

## Determination of loading strategies during landing in badminton

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### Abstract

**Background:** Evaluation of biomechanical factors like joint torques plays an important role in the treatment and prevention of injury.

**Purpose:** The aim of this study was to investigate the biomechanics of backhand, short serve and smash in order to identify the effect of these movements on the lower limb joint kinetics.

**Materials and Methods:** The study group comprised of 20 healthy men from various badminton clubs. Examinations of the kinematic and kinetic parameters of analyzed movements were carried out using Vicon system and Kistler force plates. K-means clustering method was used in order to find the motion that differentiates between the athletes studied the most. Classification trees were used to predict membership of cases or objects in the classes of a categorical dependent variable from their measurements on one or more predictor variables.

**Results:** Compared to human gait, the mean maximum values of ankle, knee and hip torques measured for backhand, short serve and smash are higher by from 132% to 688%. The results obtained in this experiment revealed the highest loading to the motor system in the areas of knee joints during backhand and in the ankle joint during smash.

**Conclusion:** We were unable to isolate the joint loading strategies during performance of individual elements of badminton playing technique.

**Keywords:** backhand, injury, joint torque, smash, short serve.

### Introduction

Racquet sports have been known to cause frequent joint injuries, suggesting that the joint loads during play may be excessive. The lower limb is a primary injury site, with an increased injury risk when the level of playing skills increases (Murphy et al., 2003). Foot, ankle and knee are recognized as the most common sites for the development of overuse as well as acute injuries including sprains, strains and tears (Caine et al., 1996). According to (Nigg, 1985), mechanical loading can have both positive and negative effects on the musculoskeletal system. The positive effects include the strengthening of the muscles due to moderate overloading with adequate rest periods, while negative effects include structural damage that may ultimately lead to injury. Despite the established concept of a relationship between biomechanical variables and injuries, which include stress fractures, shin splints, tendonitis or fasciitis, the exact causes that lead to overuse injury have yet to be determined (Hreljac et al., 2000). Repetitive tissue micro-trauma and overloading due to repetition of a specific movement have been cited as causes for the development of overuse injury (Kaderet al., 2002; Kvist, 1994). Consequently, ground reaction forces, torques and power during repetitive tasks, particularly running and jumping; have been studied as contributors to overuse injury development (Bates et al., 2013; Buczek et al., 1990; Scott et al., 1990). These studies provide insight into the functional significance of the joints of the lower limbs, highlighting the contribution of the ankle and knee, and provide a framework for the cause and effect relationship between motion and injury by quantifying peak loads. It seems obvious that the

evaluation of biomechanical factors plays an important role in the treatment and prevention of injury. Research in racket sports has tended to ignore the lower limb in favour of the upper limb. However, the actions used (e.g. side-stepping, jumping) generate unusual force profiles that can influence both performance and injury. Therefore, the aim of this study was to investigate the biomechanics of backhand, short serve and smash in order to evaluate the loading of these movements on the athlete based on muscle torques in the joints of lower limbs.

## Material and Methods

### Participant recruitment and preparation

Twenty healthy male participants were recruited from the badminton clubs, with mean age of  $24.5 \pm 6.2$  years, height of  $1.82 \pm 0.77$  m and body mass of  $76.8 \pm 6.1$  kg. The participants were previously involved in national service and playing badminton for at least three years. All participants signed informed consent forms before participation, in accordance with the guidelines of the University's Institutional Review Board.

### Instrumentation and data collection

Three force-plates (Kistler, Winterthur, CH), embedded into the floor, were used to determine GRF data at the sampling rate of 1000 Hz. A motion capture system (Vicon MX, Oxford, UK) consisting of eight infra-red cameras was employed to collect kinematics data at the sampling rate of 100 Hz. The force plates were synchronized to the motion capture system; both systems were calibrated according to the manufacturers' recommendations before the tests were conducted. Thirty four reflective markers (25 mm in diameter) were attached to the participant's body according to the PlugInGait-FullBody standards available within Vicon system. Each subject performed a natural motion of backhand, short serve and smash. The tests were repeated three times and the analysis was carried out based on the attempts without any random mistakes, with the individual performing the task naturally.

### Statistical analysis

Kinematic and kinetic data of backhand, short serve and smash were obtained from Vicon system. A detailed motion analysis was focused on the external joint torques in dynamic and static conditions normalized to body mass in the sagittal plane. In order to obtain general classification of joint loading during performance of backhand, short serve and smash, maximum peaks of muscle torques were taken into account.

In order to make more detailed analysis of loading, the surface areas under the curves of joint torques during landing were calculated. Calculations were performed using trapezoidal numerical integration in MatLab 7.0 (MathWorks, USA) in time domain. Calculations were conducted for the joints of right and left lower limbs. Higher values were exported to the Statistica 8.0 (StatSoft, PL).

Based on the calculated areas surface, the k-means clustering method was used in order to find the motion that differentiates between the athletes studied the most. The procedure follows a way to classify a given data set through a certain number of clusters. The number of clusters was chosen automatically by the software. The main idea is to define  $k$  number of centroids (one for each cluster) in a way that the centroids are placed as far from each other. The next step is to take each point belonging to a given data set and associate it to the nearest centroid. The program move objects between those clusters with the goal to minimize variability within clusters and maximize variability between clusters. The clustering method uses Euclidean distances between objects when forming the clusters.

In next step a classification tree method was used in order to isolate loading strategy for joints of lower limbs during landing for three exercises. Classification trees were used to predict membership of cases or objects in the classes of a categorical dependent variable from their measurements on one or more predictor variables. Furthermore, in order to select the motion which particularly exposed the athletes to the risk of lower limb overload, the muscle torques under static conditions were calculated. External joint torques in the ankle and hip joints were calculated for each player in the sagittal plane, under static conditions using the following formula (Wychowański, 2008):

$$M = a \cdot m + b \quad (1)$$

Where:  $m$  denotes body mass [kg];  $a$  and  $b$  are coefficients of the regression equation (Table 1).

**Table 1: Coefficients used for calculation of external joint moments in the sagittal plane (static conditions) in the ankle and hip joints according to (Wychowański, 2008)**

Joint	Movement	a	b
Ankle	Dorsiflexion	0.947	-8.421
	Plantar flexion	1.671	56.112
Hip	Extension	2.786	85.911
	Flexion	1.584	130.059

However, in order to calculate the knee torque, a polynomial was used:

$$M = b_0 + b_1 \alpha + b_2 \alpha^2 + b_3 \alpha^3 + b_4 (m - m_m) + b_5 \alpha (m - m_m) + b_6 \alpha^2 (m - m_m) + b_7 \alpha^3 (m - m_m) \quad (2)$$

where:  $m$  is body mass [kg],  $\alpha = 90^\circ$ ,  $m_m$  is mean body mass in the group and  $b_0 \dots b_7$  are coefficients (Table 2).

**Table 2: Polynomial coefficients used for calculation of the external joint moments in the sagittal plane (static condition) in the knee joint according to (Wychowański, 2008)**

	Flexion	Extension
b0	1.6391e + 02	1.56966667e + 01
b1	-8.57407407e - 02	3.46513536e + 00
b2	-6.21851852e - 03	-9.79003527e - 03
b3	3.53909465e - 06	-7.67626886e - 05
b4	1.83033505e + 00	6.06353292e - 01
b5	5.26262521e - 02	7.81243737e - 02
b6	-1.14292691e - 03	-1.44523788e - 03
b7	5.9200465e - 06	9.13499972e - 06

The area bounded by the curves of external joint moments in static and dynamic condition in time domain was calculated for backhand, short serve and smash. The calculations were performed as previously, using the trapezoidal numerical integration, for the right and left lower limbs. Higher values were exported to the Statistica 8.0. The Shapiro-Wilk test was used in order to verify whether the values of the differences in muscle moments under static and dynamic conditions did not differ from normal distribution. The results obtained were analysed using median and quartiles.

### Results

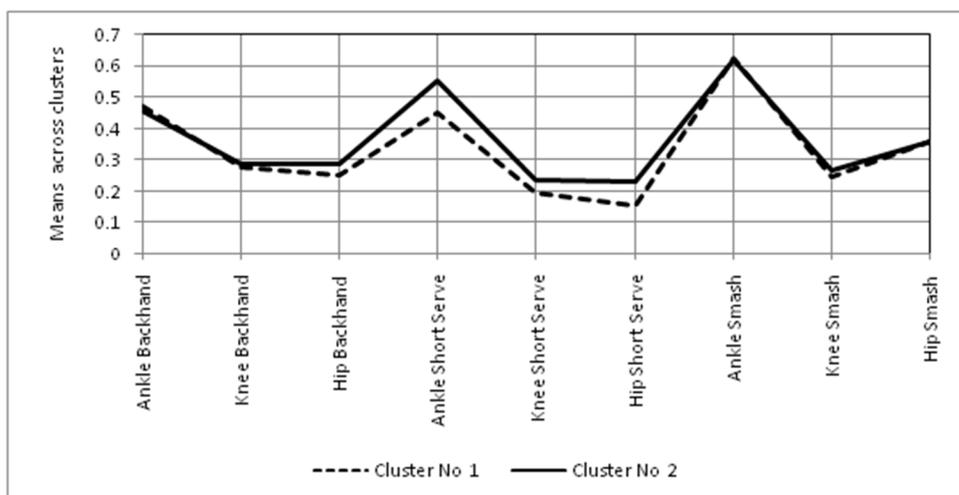
The mean values calculated from the highest torque peaks during landing for backhand, short serve and smash in the sagittal plane for the group of badminton players are presented in Table 3.

**Table 3: Average maximum peak torque (Nm/kg) for backhand, short serve and smash in the sagittal plane**

Joint	Backhand	Short serve	Smash
Ankle	1.98	2.4	3.7
Knee	1.99	2.14	2.26
Hip	1.73	1.5	3.44

The highest values were observed for smash in all the joints of lower limbs, followed by short serve, whereas the lowest values were found for the backhand movement. It is also noticeable that the peak values in the hip joint are considerably lower in backhand and short serve, whereas they rise substantially for smash. This means that all the joints in this movement are significantly more loaded, with particular focus on the hip joint.

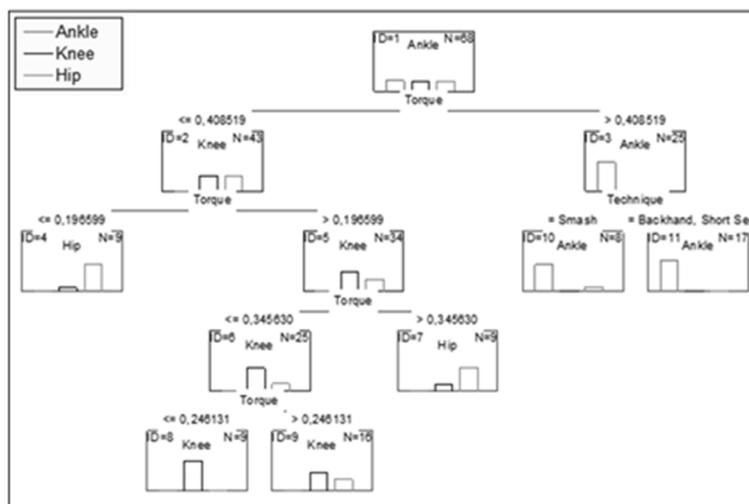
When attempting to identify other differences in loading during performance of three different technical elements in badminton, we analysed the surface area under the curve of muscle moments at landing in individual elements of badminton playing technique. Figure 1 presents the result of grouping athletes using cluster analysis.



**Figure 1: Division of the athletes playing badminton according to the criterion of the value of areas under the curves of muscle moments at landing in three joints of lower limbs during performance of three technical elements**

The data presented in Figure1 reveal two subgroups of the athletes studied, with the main element that differentiates athletes being the smash technique. The numbers in cluster 1 and cluster 2 are 14 and 6, respectively.

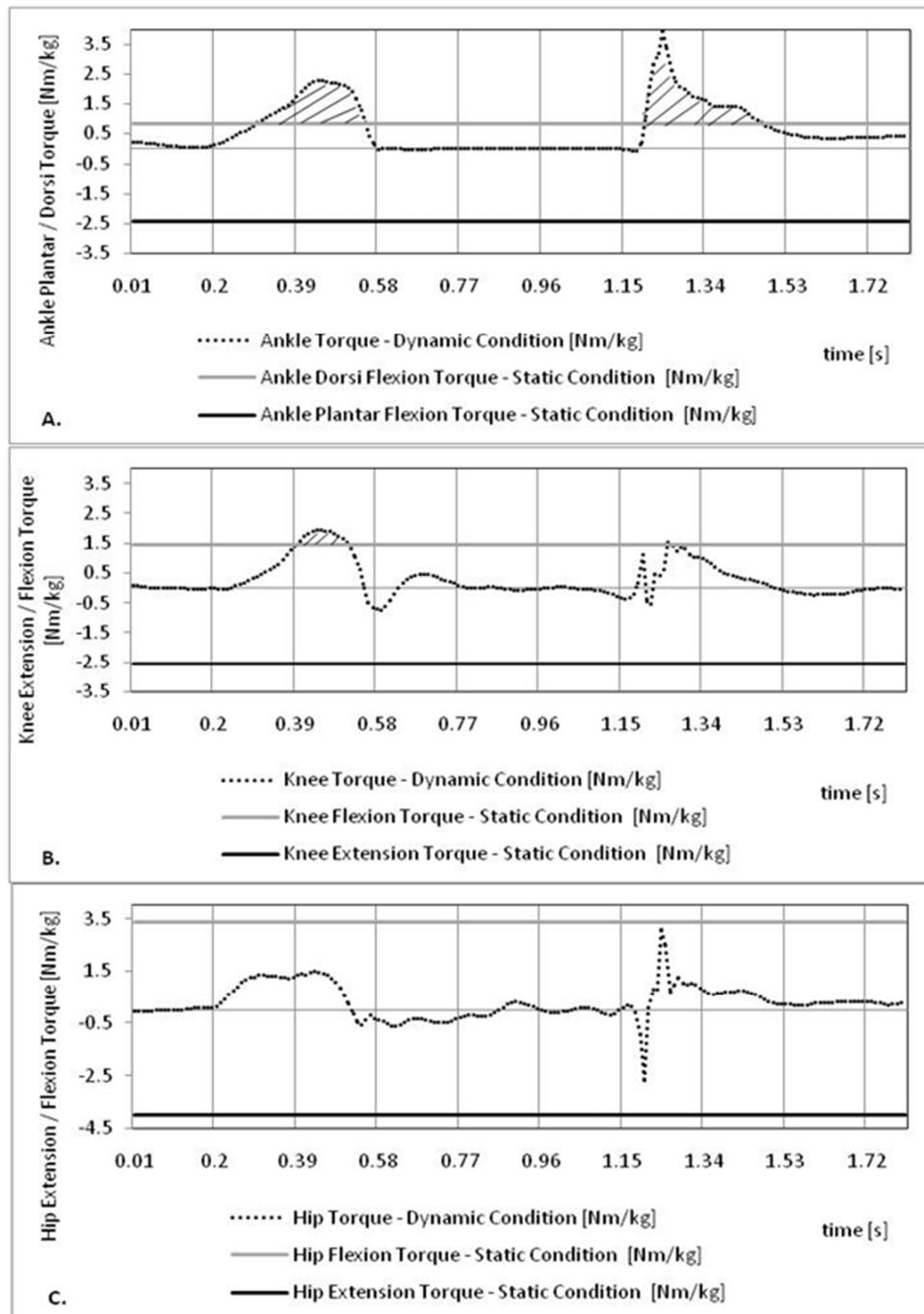
Furthermore, we used the procedure of the classification tree identification to identify the strategy types in distribution of loading in the joints of lower limbs during performance of basic elements of badminton playing technique.



**Figure 2: Classification tree for the values of areas under the curves of muscle moments at landing in the joints of lower limbs during performance of three elements of badminton playing**

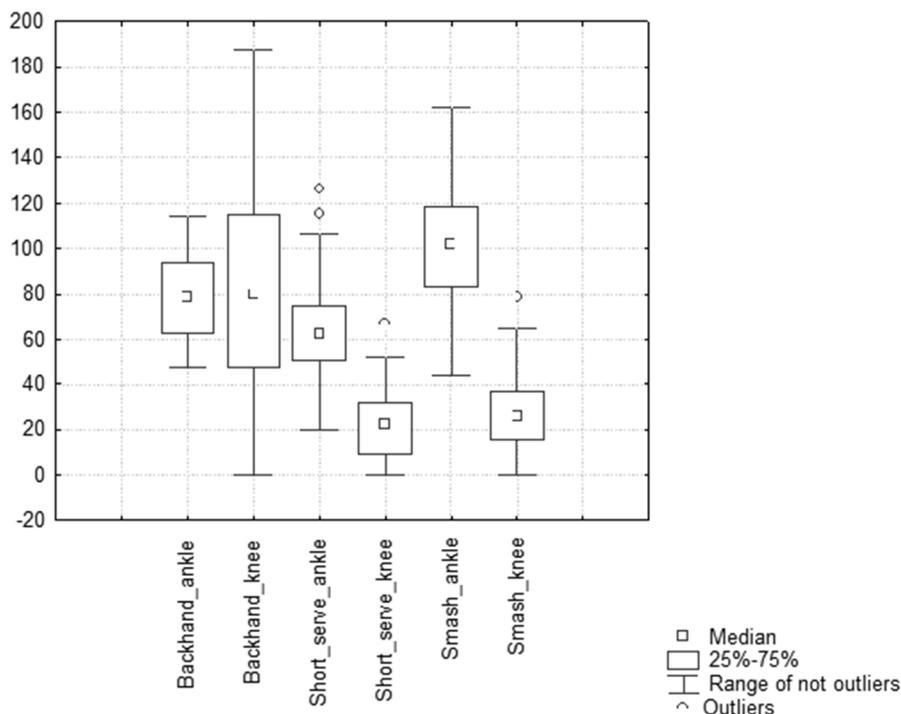
The classification tree presented in Figure2 shows that in the studied group there is no one way of landing strategy based on a general surface area of the torques in the ankle, knee and hip joints. The division in the ankle joint is determined by the movement technique, common for backhand and short serve and, independently, for smash. Furthermore, the number of 5 final nodes suggests that there are at least 5 types of division of the values of surface areas of moments of forces in the knee and hip joints in the athletes performing three elements of badminton technique.

The elements of playing technique with the values of torques exceeding boundary values determined based of torques obtained in static conditions were considered as high loading. Figure 3 is an example of an area between the graph of torque in the ankle, knee and hip joints in the sagittal plane under static and dynamic conditions for smash.



**Figure 3: Examples of the area between external joint moments in: A. ankle, B. knee, C. hip under dynamic (smash) and static conditions for one participant**

In the major part, distributions of the values of differences in moments of muscle forces under static and dynamic conditions largely depart from normal distribution ( $0.8871 < p < 0.1282$ ). The results were analysed by means of the medians and quartiles in order to find the athletes with particular risk of overloading the joints in lower limbs (Figure 4).



**Figure 4: Values of the area under the curve of moments during performance of elements of badminton techniques that exceeded the moment of static force**

The results obtained in this experiment revealed the highest loading to the motor system in the areas of knee joints during backhand and in the ankle joint during smash. Particularly dangerous for individual athletes are values of overloads revealed as outliers. An outlier is an observation that lies an abnormal distance from other values in a random sample from a population. In a sense, this definition leaves it up to decide what will be considered in this case as overloading. Outliers are values that are significantly higher than the remainder of the data. In order to be an outlier, the value must be larger than quartile 3 by at least 1.5 times the interquartile range (Aggarwal, 2013).

### Discussion and conclusion

Although badminton is one of the most popular sports in the world, it has received little attention in sports medicine. Therefore, the aim of this study was to investigate the biomechanics of backhand, short serve and smash in order to evaluate the loading of these movements on the athlete based on torques in the joints of lower limbs. There are a number of factors which affect the development of musculoskeletal injuries (Caine et al., 1996). Known and well documented are the effects of congestion in the upper limbs, resulting from the handling of racket or other utensil in a specific sport discipline. These specific effects of overuse have their own common names, such as tennis elbow or golfer's elbow (McMurtrie et al., 2012; Mucchi, 2013). However, injuries in racket sports are not only limited to the elbow or shoulder joints but they also concern the wrist (Bancroft, 2013). Despite the number of studies on loading upper limbs, the injury in lower limbs of the athletes in racket sports seems to be scarce (Jorgensen et al., 1990). Even cursory observation of the way the athlete moves reveals substantial involvement of the muscles of lower limbs. Athletes are often playing with slightly bent legs, which help them maintain balance and quickly change directions. Unfortunately, epidemiological data show that the above technique of moving on the court is a factor which significantly increases the risk of overuse and injuries. Analysis of loading lower limbs in badminton should focus on the character of loading (Jorgensen et al., 1990). This causes that ground reaction forces, torques and power have been frequently studied for various motion tasks as factors contributing to the development of overuse injuries. The results presented in Table 3 lead to the conclusion that the backhand is a movement with the lowest overload effect on the joints in the sagittal plane. In this study comparison of mean maximum values of ankle, knee and hip torques obtained for backhand, short serve and smash, against the most frequently performed activity-gait (Perry, 1992), reveals values from 132% to 688% higher for badminton (Table 3).

The values of the lower extremity joint moments found in this study are also higher than the peak values of the previously reported torques measures for the ankle joint (1.90Nm/kg), knee joint (1.88Nm/kg) and hip joint

(2.45Nm/kg) during counter movement jump(Liu et al., 2009). These values are lower than the values measured in our study for backhand, short serve and smash. Furthermore, compared to the results presented in the study (Schache et al., 2011) for running at mean velocity 9m/s, the maximal values in the study group were: ankle (4Nm/kg), knee (3.55Nm/kg), hip (4.30Nm/kg) and were higher than maximum values obtained for smash.

Explosive bursts of muscle activity are performed during the game for several times, e.g. a quick lunge and return to the start or moving off in another direction. Noticeable phases of take-off and landing can be distinguished in these movements that include concentric or eccentric muscle work. Therefore, performance in many sporting movements is related to the ability to generate high levels of force with high angular velocities (Prevost et al., 1999). In 2008, Wychowański published statistical models in the form of regression equations and mean values and variances for muscle torques in the joints of upper and lower limbs across the whole joint angle. For the ankle and hip joint, these profiles are similar to linear trend, whereas for the knee joint, the curves are parabolic. Further, Hill's equation demonstrates that the muscle force measured under isometric conditions is lower than the force developed under eccentric conditions. Therefore, one can assume that exceeding the level of isometric force represents a substantial load for a specific muscle group and specific joint. Comparative analysis of the two profiles (moment of isometric force and moment of force in motion) helps evaluate the character of the internal loading and muscle work under concentric or eccentric conditions. The results of these comparisons represent a good justification for determination of boundary conditions in modelling the work of motor organ e.g. during working (Perry, 1992), running (Buczek et al., 1990) or jumping (Bates et al., 2013). For this reason we adopted, as a criterion of substantial loading of the joint, the values which exceed the level of the isometric force (Figure 3). For hip joint, torque values calculated for the dynamic conditions were lower than those calculated for the static conditions. The torques greater than those measured in static conditions were found only for the ankle and knee joints (Figure 3). Therefore, it was possible to calculate the areas limited by these curves and, consequently to perform the statistical analysis.

Analysis of kinetic and kinematic parameters leads to the direct conclusions on the strategy of motor control in the central nervous system in individual people. Athletes training to maximize throwing speed will train differently based on the load and speed of the implements in their sport. Athletes putting the shot will do higher weight and low-repetition lifting compared to athletes that throw lighter objects like a javelin, softball, or baseball, who would train with lower weights and higher speeds of movement (Zatsiorsky et al., 2006). It turns out that we cannot change the nature (shape) of the force–velocity relationship with training, but we can shift the graph upward to improve performance (Fitts et al., 1996). Weight training with high loads and few repetitions primarily shifts the force–velocity curve up near isometric conditions, while fast lifting of light loads shifts the curve up near the maximum velocity of shortening for a muscle. Adequate strength and range of motion are essential in preventing injuries. Both concentric and eccentric training of legs at relatively fast functional velocities is recommended. Comparison of the performance of a particular motor task e.g. gait, running or hitting in badminton shows that the movements are never identical. The individual profile of preferences during performance of a motor task is noticeable for complex tasks or those with high dynamics (Zatsiorsky et al., 2006). Even with natural aptitudes for maintaining balance in standing position, two strategies were found experimentally: ankle joint strategy and hip joint strategy (Nashner, 1976). Therefore, it can be also assumed that there are specific strategies for performing smash, short serve and backhand which have not been identified so far. Our study and analysis of the results using data mining methods did not provide sufficient evidence to define these strategies.

The methodology proposed in this study and the method of analysis of the results represents the guidelines for planning development of physical characteristics. This study reveals relatively high torques on the lower extremity joints during common movement in badminton. Determination of the torques and also preferences in distribution of muscle forces in individual lower limbs represent the basis for optimization of training of specific physical traits. The results of this study have implication in adjusting training to develop strength in the muscle groups which are exposed to the major load that results from the badminton playing technique. The data presented in this study provide useful information on the joint loading during backhand, short serve and smash in badminton, which can help the athlete and coach develop specific training methods that can lead to preventing injuries.

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