Article

The Influence of Badminton on the Anterior Stability of the Knee in Badminton Players between 10 and 12 Years of Age

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Abstract: The anterior cruciate ligament (ACL) tear is a common injury in athletes and physically active people, for that reason it is a very interesting topic for orthopedics and physiotherapists. The ACL tear can lead to knee joint instability. There are two main mechanisms of the ACL tear that are described in the literature during which this injury occurs: landing after a jump and dynamic lunges. The purpose of this study was to evaluate the influence of badminton training on sagittal knee stability in young badminton players aged from 10 to 12 years old. Additionally, subjects were tested using the functional movement screen (FMS). One hundred sixteen children were included in this study. The study group consisted of 68 children, practicing badminton on a regular basis. The control group included 48 children who did not practice any sport. The results indicated that regular practice of badminton did not influence sagittal knee stability in youth players. It was also demonstrated that badminton training influences the final score in the FMS in badminton players. Additionally, based on the results of this study, there was a significant relationship between the FMS score and frontal knee stability. Considering these results, we can conclude that adequate motor preparation and badminton training have a beneficial effect on the stability of the knee joints in young badminton players.

Keywords: anterior cruciate ligament; badminton; arthrometry

1. Introduction

A high rate of anterior cruciate ligament (ACL) injury occurs during sports activity; about 70% of all ACL tears happens in noncontact mechanisms [1]. The most common circumstances of contactless injuries are landing after a jump or a sudden change in the direction of movement with the foot stabilised on the ground [2–4]. Sources also describe the activity of shearing forces as the body comes to a halt while the position of the joint is close to full extension [5]. A number of ACL injury risk factors are mentioned and can be divided into anatomic and structural, genetic, hormonal, neuromuscular, biomechanical, and environmental [6]. Exploring these interdependencies is particularly important for the process of planning and completing a rehabilitation programme, whether it is to prepare the patient for an ACL reconstruction, help them recover after surgery, or prevent an injury [7].

As Kimura et al. and Kurihara et al. show in their study, the knee injury risk factors described in the literature are present in badminton [1,8]. Motor system injuries in badminton constitute 5% of all sports injuries. Damage to the soft tissues of the lower extremities, usually connected with exertion, is the main cause of injuries in badminton [8,9]. Badminton is an individual and non-contact sport characterised by jumps, quick changes in the direction of movement, sudden, powerful, energetic movements of the dominant upper extremity in various planes as well as forward, backward and side lunges [10–12].

Although injuries in this sport are relatively rare when compared to other disciplines, the type of injury is usually serious and often requires long treatment and rehabilitation. Assessing motor behaviours often classified as movement patterns makes it possible to highlight abnormalities in the kinematic chain.

According to Shultz et al. and Alentorn-Geli et al. [7,13], fatigue reduces the efficiency of movement patterns and impairs the process of neuromuscular control. Furthermore, Sarshin claims that as fatigue progresses, the ability of badminton players to maintain proper dynamic posture control drops, which increases the risk of knee injury [14,15]. Joint sprains and ligament injuries in the lower extremities mainly affect younger badminton players, while muscle injuries are the most common in older players [12,16].

According to the statistical data of Kimura et al. [1], 37% of all badminton injuries are knee ACL injuries. The literature primarily describes two ACL injury mechanisms for badminton players. The first one and most common one is landing on one lower extremity after hitting the shuttlecock above the head. This affects the lower extremity on the opposite side of the dominant upper extremity (the one holding the racquet). The other mechanism involves a backward lunge and a side lunge. In this case, it is the lower extremity on the side of the dominant upper extremity that is injured [1,11,15]. A recommended method to minimise these risk factors is proper education and teaching related to the basics of motor training [17,18].

Early detection of potentially reduced knee stability could make it possible to launch a programme of preventive actions to minimize the risk of knee instability and of complete damage to the anterior cruciate ligament (ACL).

The purpose of this study was to define the impact of playing badminton on the anterior stability of the knee, measured by arthrometer. An additional purpose was to assess subjects using the full functional movement screen (FMS) protocol. The results of this study may be significant in the professional work of badminton coaches, orthopaedists, physical therapists, and motor training coaches.

2. Materials and Methods

2.1. Materials

A total of 116 participants were included in the study. The age of the participants was about 10 or 11 years of age at the time of joining the experiment.

The experimental group ($N = 68$) consisted of athletes who regularly and professionally trained at badminton (at least 5 times a week). At the beginning of this study, they had been practicing badminton for a maximum period of three months.

The control group ($N = 48$) was selected among physically active youth (e.g., participation in physical education lessons, outdoor extracurricular activities), but not regularly practicing any sports discipline in a professional manner. None of the study participants had a knee injury in the past.

The groups were homogeneous in terms of gender (approx. 48% of women and approx. 52% of men). Both groups were also characterized by similar body weight and height, with the experimental group having a slightly higher body height and lower body weight. Height, weight, and body mass index (BMI) differed statistically in the studied groups ($p > 0.05$). Demographic data are presented in Table 1 (measurements were taken at the beginning of the experiment). The guardians of the study participants gave their written consent for participation in the experiment.

Table 1. Demographic data.

Variable	Experimental Group (*N* = 68)	Control Group (*N* = 48)	*p*
Gender			
Boys	32 (47.1%)	23 (47.9%)	
Girls	36 (52.9%)	25 (52.1%)	0.927
Age [1]	10.2 ± 0.4	10.4 ± 0.5	0.999
Body height (cm)	143.6 ± 3.4	141.5 ± 4.2	0.010 *
Body weight (kg)	39.2 ± 1.4	43.9 ± 3.5	0.001 *
BMI (kg/m^2)	17.9 ± 0.6	20.1 ± 1.6	0.001 *

*—statistical significance ($p < 0.05$); [1]—the average age of the subjects at the time of entering the experiment.

The study design was approved by the Research Bioethics Committee of the Academy of Physical Education in Katowice—resolution no. 6/2016 dated 10 March 2016 as regards opinion on medical experiment design.

2.2. Methods

Every project participant underwent arthrometry and a test for the quality of movement patterns according to the functional movement screen, both tests twice, with a twelve-month interval between them.

FMS is a movement-competency-based test aimed to provide a clinically interpretable measure of movement quality. The FMS protocol is based on 7 motor tasks, following the order described by the creators of the method: 1. "Deep squat", 2. "Hurdle step", 3. "Inline lunge", 4. "shoulder mobility", 5. "Active straight-leg raise", 6. "Trunk stability push up", 7. "Rotary stability".

The first performed examination was arthrometry, with the use of the GNRB arthrometer, to verify the efficiency of the ACL, which is directly related to the anterior stability of the knee joints. The individual trials were named as follows: Frontal Stability 1 (first test) and Frontal Stability 2 (test after 12 months). Then, after arthrometry, seven motor tasks were assessed using the FMS functional evaluation system. The functional assessment trials were named FMS 1 (first test) and FMS 2 (test after 12 months).

An arthrometer is an objective diagnostic tool (Figure 1) used for the quantitative assessment of anterior knee stability and, as such, makes it possible to diagnose anterior cruciate ligament injury [19]. During arthrometry, the tibia is translated against the femur in the sagittal plane and the device records the size of that translation in a numerical form (mm) and as a chart. The result is interpreted based on the difference between the values of the tibia translation as measured for both lower extremities. The difference between the size of translation in the right leg (translation R) and left leg (translation L) is a stability index.

Figure 1. An arthrometer as an objective diagnostic tool.

A stability index above 3 mm may point to complete ACL damage and to substantial anterior instability of the knee. Additionally, a 1.5 mm difference threshold has been adopted as indicative of partial ACL impairment and thus to reduced anterior stability of the joint. Values below 1.5 mm are treated as normal. A graphic representation of the arthrometry results suggesting complete anterior cruciate ligament injury is presented in Figure 2.
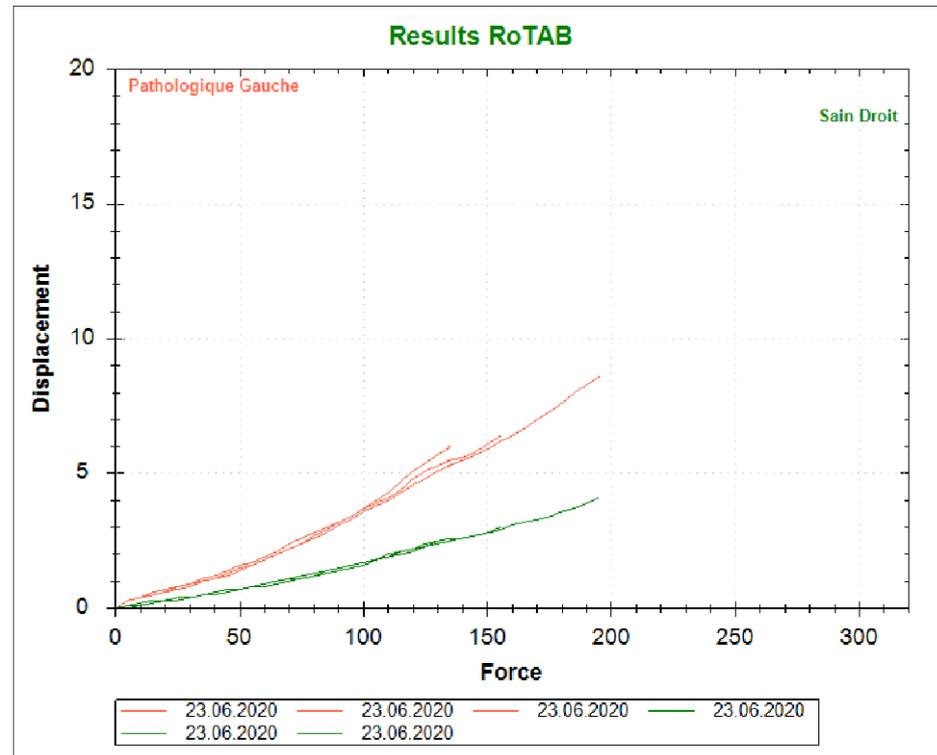

Figure 2. Arthrometry results suggesting complete anterior cruciate ligament injury.

2.3. Statistical Analysis

The normality of distributions was assessed by using the Shapiro–Wilk test. Most of the variables have a non-normal distribution therefore the non-parametric tests were used. Basic statistical measures, i.e., arithmetic mean, standard deviation and median were calculated. Differences between experimental and control groups were evaluated by the U Mann–Whitney test. The significance of changes between measurement I and II was determined using the Wilcoxon test. Relative (II-I %) and absolute (II-I) increases were calculated for each variable. The analysis of the relationships between individual variables was measured using the Spearman's rank correlation, while the character of the relationships was determined using forward selection regression. The analysis was performed with the GNU R (General Public License GPL) software and Statistica 13 (StatSoft, Kraków, Polska).

3. Results

Table 2 presents the results of the tests carried out on the arthrometer and the results of the FMS test.

Table 2. Results of arthrometer test and functional movement screen test.

Variable	Measurements	Experimental Group (N = 68)					Control Group (N = 48)					*p* (E-C)	r (E-C)
		M	SD	Me	*p* (I-II)	r (I-II)	M	SD	Me	*p* (I-II)	r (I-II)		
Translation R	I	7.48	1.89	7.25	0.309	0.12	6.84	1.75	6.80	0.010 *	0.37	0.120	0.14
	II	7.44	1.67	7.10			7.33	1.55	7.45			0.864	0.02
Translation L	I	7.26	1.96	7.20	0.415	0.10	6.99	1.54	7.15	0.066	0.27	0.497	0.06
	II	7.61	1.56	7.60			7.25	1.36	7.15			0.250	0.11
Stability index	I	1.00	0.93	0.70	0.015 *	0.29	0.73	0.59	0.60	0.757	0.04	0.213	0.12
	II	0.82	0.93	0.50			0.73	0.51	0.60			0.550	−0.06
FMS	I	14.21	1.96	14.00	0.006 *	0.33	13.38	1.91	13.50	0.0001 *	0.61	0.045 *	0.19
	II	14.60	2.10	14.00			14.15	1.86	14.00			0.210	0.12

*—statistical significance ($p < 0.05$); I—initial measurement; II—measurement measurement at the end of the experiment; M—mean value; SD—standard deviation; Me—median; *p* (I-II)—Test probability for the difference between Measurement I and Measurement II; r (I-II)—effect size for *p* (I-II); *p* (E-C)—Test probability for the difference between experimental and control groups; effect size for *p* (E-C).

The analysis shows that for individual translations (Translation R and L) in the experimental group, no significant changes ($p < 0.05$) of these parameters were observed under the influence of the training applied. In the case of the control group, there is a significant difference for the right limb (Translation R), which is about 0.49 mm. For both translations in measurements I and II, no significant differences were observed between the experimental and control groups.

When analyzing the results of the stability index, there is a significant difference (0.18) in the experimental group ($p < 0.05$). From the value of 1 mm, this index drops to the value of 0.82 mm, which shows the positive effect of the applied training on the stability of the lower limbs. It is significant that such a situation was not observed in the control group.

The performed FMS test showed a significant difference (0.83) in the scores between the experimental group and the control group in measurement I. The experimental group obtained more points in measurements I (14.21) and II (14.60) compared to the control group (I—13.38 and II—14.15). Within both groups, there was a statistically significant ($p < 0.05$) increase in the number of points in measurement II compared to measurement I.

Table 3 shows the Spearman correlation coefficients between the arthrometer results and the FMS score.

Table 3. Correlation coefficients between arthrometer test and FMS test.

	Measurement I			Measurement II			Stability II-I	Stability II-I (%)
	Translation R	Translation L	Stability	Translation R	TranslationL	Stability		
Experimental group (N = 68)								
FMS I	0.09	0.06	0.02	0.10	0.09	−0.10	−0.07	−0.17
FMS II	0.19	0.24 *	0.01	0.13	0.19	−0.04	0.00	−0.09
FMS II-I	0.14	0.32 *	−0.05	0.05	0.14	0.14	0.22	0.23
FMS II-I (%)	0.13	0.30 *	−0.06	0.04	0.13	0.14	0.23	0.25 *
Control group (N = 48)								
FMS I	−0.23	−0.26	0.09	−0.08	−0.26	0.18	0.08	0.04
FMS II	−0.13	−0.18	0.04	0.01	−0.16	0.21	0.12	0.08
FMS II-I	0.23	0.11	−0.05	0.11	0.04	0.04	0.05	0.05
FMS II-I (%)	0.29 *	0.17	−0.05	0.16	0.10	0.02	0.04	0.05

*—statistical significance ($p < 0.05$); R—right, L—left; II-I –difference between measurement I and II; II-I (%)—percentage difference between measurement I and II.

For the FMS and Stability variables, the correlations between relative and absolute increases were additionally calculated. The analysis shows that there are statistically significant ($p < 0.05$) relationships between the translation of the left limb and the results of

the FMS test in the second measurement, as well as relative and absolute increments in the FMS scores. These relationships are positive and weak (0.24, 0.32 and 0.30).

In the control group, only one significant relationship is observed, the strength of which is also at the level of 0.29. This relationship exists between translation R and the percentage (relative) increment of the FMS test.

In the experimental group, there is also a significant relationship between the relative increase in stability and the relative increase in the FMS test (0.25; $p < 0.05$). The significant fact is that this relationship is observed only in the experimental group, no such relationship is observed in the control group.

The analysis of the relationship between the height, body weight, and BMI did not show any statistically significant relationships with the increases in stability and FMS (Table 4).

Table 4. Correlation coefficients between body weight, body mass, BMI and stability, and FMS test.

	Body Height (cm)	Body Weight (kg)	BMI
Experimental group			
Stability II-I	0.10	−0.04	−0.04
Stability II-I (%)	0.04	0.00	0.00
FMS II-I	0.05	0.15	0.15
FMS II-I (%)	0.05	0.15	0.15
Control group			
Stability II-I	−0.21	−0.01	−0.01
Stability II-I (%)	−0.22	−0.03	−0.03
FMS II-I	−0.18	−0.03	−0.03
FMS II-I (%)	−0.20	0.00	0.00

II-I—difference between measurement I and II; II-I (%)—percentage difference between measurement I and II.

The next stage of the analysis was a particular assessment of the influence of age, body weight, body height, gender and increase FMS (II %) on the increase in stability for experimental group. The analysis shows that the only variable that models the increase in stability is the variable describing the increase in points in the FMS test. The calculated regression model is characterized by a relatively low determination $R^2 = 0.016$. The calculated model has the form:

$$\text{Stability II} - \text{I} \,(\%) = 0.24 + 0.025 * \text{FMS II} - \text{I} \,(\%); R^2 = 0.016 \qquad (1)$$

Equation (1) Calculated regression model.

4. Discussion

The first hypothesis in this study, that regular badminton practice reduces the anterior stability of the knee joints in badminton players between the ages of 10 and 11, was not confirmed. During the period of our research, the group of subjects did not experience any trauma causing damage to the ACL and the stability of the knee joints did not decrease in the subjects. It can even be observed that practicing badminton on a regular basis in the training macrocycle increased the frontal stability in the group of subjects. When analyzing the results of the stability index, there is a significant difference in the experimental group ($p < 0.05$) between the first and second tests, which shows the positive effect of the badminton training on the anterior stability of the knee joint. It is significant that such a situation was not observed in the control group.

Based on the literature review, it can be presumed that improved stability of the knee joints is most likely due to the improvement of the neuromuscular control of the trunk and lower limbs as a result of regular badminton training [20–22]. There is a strong correlation between extensors, abductors and external rotators of the femur and the injuries of the ACL. Researchers claim that disturbed work of these muscles can cause valgus of

the knee joints during dynamic movement with load, which contributes to the damage of the ACL [4,23,24]. The muscles acting on the knee joint can also affect the anterior cruciate ligament by increasing or reducing its tension. For example, the quadriceps muscle of the thigh generates forces that act in opposition to the ACL, increasing its tension, which is associated with overloading and the risk of damage to the ACL [25]. On the other hand, the group of hamstring muscles supports the work of the ACL, reducing its tension. This is confirmed by the studies of Fleming et al. [26], Alentorn-Geli et al. [13], and Blackburn et al. [27], according to which it is a group of muscles that interact with the ACL, preventing excessive forward shift of the tibia. Taking into account the results of the research by Sarshin et al. [14], muscle fatigue during training affects the dynamic control of posture, which may be associated with an increased risk of knee joint injury. Movements which were examined in this study were lunges which are similar to the movements performed during a badminton game.

Our second assumption was that practicing badminton on a regular basis affects the functional assessment of badminton players between the ages of 10 and 11. Analyzing the data on the value of functional assessment, it can be observed that the results showed an upward trend in the group of girls and boys after the training macrocycle. There was a statistically significant ($p < 0.05$) increase in the number of points in the functional assessment in measurement II compared to measurement I. It is worth noting that the movement pattern, which is the squat, improved by 1 point on the 0–3 scale in the majority of people in the study group. This is significant progress in performing this particular motor task, which positively influences the overall result of the assessment. Training programs run by sports clubs can therefore increase the stability and neuromuscular control of the hip, knee, ankle, and torso joints.

Similar trends were observed in the studies by Adamczyk et al. [28] and Zahradnik et al. [29]. In our opinion, the squat, due to the complexity of the movement and its functionality, is an important element of the FMS assessment. The squat pattern gives us information on joint mobility, trunk stability and the alignment of the knee joints in motion, which are indirectly related to the mechanisms contributing to the increased risk of knee joint injuries [30]. Subsequent studies have also shown that FMS results can be improved with the right correction program [31].

The results of our research indicate that the test of arm bending in the front support ("push-up") was the weakest in the group of subjects and the control group. As Rzepka writes [32], this test requires the strength of the upper limbs and the shoulder girdle and high stability of the torso. This test caused many difficulties in the study group and the control group. It is worth noting that the low result of this test significantly reduces the overall FMS score.

Our third assumption was that the FMS result is related to the anterior stability of the knee joints in badminton players between the ages of 10 and 11. In the experimental group, there is a significant relationship between the stability index and the result in the FMS assessment. The significant fact is that this relationship is only observed in the experimental group. In our study, 39 people from the test group had a score of ≤14 points. The FMS assumes that a score of ≤14 increases the risk of injury [33]. During the period of our research, no injury was found in any competitor, there was no partial or complete damage to the ACL, which is related to the anterior instability of the knee joint. On the other hand, better anterior stability of the knee joints was observed in people who obtained more points in the FMS assessment. This is most likely related to better neuromuscular control in people who scored better on FMS. As the researchers write, FMS gives results that help to determine the asymmetries of the left side of the body to the right, disorders of the movement apparatus, such as mobility of peripheral joints or trunk stability, which are associated with an increased risk of injury. Yildiz et al. write that FMS can be an effective tool for testing the stability and mobility level of children and adolescents aged 10–17 [34]. The FMS can provide a wealth of information on the physical fitness of young athletes. These studies also assessed the functional tasks of FMS and their impact on the athletic

performance of 10–12-year-old tennis players. On the basis of 28 subjects, it was found that FMS is a good tool for showing the abnormalities of the movement apparatus in children. According to the researchers, thanks to the conclusions drawn from the FMS assessment, corrective exercises can be implemented to reduce the risk of injuries later in life [34].

Our research shows that there are no statistical differences in terms of the analyzed variables between boys and girls. The analysis of the relationship between height, body weight, and BMI also did not show any statistically significant relationships. Scientific evidence shows that women have a higher injury rate than men. Such variability is observed from an early age. There is research showing that muscle strength and muscle activation may pose a greater risk of injury in girls than in boys. As Shultz et al. write [18], the stability of the knee joint is not the same in different directions and planes of movement and may partially depend on the age of the respondents, body composition and weight, muscle strength and anatomical conditions of the lower limbs in women and men. Shultz et al. showed in their studies that greater valgus of the knee joints in women can be largely explained by the anatomical conditions of the hip joint [18]. The literature review conducted by Kuszewski also confirms that women are 2–3 times more likely to suffer knee injuries than men [35]. The most common knee injuries affect women who play basketball, handball, and football. Damage to the ACL usually occurs during the so-called "feint". One of the reasons for this fact is a slightly different structure of muscle tissue and the related stabilization mechanisms. In men, greater muscle stiffness is observed, which gives better control of displacement in the joint. In women, on the other hand, the joints are more flaccid due to more flexible muscles, which favors the creation of greater loads on the ligamentous apparatus.

Another important feature that may have an impact on the damage to the ACL is age. Flynn et al. used arthrometry to investigate the stability of the knee joints in healthy children aged 6 to 18 years [36]. There were no statistical differences in the stability of the knee joints between boys and girls a similar age. The researchers found that the laxity of the knee joints was greater in younger children than in older children. Based on their research, Mouton et al. concluded that the stability of the knee joints was not significantly influenced by any of the individual characteristics of the examined persons, e.g., body weight and height [37]. There were no significant differences in the frontal stability of the knee between women and men. These studies therefore suggest that gender does not affect the passive stability of the knee joints.

The impact of increased effort and fatigue on the change in the anterior stability of the knee joints was studied by Shultz et al. [38]. It was found that the training that led to fatigue did not alter the anterior stability of the knee joints. On the other hand, it has been found that lower limb muscle fatigue affects landing mechanics in both women and men. In women, fatigue resulted in greater valgus movement and a smaller hip flexion angle, as well as a lower dorsiflexion angle in the ankles. In men, however, no significant increase in knee valgus was observed, while the angle of flexion in the hip and ankle joints increased, which resulted in an increased load on the quadriceps muscle of the thigh. In the research of Anderson et al. it was noted, however, that women obtained fewer points in the FMS assessment compared to men [39]. The difference was caused by a much worse performance of bending arms—"push-ups"—in the group of girls. We are aware that a larger number of subjects would bring us to clear, objective conclusions. More research is essential. In our opinion, a longer period of testing the respondents is also advisable in order to better show the tendency of the final results.

5. Conclusions

There are many factors that can reduce the risk of knee injuries and anterior cruciate ligament injuries, and one of the most important factors is proper muscle and nerve control. Therefore, it can be concluded that adequate motor preparation and badminton training have a beneficial effect on the stability of the knee joints in young badminton players.

In our opinion, the multitude of benefits of badminton should be used to promote not only this sport discipline but above all general physical activity among children, which improves health and maintains well-being and high self-esteem.

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