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Accuracy in reproduction of movement range and pressure force in sportsmen

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Abstract
Introduction. Studies have proven that the level of proprioceptive ability is related to motor learning. Many authors also indicate the importance of proprioception in sports and have reported the existence of a correlation between kinesthetic differentiation abilities and success in different sports. Aim of Study. The aim of the study was to evaluate the accuracy of reproduction of the range of movement for forearm pronation and supination in the elbow joint as well as the level of hand pressure force in table tennis players, soccer players and non-training subjects. The study also attempted to examine changes in the level of this accuracy after six months of training. Material and Methods. The study was conducted on groups of table tennis players (10), soccer players (10), and non-training controls (10), aged 14.5 years. The participants undertook six tasks demonstrating their level of proprioceptive ability: accuracy of recreating pronation and supination of the forearm at the elbow joint; and accuracy of recreating hand pressure force. The test was carried out twice during the year. Results. The results revealed small differences between the groups after the first test and more significant differences after the second test. The soccer players showed a higher level of proprioceptive ability than the other two groups of participants. Conclusions. This study points to the significance of proprioceptive ability in soccer. The results of proprioceptive tasks are varied and depend on multiple factors, which is probably typical for this ability.

KEYWORDS: proprioceptive ability, table tennis, soccer, reproduction of movement, joint position sense.

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What is already known on this topic?
"Ball feeling" is probably the most comprehensive manifestation of soccer players' aptitudes, among which numerous authors indicate proprioceptive ability as the most basic. Researchers have attempted to evaluate the importance of proprioception in sport, having proven that the level of proprioceptive ability is related to motor learning. Many authors also stress the importance of this ability in sports and report the existence of a correlation between the level of kinesthetic differentiation abilities and success in different sports.

Introduction

Table tennis and soccer are two very popular and accessible sports. They differ in technique, equipment, and playing area. The most noticeable difference is the use of different body parts by table tennis and soccer players. Table tennis players use their upper limbs to perform precise movements by means of a hand-held racket to direct the ball onto a selected area on the table. By contrast, soccer players use their lower limbs in order to strike or pass the ball to their teammates, direct the ball to the goal, or to block the opponent's play and take control of the ball. Touching the ball with hands is not allowed, except for goalkeepers. Soccer is a sport requiring a plethora of technical skills as well as static, semi-dynamic, and dynamic balance [1].
Both sports differ from each other but they also have some common features, such as constantly changing

situations that require quick and accurate responses of players, or defensive and offensive actions. Both sports also make use of the term “ball feeling”, which is regarded by many authors, players and coaches as a very important trait [2, 3, 4]. “Ball feeling” in table tennis is often understood as the ability to discern and recognize ball movement parameters, for example, rotation, direction of flight and velocity, which allow for an adequate selection of playing parameters: angle of racket inclination during the contact with the ball or assessment of the force to be used to hit the ball [3]. The concept of “ball feeling” in soccer can be referred to very similar abilities. This feeling is a comprehensive manifestation of player’s aptitudes, among which numerous authors indicate kinesthetic differentiation as the most basic [2, 5, 6]. Few studies have attempted to evaluate the importance of this ability in sport. Furthermore, few authors have emphasized the essential role of proprioception in table tennis [7, 8, 9]. Few studies have also been published regarding the significance of proprioception in soccer. Leite, Ribeiro & Rebelo evaluated the accuracy of movement reproduction in the knee joint before and after a series of shots in soccer and found no changes in the accuracy of reproduction after performing a shot [10]. Mohammadi and Roozdar found a decrease in the accuracy of feeling the position in the ankle joints after fatigue during a match [11]. Bekris et al. indicated that training oriented at improvement of proprioception leads to a better level of mastery of technical skills in soccer [1]. Carlson emphasized the importance of “kinesthetic awareness” in soccer, and Muaidi, Nicholson and Refshaug found that elite soccer players had better proprioceptive acuity than untrained controls [12, 13].

Assessment of the level of proprioceptive ability can yield necessary information about its significance in soccer and table tennis. It can also emphasize the necessity to take into consideration training activities increasing the level of proprioception. One of the most important components of proprioceptive ability discussed in literature is reproduction of changes in movement parameters (pressure force or displacement of the joint), while the accuracy of these changes is considered a measure of the level of kinesthetic differentiation or proprioceptive ability [2, 14].

Aim of Study

The aim of the study was to assess the accuracy of reproduction of range of movement for forearm pronation and supination in the elbow joint, and accuracy of reproduction of hand pressure force in table tennis players, soccer players, and untrained subjects. The aim of the study was also to examine changes in the level of this accuracy after six months of training.

Material and Methods

The study sample consisted of athletes on an intermediate training level: soccer players and table tennis players. The control group comprised secondary school students at a similar age (control group, not involved in any sport on a regular basis). In total, thirty participants: 10 table tennis players, 10 soccer players, and 10 untrained subjects underwent the tests. The participants’ age was 14.5 (± 1) years, mean body – 67 kg (± 4.6), and mean body height – 173 cm (± 3.8). Each study group included a person with a dominant left limb, although in the analysis the terms “right limb” is used for the dominant limb and “left limb” for non-dominant limb. The local ethics committee gave their approval to the study. All participants agreed to take part in the study voluntarily and signed a written informed consent form. The tests were carried out in November 2014 and in May 2015 in the same conditions for each study group, i.e. in closed rooms ensuring a quiet environment during the test, from 1:00 to 3:00 p.m.

The evaluation of the spatial components of proprioceptive ability indicated participants’ ability to accurately reproduce a range of pronation and supination of the forearm to the 45 degree angle. The testing station was equipped with a specially constructed device to measure forearm pronation and supination at the elbow joint (Figure 1). It consisted of a stationary main body with a rotating cylinder on a Teflon bearing attached to a handle. The apparatus was fixed to a table.

Figure 1. Testing station for assessment of the range of motion – goniometer

A revolving linear potentiometer fixed at the end of the cylinder recorded the angle of rotation. The angular values were recorded with the use of Labview software ver. 2009 (National Instruments) and an analogue–to-digital converter NI USB 6008 (National Instruments). Each participant sat on a chair of adjustable height and was holding the appliance handle in such a way that the forearm and the upper arm formed a right angle (adjusted by the chair's height), while the elbow of the arm executing the movement was positioned touching the body. The researchers made sure that the forearm's axis coincided with the axis of movement, while the capitulum of the third metacarpal bone coincided with the rotational axis in accordance with the requirements of the range of movement to be measured.

The participants did not have any opportunity to familiarize themselves with the appliance prior to the tests. Each participant performed two tasks in each series. Blindfolded, they were asked to execute a pronation and supination movement with the dominant limb three times (standard movement), beginning from the so-called neutral position (zero angle) and ending at the angle of 45 degrees. Upon reaching the 45 degree angle a loud ring was automatically activated. Immediately afterwards the subjects repeated the same movement five times, but this time from memory (blindfolded with no audio cue). Then, they performed the same tasks using the non-dominant arm. The computer software recorded the maximum range of movement in each direction as the angle was attempted to be reproduced by a subject. The researchers controlled and corrected the subject's starting position prior to each test. The time to make the five movements with each arm did not exceed 30 seconds. The level of kinesthetic differentiation was determined for the dominant and non-dominant limbs by calculating the precision indices. The computed indices were standard deviations of the recreated angular values. The following indices were taken for further analysis:

- P-R (precision rate: dominant limb-pronation)
- S-R (precision rate: dominant limb-supination)
- P-L (precision rate: non-dominant limb-pronation)
- S-L (precision rate: non-dominant limb-supination).

A lower precision index was treated as an indicator of a higher level of precision of reproduction (so-called spatial components of proprioceptive ability – joint position sense).

The dynamometer used to evaluate the so-called force components of proprioceptive ability enabled the researchers to determine the precision of reproduction of hand pressure force. (Figure 2).

Figure 2. Testing station for assessment of hand pressure force reproduction – dynamometer

The appliance recording hand pressure force consisted of a metal cylinder with a cover and an extensometer (KMM 20, Wobit) (Figure 2). An electrical signal from the extensometer was transmitted to the analogue–to–digital card (NI USB 6008, National Instruments) and then recorded with the use of Labview software ver. 2009 (National Instruments). Similarly to the examination of spatial components, the subjects performed two tasks. They stood by the testing station with their hands placed on the measuring device, and pressed it three times with a previously determined force of 20 N. Upon reaching 20 N a loud ring was sounded. In the second session, the subjects reproduced the pressure from memory five times with no audio cue. The following two indices were taken for further analysis:

- F-R (precision rate – pressure force, dominant limb)
- F-L (precision rate – pressure force, non-dominant limb).

Also in this case, the researchers assumed that the lower values of the indices reflected a higher level of precision of force reproduction (so-called force components of proprioceptive ability).

The level of proprioceptive ability was assessed on the basis of six indices, four related to spatial and two to force components.

Statistica for Windows software ver. 10 was used in statistical analysis. The basic statistics were calculated (arithmetic means, standard deviations, coefficients of variation), normal distribution was verified by means of the Shapiro-Wilk test, and the non-parametric Kruskal-Wallis test and LSD test were performed to determine differences between groups and individual studies.

Results

The results of the proprioceptive ability tests were analyzed with respect to data concerning both upper limbs. The study compared the results of the three groups: table tennis players, soccer players, and untrained young people (students from sports classes who did not declare professional playing of any sport). Values of coefficients of variation were significant in the most of tests performed, which means that the studied groups were varied.

The examination of the right limb (dominant) and the task of reproduction of the pressure force (F-R) revealed that table tennis players and untrained study participants were characterized by a similar level of performance (table tennis players – 0.67, untrained young people – 0.68, Tab. 1, Figs. 3 and 7). For the same variable, better results were obtained by soccer players (0.53, Tab. 1, Fig. 5). It was also found that soccer players were characterized by the highest group homogeneity. Standard deviation in this group (0.18, Tab. 1) was over three times lower than the table tennis players, and lower than untrained controls. This is also demonstrated by the coefficient of variation values.

In the second study test, after a six-month break, a non-significant improvement was found in the soccer players' F-R index (mean: 0.41, Tab. 1, Fig. 5), but it was still the best result in all the groups. This group also showed the greatest uniformity across the sample. An insignificant improvement was found also in table tennis players (0.63, Tab. 1, Fig. 3), and a decrease in mean F-R index in the second study test in the control group (0.75, Fig. 7).

The analysis of results of the same task for the left limb revealed the lowest arithmetic mean of F-L in the first study test in the group of soccer players (0.36, Tab. 1, Fig. 5). Over a twice higher mean result was obtained by the untrained controls (0.88, Fig. 7).

Individual variables related to the pressure force of the left limb in the groups of soccer and table tennis players were also lower (better) in both study tests, as compared with the results of the test performed with the right limb (Tab. 1, Fig. 5).

The arithmetic means of supination accuracy index for the right limb (S-R) showed that the table tennis players and the untrained participants were characterized by a similar level of performance of this task in the first study test. The table tennis players attained the mean of 5.30 (Tab. 1, Fig. 4), whereas the untrained controls of 5.06 (Tab. 1, Fig. 8). The soccer players attained the index value of 7.59 (Fig. 6), which reflected their slightly worse performance of this task. The group of soccer players was the most varied, with the coefficient of variation of 77.58% and a high SD – 5.89. In the second study test the index for the right limb (S-R) also showed an insignificant improvement in table tennis players (5.27), a significant improvement in soccer players (5.47), and a higher improvement in the untrained subjects (4.71) (Fig. 4, 6 and 8, respectively). The highest variation in this test was also found for soccer players, reflected by the highest standard deviation and coefficient of variation.

Arithmetic means for S-L (supination left limb) are very similar in all the groups, with the lowest for the soccer players (5.01), followed by the table tennis players (5.73), and untrained controls (5.78) (Fig. 6, 4 and 8, respectively). The highest improvement of this index in the second test was noted in the table tennis players, i.e. 4.81 (Fig. 4). An improvement was also observed in the

Table 1. Arithmetic means ($\bar{x}$) and standard deviations (SD) in all studied groups in all tests

	FP				TT				CG			
	Research 1		Research 2		Research 1		Research 2		Research 1		Research 2	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
F-R	0.53	0.18	0.41	0.22	0.67	0.51	0.63	0.32	0.68	0.33	0.75	0.48
F-L	0.36	0.13	0.42	0.25	0.49	0.25	0.53	0.44	0.88	0.52	0.56	0.25
P-R	5.98	4.24	4.02	1.97	6.42	2.58	7.08	3.62	5.11	2.79	5.44	3.27
S-R	7.59	5.89	5.48	3.36	5.30	2.18	5.27	2.42	5.06	2.26	4.72	1.54
P-L	4.65	1.79	5.89	3.23	6.35	2.67	7.44	2.95	5.87	2.43	6.91	4.22
S-L	5.01	2.28	6.27	3.42	5.73	2.16	4.81	1.81	5.78	3.25	5.04	2.04

FP – soccer players, TT – table tennis players, CG – control group, F-R – reproduction of force, right limb, F-L – reproduction of force, left limb, P-R – reproduction of pronation, right limb, S-R – reproduction of supination, right limb, P-L – reproduction of pronation, left limb, S-L – reproduction of supination, left limb.

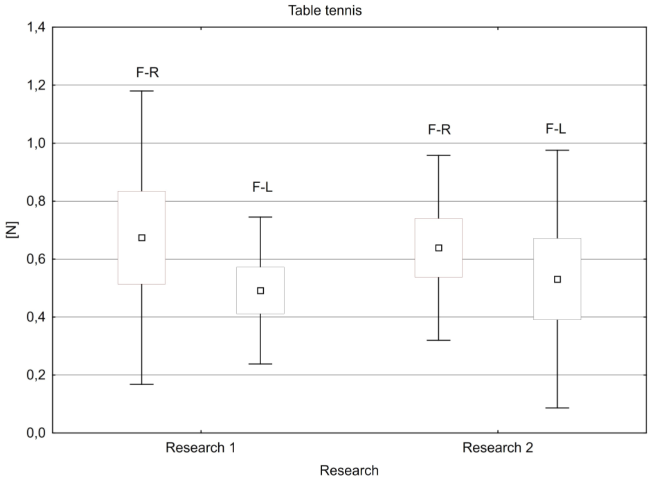

Figure 3. Reproduction of pressure force (FR – pressure force – right limb, FL – pressure force – left limb) in table tennis players

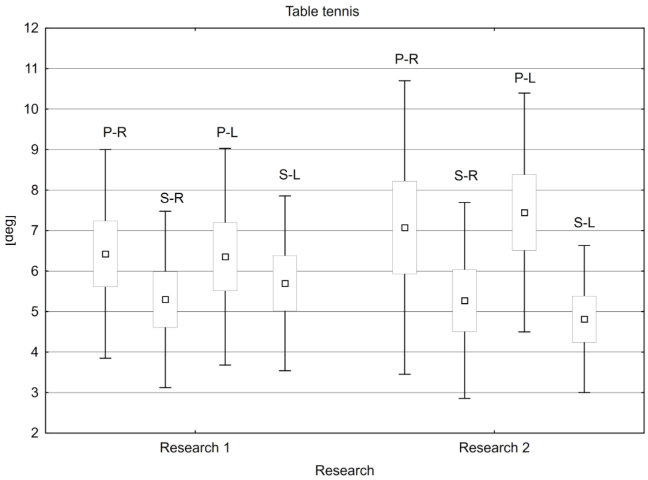

Figure 4. Reproduction of supination (SR – supination – right limb, SL – supination – left limb) and pronation (PR – pronation – right limb, PL – pronation – left limb) in table tennis players

untrained subjects (5.04, Fig. 8), whereas the arithmetic mean was higher in the soccer players (6.26, Fig. 6), thus decreasing the accuracy level in performing this task. The coefficient of variation values were similar across the groups.

The analysis of another accuracy index (pronation) revealed that the lowest arithmetic mean in the first study test for the right limb (dominant, P-R) was demonstrated by the untrained controls, i.e. 5.11 (Fig. 8) followed by the soccer players (5.98) (Fig. 6), and table tennis players (6.42) (Fig. 4). The soccer players were the most varied group in this sample, which was reflected by their coefficient of variation of 70.92%. Test 2 showed the greatest improvement of this coefficient in the soccer players (4.02, Fig. 6). An increase was also observed in the group of table tennis players group (7.08, Fig. 4), and the untrained controls (5.454, Fig. 8). With respect to the left limb (non-dominant), the accuracy of pronation (P-L) was the best in soccer players (4.65, Fig. 6). Higher values of the means were found in the untrained subjects (5.87, Fig. 8), and the highest – in table tennis players (6.35, Fig. 4).

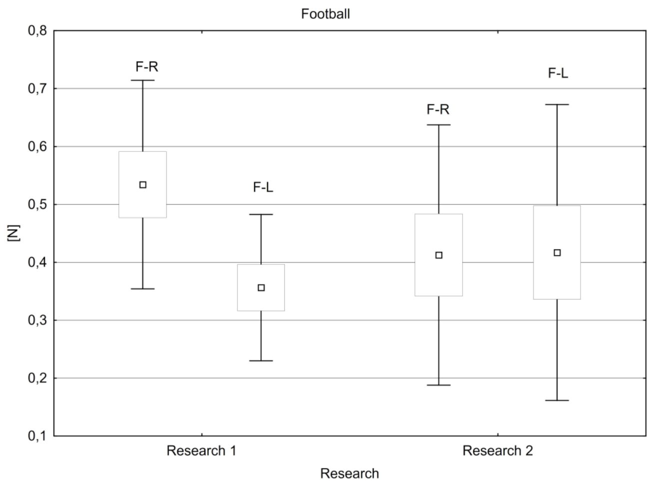

Figure 5. Reproduction of pressure force (FR – pressure force – right limb, FL – pressure force – left limb) in soccer players

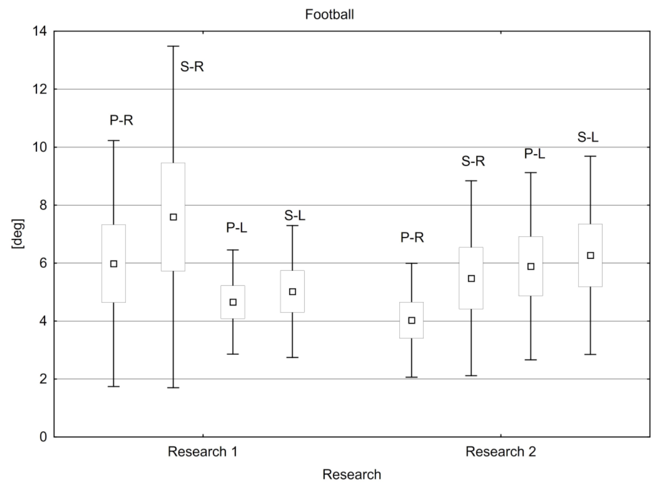

Figure 6. Reproduction of supination (SR – supination – right limb, SL – supination – left limb) and pronation (PR – pronation – right limb, PL – pronation – left limb) in soccer players

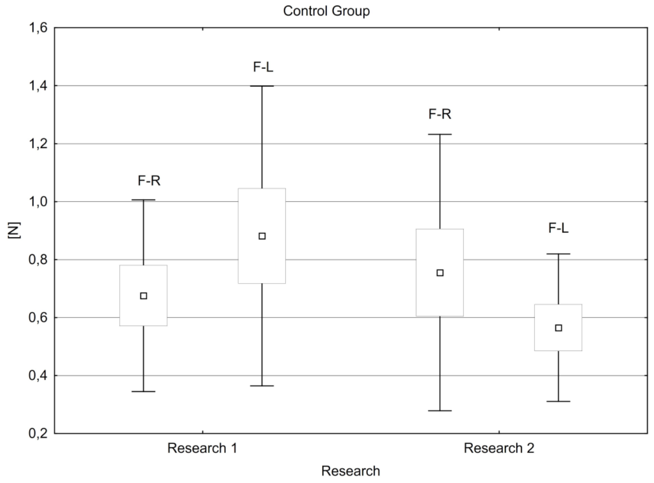

Figure 7. Reproduction of pressure force (FR – pressure force – right limb, FL – pressure force – left limb) in the control group

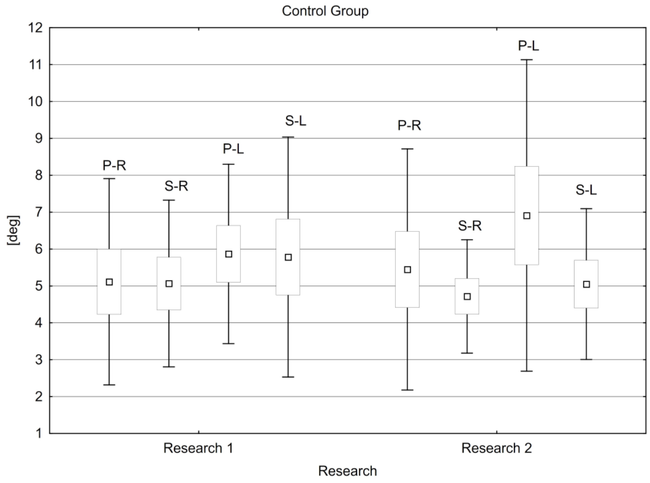

Figure 8. Reproduction of supination (SR – supination – right limb, SL – supination – left limb) and pronation (PR – pronation – right limb, PL – pronation – left limb) in the control group

An increase in the mean value was found in all groups in the second test: 7.44 in table tennis players, 5.89 in soccer players, and 6.91 in untrained controls (Figs. 4, 6 and 8, respectively).

Table 2. Results of the test of significance of differences: p values (only significant values at $p \leq 0.05$)

	FP vs CG	FP vs TT	TT vs CG
F-R	0.04 (res. 2)		
F-L	0.02 (res. 1)		
P-R		0.03 (res. 2)	
P-L			
S-R			
S-L			

FP – soccer players, TT – table tennis players, CG – control group, F-R – reproduction of force, right limb, F-L – reproduction of force, left limb, P-R – reproduction of pronation, right limb, S-R – reproduction of supination, right limb, P-L – reproduction of pronation, left limb, S-L – reproduction of supination, left limb.

The test of significance of differences was used to compare the performance of tasks in all the groups. The Shapiro-Wilk test showed that the distribution was not normal for F in the first test with respect to the left and right limbs. Therefore, the non-parametric Kruskall-Wallis test was used to assess intergroup differences. It demonstrated statistically significant differences in F for the left limb (F-L) between the untrained subjects (CG) and soccer players (FP) in the first study test (Table 2). Furthermore, the parametric LSD test was employed for comparison of other characteristics between groups and between individual tasks where distribution was normal. It revealed statistically significant differences between groups with respect to F index for the right limb (F-R) in the second study test: the soccer players (FP) performed better than the untrained subjects (CG). Similar differences were also observed for pronation in the second study tests for P-R: soccer players (FP) performed this task better than table tennis players (TT) (Table 2).

Discussion

The aim of the study was to compare the accuracy of reproduction of movement parameters: pressure force and range of motion, and, consequently, to assess the level of kinesthetic differentiation of table tennis players and soccer players. The players' results were compared with the results of non-training students at the same age. Proprioceptive ability, also known as kinesthetic differentiation ability, is one of the most important coordination abilities that allows people to behave rationally in their environment [2, 14]. Researchers have emphasized that this ability comprises three components: force (force differentiation), time (time differentiation) and space (e.g. differentiation of the position of individual body parts) [2]. It has a universal character since it is necessary in almost all physical activities and sports [2, 5, 14]. A high level of this ability allows performing accurate movements in time and space, i.e. economic movements [2, 14]. Proprioceptive ability is manifested in various types of "feeling" in different types of sport. According to Starosta, examples of the "feeling" include "ball feeling" in various ball games, "ice feeling" in ice skating, "opponent feeling" in combat sports, "partner feeling" in various types of dancing, "distance feeling" in boxing, or "field/court feeling" in team sports [2, 14]. Table tennis is also a sport in which much emphasis is put on "ball feeling" as a derivative of proprioceptive ability [3]. This ability in table tennis is also manifested by the abilities to locate the ball on the table and to make the ball rotate in a specific manner, or by the speed of performing strokes, etc. [6, 7]. Schriener pointed out the role of kinesthesia, proprioception, and ball control in soccer [15].

The present study assumed that the level of proprioception of upper limbs in sports players was higher than in untrained individuals. Another assumption concerned differences between the results of tests after six months of training, i.e. that an increase in the level of proprioceptive ability can be observed more noticeably in the group of athletes compared to untrained controls. Research has demonstrated that athletes (gymnasts, hockey players) are characterized by a higher level of proprioception compared to untrained controls [16, 17]. Lephart et al. studied ballet dancers and found that extensive training had a positive influence on knee kinesthesia in addition to increasing muscle tone [18]. Han at al. found that ankle proprioceptive ability was significantly correlated with athletes' performance level [19]. Many other authors found relationships between the levels of proprioceptive ability and sport skills [2, 5, 14]. The results of the present study show that soccer players performed the tasks the best in the first and the second study tests. The comparison of the results in the first test and repeated tests shows that the highest level of proprioceptive ability can be found in the group of soccer players, who performed tasks with lower mean indices than the other groups – in 3 of 6 trials in the first study and 4 of 6 in second one. In three tasks these differences were statistically significant. The observed relationship may lead to the conclusion that there are differences between soccer players and untrained individuals in terms of their level of reproduction of movement parameters that results from sport activities. This would be more noticeable in examinations of athletes with higher levels of sport skills participating in a more regular, continuous training process. The other participants, i.e. table tennis players, did not differ in most of tasks at the level of statistical significance from students who declared that they were not involved in any sports. This is likely to be affected by the level of athletes' sport skills and other disturbing factors (the accuracy of tasks assessing the level of proprioceptive ability can be affected by many factors e.g. temporary problems with focus of attention). The above observations would have to be confirmed in a greater group of athletes with a higher level of sport skills against untrained subjects.

The comparison of results of tests repeated after six months shows a slight reduction (i.e. improvement) in accuracy indices adopted for individual tests. The results (arithmetic means) were improved in more than half of all tests for all the groups. However, the changes were statistically non-significant. Nevertheless, a non-significant increase in the accuracy of reproduction of pressure force and range of motion can be typical for the participants' age, and it results from their biological development. Many researchers have shown a significant development of proprioception at the age of 15 years [2, 5].

Proprioceptive ability is also highly individual, and the results of studies depend on multiple factors (age, experience, opportunities for concentration) [20]. Panics et al. found that proprioception training improves joint position sense in the knee in elite female handball players, but they also pointed out that even the lack of normal communicative skills on the part of the subjects constrained the applicability of proprioception tests [21]. Therefore, a few researchers studying proprioceptive ability and using different methods have found contradictory results. Barrack et al. tested joint position sense in ballet dancers using two tests measuring the threshold of perception of joint motion and the ability to reproduce a joint position [22]. They found that the dancers performed significantly worse than controls in their ability to reproduce the knee angle, but with better sensitivity to detection of passive motion. Kollarovits as well as Kollarovits and Gerhat pointed out that proprioceptive ability was very individual and too inconsistent to be measured when the examined athletes did not differ substantially from subjects who did not practice any sport [23, 24]. Jerosh et al. compared female table tennis players with a control group, and found no differences in the accuracy of reproducing movements at the elbow joint [25]. In the present study an average or high variability was found among the study participants in all groups - individual groups were non-homogeneous in terms of the results obtained for accuracy of reproduction. This individual variability may be typical of proprioceptive ability. It is characteristic that a high variability of results was found for most of tasks in all the groups.

Conclusions

1. Athletes, especially soccer players, performed better in the tests than untrained controls. Compared to the other groups, soccer players differed significantly in a few tests. This is likely to have been caused by the sport they were involved in, and it indicates the importance of this ability in soccer.
2. A non-significant improvement in proprioceptive ability was observed in all study participants in more than half tests repeated after six months. However, this was not supported with results of statistical significance. Nevertheless, an insignificant increase in accuracy of reproduction of pressure force and range of motion can be typical for the age of subjects, and it results from their biological development.
3. An average or high variability of results was found among the study participants in all groups, with individual groups being non-homogeneous in terms of the results attained for accuracy of reproduction. This individual variability may be typical of proprioceptive ability.

What this study adds?

The authors point out the role of proprioceptive ability in soccer. An important observation is that results of proprioceptive ability tasks are varied, which is probably typical of this ability, and depend on many factors, being fairly individual and inconsistent when measured.

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