all variables. Intersession reliabilities of the PSJT measures were quantitatively assessed with the intraclass correlation coefficient (ICC) and their respective 95% CI. An ICC with values >0.75, ≥0.40 and ≤0.75, and <0.40 indicated "excellent", "fair to good", and "poor" reliability, respectively. Furthermore, as a qualitative method, Bland–Altman plots were used to define the magnitude of agreement between test–retest values. The difference of the paired intersession measurements was plotted against the respective average. The evaluation criterion was that 95% of the data points should lie within the mean of the differences for the intersession measurements, which corresponds to the 95% CI. Effect sizes (f) were calculated, where f-values of 0.10, 0.25, and 0.40 indicated small, medium, and large effects, respectively. The factorial validity and the relationships between the measured variables were established by Pearson's correlation coefficients. The level of significance was set at $p < 0.05$.

3. Results

3.1. Test reliability

Descriptive statistics of the two testing sessions and the intersession analysis are presented in Tables 2 and 3.

Table 2. Mean PMERE values, Mean of differences, ICC, 95% CI, and *f* values for calculated for intersession reliability for the index finger

Resistance	Session 1	Session 2	Mean dif	±2SD	ICC	95% CI	*f*
60 g	9.71	9.84	–0.12	0.81	0.987	0.981–0.991	0.065
80 g	26.06	25.83	0.23	3.66	0.959	0.940–0.972	0.049
100 g	18.84	18.96	–0.11	0.72	0.994	0.991–0.996	0.047
120 g	16.16	16.18	–0.01	0.83	0.996	0.994–0.997	0.005
150 g	13.67	13.93	–0.25	2.48	0.958	0.940–0.971	0.008

Table 3. Mean PMERE values, Mean of differences, ICC, 95% CI, and *f* values for calculated for intersession reliability for the middle finger

Resistance	Session 1	Session 2	Mean dif	±2SD	ICC	95% CI	*f*
60 g	12.98	13.13	–0.15	0.63	0.989	0.979–0.994	0.089
80 g	31.22	30.94	0.28	1.73	0.986	0.979–0.991	0.071
100 g	23.76	23.57	0.19	1.19	0.983	0.974–0.989	0.07
120 g	21.16	21.35	–0.19	1.20	0.988	0.982–0.992	0.064
150 g	19.88	19.71	0.17	4.09	0.920	0.885–0.944	0.046

No changes in PMERE performance were observed between testing sessions. The calculated ICC values for PMERE performances across the 2 testing sessions were >0.75 indicating an excellent intersession reliability.

The significance test performed showed no statistically significant differences regarding the difference between the middle and index fingers.

3.2. Correlation with shooting skill

All correlation coefficients indicated correlations among shooting skill indicators and PMERE of the index and middle fingers of the leading hand (Tables 4 and 5).

During multi-joint movements such as basketball shots, proprioceptive information is crucial for shot control and coordination [32], and is particularly required to control moments of interaction produced at proximal joints when visual information is not available to the hand [17].

Scientists have only recently explored the possible link between proprioceptive status and athletic performance. This has been done in relation to basketball by assessing the relationship between the success rate of free throws and JPS in the knee and shoulder [2].

These studies identified the wrist joint as a distal joint during the basketball shot. We noted that, in this exercise, the fingers are the last part of the body to come into contact with the ball, so through the "compensatory variation" they can influence the final success of the task.

Table 4. Correlation between shooting skill indicators and PMERE of the index finger of the leading hand

PMERE	2PS	2PS40 (made)	2PS40 (suc.)	FT	3PS	3PSO	3.5 mS
60 g	–0.483*	–0.310	–0.783**	–0.729**	–0.342	–0.383	–0.463*
80 g	–0.459*	–0.783**	–0.349	–0.454*	–0.764**	–0.457*	–0.855**
100 g	–0.416*	–0.717**	–0.250	–0.314	–0.251	–0.841**	–0.608**
120 g	–0.740**	–0.214	–0.769**	–0.864**	–0.203	–0.745**	–0.776**
150 g	–0.262	–0.355	–0.818**	–0.377	–0.712**	–0.709**	–0.765**

** $p < 0.01$, * $p < 0.05$.

Table 5. Correlation between shooting skill indicators and PMERE of the middle finger of the leading hand

PMERE	2PS	2PS40 (made)	2PS40 (suc.)	FT	3PS	3PSO	3.5 mS
60 g	–0.473 *	–0.400	–0.793 **	–0.749 **	–0.342	–0.683 **	–0.563 *
80 g	–0.663 **	–0.761 **	–0.333	–0.451 *	–0.759 **	–0.444 *	–0.765 **
100 g	–0.445 *	–0.717 **	–0.678 **	–0.315	–0.232	–0.761 **	–0.619 **
120 g	–0.737 **	–0.204	–0.757 **	–0.798 **	–0.213	–0.701 **	–0.777 **
150 g	–0.245	–0.343	–0.812 **	–0.297	–0.709 **	–0.700 **	–0.743 **

**$p < 0.01$, *$p < 0.05$.

4. Discussion

Motor control experts point out that variation in movement can be beneficial in achieving success while performing a task because it gives flexibility despite potential perturbations or limitations [7]. By examining cooperative behavior between the joints of the shooting hand, they indicated that erroneous deviations of the more proximal limb segments can be compensated for by more distal joints through so-called "compensatory variation" [9], [31], [32], [40].

A special test was developed to determine proprioceptive sensitivity based on the reproduction of predetermined muscular effort by the index and middle fingers of the leading hand. Data suggest that the test has a high intersession reliability. Furthermore, for the first time, a correlation was identified between the indices of reproduced muscular efforts by the index and middle fingers of the leading hand and the effectiveness of basketball shots confirming the reports [1], [2], [14], [29] that the index and middle finger affect the performance of the throw. The research on throws in basketball indicates a compensatory variability between the joint movements of the shooter's throwing arm. At least six different joints are involved in the execution of a free throw, from the foot joints to the hand joints. By default the onset of the free-throw always involves some disturbances which must be compensated for [27]. It has been reported that proprioceptive exercise may improve grip force sensibility and that precision of force reproduction of the hand and wrist can be improved using proprioceptive exercises [39]. Proprioceptive exercises are regarded to have superior effects compared to conventional exercises and should be introduced to training programs as the addition of proprioceptive training can augment motor learning and improve sensory acuity [15], [38].

The correlations observed at the present study suggest that, the sense of finger position can lead to greater precision in shots. However, the correlations differed between resistances and shooting skill tests. For both the middle finger and the index finger, the greatest correlation was found with the throwing efficiency for a load of 120 g ($p < 0.01$ for 2PS; 2PS40 suc; FT; 3PSO and 3.5 mS). The findings of the present study suggest that shooting skill tests with a fatigue component (2PS40, 3PSO, 3.5 mS) were highly associated with greater resistances (120 g), while lower resistances demonstrated lower correlations with these tests. This finding shows a possible link between finger strength, proprioception and fatigue, and is consistent with previous data suggesting a link between fatigue, shooting accuracy and some technical skills in basketball [11], [18], [22], [23], [36].

The low correlation between high resistances and shooting skill accuracy may be attributed to reduced strength capabilities of the respective fingers or hands of the participants. Research reported significant correlation between short distance shooting accuracy and wrist isokinetic strength, and between long distance shooting accuracy and elbow extensor isokinetic strength [30]. One of the limitations of the present study was that the strength qualities of the participants were not assessed so as to be conclusive on this observation. High reproducibility of the proprioceptive sensitivity of the index and middle finger of the guide hand was found in basketball players between the first and second sessions. There were no statistically significant differences in the results of the task performance for five load ranges (60, 80, 100, 120 and 150 g).

The lack of strength is also associated with an early onset of fatigue. The presence of neuromuscular fatigue may deteriorate shooting performance in basketball by impairing neural pathways involved in co-contraction [21]. The reduction in movement accuracy during post fatigue fast elbow extensions has been associated with a decrease in muscle co-contraction, a strategy used by the motor system to modulate the relative weights of accuracy and energy economy in the fatigued muscle [28].

5. Conclusions

The obtained results may suggest that compensatory behaviour between joints can be organised on the basis of proprioception, with the last compensatory movements of the kinematic chain being performed by the index and middle finger of the hand. The demonstrated high proprioceptive sensitivity of the index and middle finger of the leading hand in basketball players at a weekly interval may indicate ability to maintain high repeatability of movements controlled by these fingers. The revealed high correlations between lead finger proprioceptive sensitivity and throwing effectiveness enable trainers to use one of these elements to develop the other two. For example, a decrease in this index indicates an improvement in the proprioceptive sensitivity of the fingers and the ability to more accurately control the release time of the ball during a throw. This can have a positive effect on the effectiveness of players' shots.

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