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Reproduction of movement range and pressure force of the upper limbs in table tennis players

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Abstract

Introduction: Kinesthetic differentiation is frequently reflected in table tennis skills such as making an appropriate racket angle, adjustment of force and speed of arm movement upon hitting the ball, quick assessment of the arm position in reference to the ball, and making decisions about appropriate adjustments or changes. The level of kinesthetic differentiation of table tennis players should be fairly high. Aim of Study: The aim of this research was to assess and compare the accuracy of hand pressure force and range of supination – pronation reproduction in female table tennis players representing different sports levels, and in girls who did not practice table tennis. Material and Methods: The research was conducted on 32 female subjects: a group of table tennis players (*n* = 20) and a control group (*n* = 12). The subjects took part in six tasks aiming to demonstrate their levels of kinesthetic differentiation. Four of the tests enabled the assessment of accuracy of recreating pronation and supination of the forearm at the elbow joint. Two other tasks evaluated the force components and assessed the precision of recreating hand pressure force. Results: The precision indices for pronation performed with the dominant limb attained by the table tennis players were the lowest (i.e. the best) for those representing the highest sport level. The results of tasks designed to evaluate the ability of kinesthetic differentiation were slightly better for the table tennis players than for the control group. Conclusions: A statistically significant difference was observed only in supination of the dominant limb. This task may be specific to table tennis since the greater precision in the range of the dominant limb results from the use of the dominant arm in the game. The best results in supination of the dominant limb were obtained by the most advanced group of players with the longest training experience, which may indicate a correlation between kinesthetic differentiation and sports level in table tennis.

KEYWORDS: proprioception, kinesthetic differentiation, joint position sense, force sense, table tennis.

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What is already known on this topic?
An accuracy of movement during the performance of a motor task is possible due to the perception of force, time and space (acceptance and analysis of kinesthetic sensation). Many researchers have proven that the level of kinesthetic differentiation (proprioception) is related to motor learning. Many authors have also indicated the importance of kinesthetic differentiation in sports and reported an existence of a correlation between the level of kinesthetic differentiation abilities and success in different sports.

Introduction

The ability of kinesthetic differentiation is one of motor coordination abilities. In Hirtz's theory of hierarchical structure of motor coordination kinesthetic differentiation (along with spatial orientation) is considered to be a basic ability. It has been described by many authors as the main or most important ability which has an influence on the precise and economy of movement performance [1, 2, 3, 4]. The level of this ability is determined by three components: space, time and force, which contain information on the angular joint position, muscle tension and the speed of movement [5]. Accurate movements during the performance of a motor task are possible due to the perception of force, time and space (acceptance and analysis of kinesthetic sensation). Supported by sight or hearing kinesthetic differentiation enables an athlete to steer and regulate their movements [3, 5] and facilitates the accurate feeling of movement [6]. Results of kinesthetic differentiation and its evaluation discussed in many research studies focus on the comparison of its level between athletes and non-training individuals. Kiefer et al. [7] observed a high level of proprioception in ballet dancers, while Lephart et al. [8] noted a higher level of kinesthesia in gymnasts; Stefaniak [9] published similar results obtained by martial arts competitors; while Siu Ming Fong et al. [10] proved a higher level of proprioception in the knee joint area in taekwondo competitors. Many researchers have revealed that the level of this ability is related to motor learning [11, 12]. Many have also pointed out the importance of kinesthetic differentiation in sports and reported a correlation between the level of kinesthetic differentiation abilities and success in different sports. Such correlations have been revealed in ice skating [13], ice luge [14] and ice hockey [15]. According to many researchers the level of kinesthetic differentiation is varied, while its components (force, space, time) are fairly independent variables characterized by considerable individual instability reflected by differentiation which depends on many factors (motivation, concentration, etc.) [16]. Research on kinesthetic differentiation conducted on table tennis players and fencers showed a large diversification of the results in those two groups. The difference was, however, smaller than one observed in non-training individuals [17]. Kinesthetic differentiation and sensibility are both significant in such sports as table tennis [18, 19]. Kinesthetic differentiation is frequently reflected in table tennis skills such as assuming an appropriate racket angle, adjustment of force and speed of arm movement upon hitting the ball, quick assessment of an arm position in reference to the ball, and decision about appropriate adjustments or changes. It seems that the level of this ability should be high in those who practice table tennis. It should even increase along with development of sports skills, as described in studies on different sport disciplines. A confirmation of this assumption may provide further opportunities to apply methods assessing kinesthetic differentiation in the table tennis training process (control, monitoring, selection).

Aim of Study

The aim of this research was to evaluate and compare an accuracy of hand pressure force and range of supination-pronation reproduction in female table tennis players representing different sports levels and in girls who did not practice table tennis.

Material and Methods

The research sample consisted of 32 participants: 10 girls from the Polish national table tennis team (cadet category), 10 girls from the Lower Silesian regional team (cadet actegory), and 12 elementary school female students who did not train any sports. Table 1 presents subjects' characterisics.

Assessment of the level of kinesthetic differentiation was based on an evaluation of the accuracy of reproducing a previously determined range of movement and the value of a force [20, 21, 22].

The evaluation of the spatial components of kinesthetic differentiation indicated the subjects' ability to accurately reproduce a range of forearm pronation and supination to a 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 attached to a handle rotating on a Teflon bearing. The apparatus was fixed to a table. 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

Table 1. Characteristics of the examined groups: age, training length, body height and body mass

	Age		Training length		Body height		Body mass	
	$\overline{x}$	*SD*	$\overline{x}$	*SD*	$\overline{x}$	*SD*	$\overline{x}$	*SD*
Polish national table tennis team (*n* = 10)	14.0	1.1	7.7	1.2	162.4	4.8	55.7	4.8
Lower Silesian table tennis team (*n* = 10)	13.1	1.6	5.3	2.4	158.5	7.6	49.0	8.6
Control group (*n* = 12)	13.0	0.5	0.0	0.0	159.9	5.2	49.9	5.2

$\overline{x}$ – arithmetic mean; SD – standard deviation

(National Instruments, ver. 2009) and an NI USB 6008 analogue–to–digital converter (National Instruments). During each test a participant sat on a chair of adjustable height and held the apparatus 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 testing. 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), from the so-called neutral position (zero angle) and to the angle of 45 degrees. Upon reaching the 45 degree angle a loud buzzer was automatically activated. Immediately after that, the participants repeated the same movement five times, but this time from memory (blindfolded with no audio cue). Then, they performed same tasks with 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 the subject. The researchers controlled and adjusted the participant's starting position prior to each test. The time to make the five movements in each arm did not exceed 30 seconds. The level of kinesthetic differentiation was determined for both 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 considered for further analysis:

- PD (precision index: dominant limb – pronation)
- SD (precision index: dominant limb – supination)
- PND (precision index: non – dominant limb – pronation)
- SND (precision index: non – dominant limb – supination).

A lower precision index was considered an indicator of higher level kinesthetic differentiation ability (its spatial component).

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

Figure 1. Testing station for range of movement assessment – goniometer

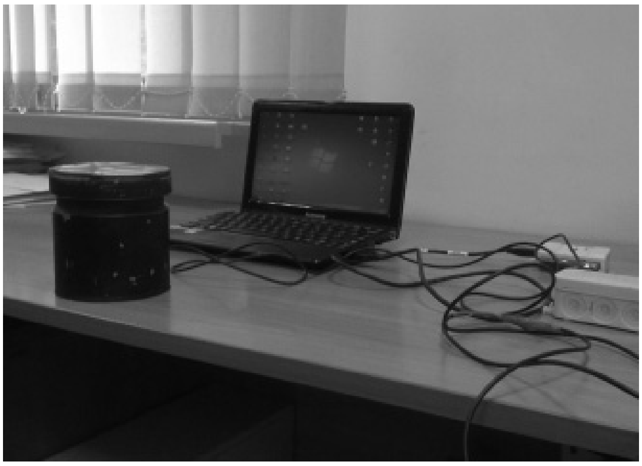

Figure 2. Testing station for assessment of reproduction of hand pressure force – dynamometer

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). Similar to the examination of spatial components, the subjects performed two tasks. They stood by the 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 buzzer was sounded. In the second session, the participants reproduced the pressure from memory five times with no audio cue. The following two indices were considered for further analysis:

- FD (precision index, pressure, dominant limb)
- FND (precision index, pressure, non-dominant limb).

Also, in this case, the researchers assumed that the lower values observed in the indices reflected a higher level of kinesthetic differentiation in reference to the force component.

The level of kinesthetic differentiation was assessed on the basis of six indices: four related to spatial, and two to force components. Statistical analysis of the results was performed with the use of Statistica for Windows. After descriptive statistics were calculated, the Kruskal-Wallis one-way analysis of variance and the Mann-Whitney U test were made to compare the examined groups.

Results

The subjects took part in six tasks aiming to demonstrate their levels of kinesthetic differentiation. Four of the tests referred to the so-called spatial components and enabled the assessment of the precision of recreating pronation and supination of the forearm at the elbow joint (to 45 degrees). The tasks were performed with both upper limbs. The next two tasks assessed the force components and the precision of recreating hand pressure force of the right and the left hand. As normal distributions were not found in all of the movements, further analysis was conducted with the use of non-parametric tests.

The precision indices for pronation performed with the dominant limb (SD – Figure 3) attained by the table tennis players were the lowest for those with the highest sport level and equaled 3.79 degrees, with a quartile deviation of 1.47 and variation coefficient of 33.8%. The highest median among the three groups was revealed in the group of tennis players from the Lower Silesian team and equaled 8.02, with a quartile deviation of 5.09 and coefficient of variation of 40.6. The SD median in the control group was 6.06, standard deviation 4.01, while the coefficient of variation was 51.03%, i.e. the highest.

The precision of reproduction of pronation (PD) was similar in all the groups (Figure 3). The median of the more advanced athletes was 4.24, quartile deviation of 3.17, and a coefficient of variation 47.91. The athletes from the Lower Silesian team were characterized by the following values: median PD – 9.91, quartile deviation – 2.8 and a very high coefficient of variation – 80.89%. Though the median was similar, the largest difference in all three groups was in the control group and equaled 5.66 with quartile deviation of 2.20 and coefficient of variation of 35.29%. Differences between these groups were also observed in tasks performed by the non-dominant limb, yet they were very small (Figure 3). The median values were similar in the case of supination (SND), and in the advanced group were 4.87 (deviation of 1.15 and a high coefficient of variation of 60.2%), 4.21 in the Lower Silesian team (deviation – 5.21 and a high coefficient of variation – 75.95%). The highest median was observed in the control group – 6.65 (deviation – 3.28 and the lowest coefficient of variation – 33.40%).

Analysis of the results of pronation of the non-dominant limb (PND) revealed the lowest median in the Polish national table tennis team, i.e. 44.41 (quartile deviation – 3.01, coefficient of variation – 50.32%). The Lower Silesian team were characterized by a median value of 6.84 (quartile deviation – 2.43, coefficient of variation – 37.97), and the control group scored 5.20 (quartile deviation – 3.38, coefficient of variation – 49.65%).

Analysis of the results of the reproduction of hand pressure force revealed slightly lower medians for the table tennis players compared to the control group (Figure 4). In the test of hand pressure force performed with the dominant hand (FD), the median for the Polish national team was 0.61 (quartile deviation – 0.53, coefficient of variation – 63.22%), the Lower Silesian team – 0.54 (quartile deviation – 0.44, coefficient of variation – 66.36%), and the control group 0.63 (quartile deviation – 0.64, coefficient of variation – 44.68%).

A slightly different distribution could be observed in the results of the test of hand pressure force reproduction of the non-dominant hand (FND). The median value of the Polish national team was 0.38, the Lower Silesian team – 0.78 (quartile deviation – 0.58, coefficient of variation – 59.32%), while in the control group it amounted to 0.62 (quartile deviation – 0.69, and a very high coefficient of variation of 93.78%).

Analysis of the median values in the six tasks revealed that the majority of the lowest values were observed in the most advanced table tennis group (FND, PND, SD). The control group did not obtain the lowest median value in any of the performed tasks. Interesting to note are the high values of the coefficient of variation observed in each task in each group, with the values between average and very high. The Kurskal-Wallis test results were used to determine a task to observe differences in the results between the groups. Only one

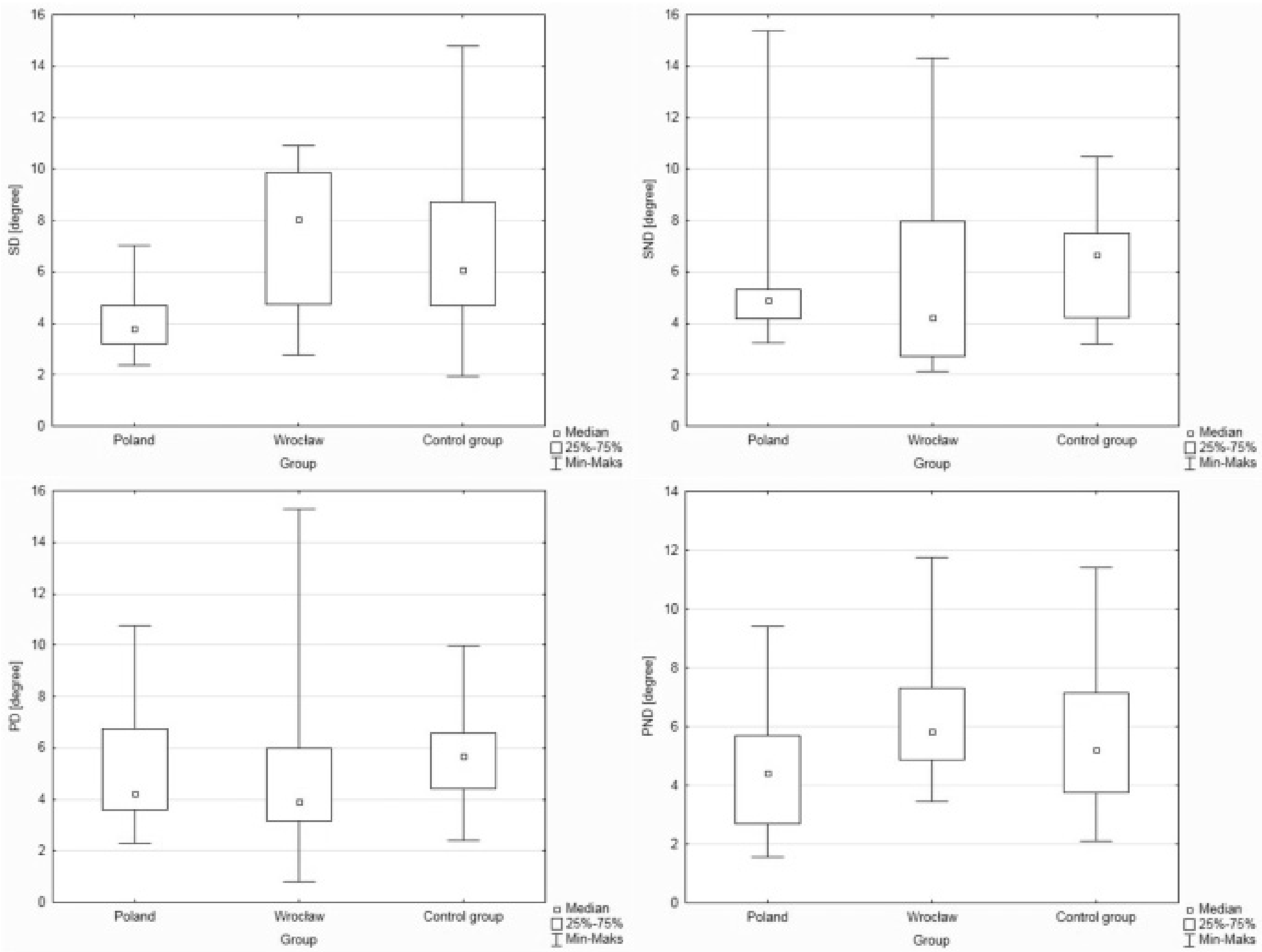

Figure 3. Reproduction of movement range results of the three groups

SD – supination - dominant limb, SND – supination - non-dominant limb, PD – pronation - dominant limb, PND – pronation - non-dominant limb

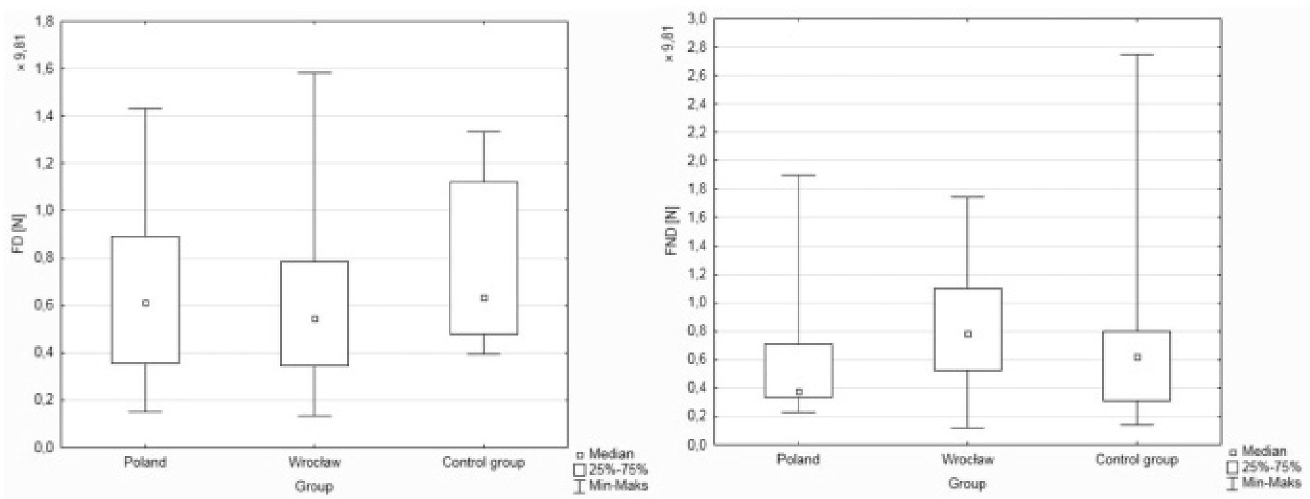

Figure 4. The results of reproduction of hand pressure force in the three groups

FD – force with the dominant limb, FND – force with the non-dominant limb task, the reproduction of supination with the dominant limb (SD), revealed a significant difference between the results of the three groups (Table 2).

Table 2. Results of the ANOVA Kurskal-Wallis test – assessment of differences between the three groups ($p \leq 0.05$)

	H	*p*
SD	7.86	**0.0196**
PD	1.87	0.3925
SND	1.58	0.4530
PND	2.56	0.2775
FD	1.21	0.5465
FND	1.57	0.4557

H – value of the test, *p* – p coefficient, SD – supination - dominant limb, SND – supination - non-dominant limb, PD – pronation - dominant limb, PND – pronation - non-dominant limb, FD – force - dominant limb, FND – force - non-dominant limb

The next step in the statistical analysis was the application of the Mann-Whitney U test, which was used to find differences between the groups in terms of reproduction of the range of movement and force. The test showed significant differences in the results of supination of the dominant limb (SD) only in two cases: between the Polish national team and the Lower Silesian team ($p = 0.014$), and between the Polish national team and the control group ($p = 0.027$). Such significant statistical differences were not observed between the Lower Silesian team and the control group. No statistically significant differences between the groups were observed in the other tests.

Discussion

Table tennis is a sport which requires good "feeling of the ball" and "feeling of the racket" which are quite clearly related to the ability of kinesthetic movement differentiation [3, 19]. However, there has not been much research on this issue in reference to table tennis. Previous studies conducted by the author indicated that the level of this ability may be significant in table tennis players [21, 23]. Nevertheless, kinesthetic differentiation has been subject to more extensive research. Its importance in sport as well as in everyday life has been emphasized by numerous researchers [4, 5, 24]. A comparison of kinesthetic sensitivity and kinesthetic differentiation between athletes and non-training controls has been conducted in many sport disciplines such as boxing, karate, ballet, ice hockey and others, and has indicated a higher sensitivity level in all the performing athletes [9, 25, 26]. Many authors have pointed out a higher kinesthetic sensitivity of the body parts which are most engaged in a given sports activity, for example, the upper limbs and hands in basketball players, lower limbs in monofin swimmers, and lower limbs in dancers [7, 27, 28, 29]. Boyara et al., when evaluating the arm position of tennis players and non-training individuals, found a higher level of proprioception in the former [30]. They also observed greater differences in sensing the position of the upper dominant and non-dominant limbs. The results of this study showed a statistically significant difference between the athletes and the girls who did not train table tennis only in one task: supination of the dominant limb at the elbow joint. This difference was observed in the higher level competitors who had been training for longer. Lower median values (which describe higher accuracy) were observed in all tests associated with force and range of movement reproduction in both table tennis groups (both groups at the same time in three tasks, one in the remaining three). It can be assumed that table tennis players obtained slightly better results in the accuracy of movement reproduction, which reflected their slightly higher level of kinesthetic differentiation of movement of the upper limbs compared to the control group. The observed differences were mainly characterized by a higher level of skills. It may result from the earlier selection of this sport. Perhaps the ability can be developed by specific table tennis training, which may be related to a concept described in literature as waking or refreshing kinesthetic sensitivity [24]. This process is also related to the level of proprioception and motor learning as described in some papers [11, 12]. This present study also demonstrated a difference in the accuracy of the reproduction of supination of the dominant limb between two groups of table tennis players. The results obtained by the Polish national team were better than those by the Lower Silesian team. Perhaps there is a correlation between practicing table tennis and sports skills. Such correlations have been observed in canoeists, judokas, and wrestlers. A significant increase in kinesthetic sensitivity noted by Starosta et al. in the athletes performing those sports was much greater in competition than in training [20]. Researchers also showed a higher level of differentiation of movement and kinesthetic perception in more advanced hockey players [15]. When examining figure skaters, Starosta found a mutual relationship between the level of kinesthetic sensitivity and athletic achievement [13]. Additionally, the results of the present study concerning more precise performance of supination of the dominant limb confirmed previous findings of the tests conducted on boys who practiced table tennis [23]. Better precision of the dominant limb probably resulted from its frequent use in competitive matches. The accuracy of forearm supination may also result from the specific character of table tennis. Researchers also presented different points of view on the kinesthetic sensitivity of table tennis players and their level of play. A comparison of table tennis players (and football players) with non-training individuals by Kollarovits and Gerhat indicated a lack of clear differences [31]. Li and Pan in their assessment of precision of reproduction and recognition of foot position in the ankle joint in Wushu, table tennis competitors and runners did not confirm any correlation between training for table tennis and proprioception at the ankle joint [32]. Those researchers confirmed a high level of sensitivity in the foot area in Wushu competitors. Differences between the results may be caused by the different methods used to evaluate the level of participants' abilities. Diversification of the results and opinions may be also related to the variability of results in individual kinesthetic differentiation. Kollarovits and Teplitzka pointed out little stability in a given ability, and the dependence of its level on many factors, e.g. motivation, momentary disposition, etc. [16]. The evaluation of the precision of force differentiation in joints of the lower limbs of football players conducted by Boraczyński and Zaporożanow indicated an individual kinesthetic level of both the examined subjects as well as evaluated indices in different joints [33]. Juras et al. found the complexity and heterogeneity of an ability reflected by the diverse results depended on its different components [34]. The present study was characterized by high values of coefficients of variation in the greater majority of tasks.

Conclusions

1. The results obtained from the tasks designed to evaluate the kinesthetic movement differentiation were slightly better for the group of table tennis players than those obtained by the control group. A statistically significant difference was observed only in supination of the dominant limb. This task may be specific to table tennis while greater precision in the range of the dominant limb results from its use in the game.
2. The best results in the above task (supination of the dominant limb) were obtained by the most advanced group (Polish national team) with the longest training experience, which may indicate a correlation between kinesthetic differentiation and sports level in table tennis players.

What this study adds?

This research indicated that table tennis players demonstrated a slightly higher level of ability of kinesthetic differentiation of movements of the upper limbs compared to the control group. However, a statistically significant difference was observed only in supination of the dominant limb. This task may be specific to table tennis while greater precision in the range of the dominant limb results from its use in the game. The research also points to a correlation between kinesthetic differentiation and sport level in table tennis.

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