Journal of Physical Education and Sport ® (JPES), Vol. 22 (issue 12), Art 404, pp. 3183-3188, December 2022
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Biomechanics analysis of badminton forehand smash in standing classification disability players

SAPTA KUNTA PURNAMA[1], RUMI IQBAL DOEWES[2]
[1,2]Faculty of Sport, Sebelas Maret University, INDONESIA

Published online: December 25, 2022
(Accepted for publication December 15, 2022)
DOI:10.7752/jpes.2022.12404

Abstract:
High-velocity smashes are required by players to complete profitable rallies. The research purpose was analyzed the biomechanics of the badminton forehand smash in standing classification disability players. The research sample is Suryo Nugroho (a para-badminton player with standing upper classification (SU5)). The badminton forehand smash movements analyzed include the jump stage and the arm swing stage. The forehand smash movement is analyzed with dartfish software. Microsoft Excel used to calculate angular velocity, velocity and kinetic energy of shuttlecock, force, and power. The results showed that the shuttlecock speed of Suryo Nugroho's forehand smash was 15.07 m/s. This speed was indicated by the shoulder angle of 164.6°, the elbow extension angle of the hitting arm of 148.3°, the frontswing angle of 10.80 rad/s. The kinetic energy of the moving shuttlecock is 0.62 J which is transferred by the arm swing force of 0.31 N and the arm swing power of 4.69 J/s. At the beginning of the forehand smash, Suryo Nugroho jumps using both legs with a knee flexion angle of 101.6° and a knee extension angle of 177.9° produces a force of 302.94 N and a power of 342.6 3 J/s. Suryo Nugroho's jump height was 0.43 m to reach the shuttlecock as high as 2.95 m and resulted in a steep shuttlecock trajectory with a depression angle of 15.4°. In this study, it can be concluded that in performing a forehand smash to produce optimal shuttlecock speed, it is necessary to pay attention to the shoulder angle, elbow extension angle of the hitting arm, frontswing elbow angular speed, kinetic energy of the moving shuttlecock which is transferred by force and power. In addition, the jump at the beginning of the smash movement plays a role in the steep shuttlecock trajectory, which is carried out using both feet and is influenced by the angle of flexion and extension of the knee, force, and power.
Keywords: Biomechanics, Badminton, Smash, Disability.

Introduction

Badminton is a racquet sport, requiring quick changes of direction, jumps, lunges on the net, and fast arm movements from various positions (Hoffmann, et al., 2018). Persons with disabilities can participate in para-badminton which is a special badminton variant for disabled athletes (Strapasson et al., 2019). Every individual with a disability carries out sports activities in accordance with the circumstances or conditions of her/his physical or mental disorder. Each Paralympic sport determines a functional classification system for physical disabilities, a system based on functional skills and specific assessments that allocates para-athletes to specific sport classes (Strapassson, et al., 2021). The para-badminton event includes several classes to ensure fair competition based on the degree of disability of each athlete, where there are six sports classes according to the type or level of disability ranging from wheelchairs which are divided into 2 classes (WH1 and WH2), standing which is divided into 3 classes. (SL3, SL4, and SU5), and short stature (SH6) (BWF, 2020). The development of para-badminton in Indonesia is increasingly attracting attention, this is because para-badminton is also the mainstay of Indonesia as well as badminton in general, one of the athletes is Suryo Nugroho, who is a single SU5 athlete with Rank 6 para-badminton men single SU5, participated in 9 tournaments and has 38,850 points based on the BWF Para Badminton Rankings 2022 (BWF, n.d.).

Zhang et al (B. Zhang et al., 2013), explained that to win the game, players must have good badminton techniques, and the most exciting moment in badminton matches is the smash technique where many scores often rely on smashing. Smash is an overhand stroke on the shuttlecock to go at high speed, directed to the opponent's court with a steep trajectory, thus making the opponent lose defense because the shuttlecock cannot be returned (Ferreira et al., 2020). This punch is identical to the attacking punch because the goal is to kill the opponent's game. In the implementation of the badminton forehand smash, it takes a high jump to produce a high speed on the smash. In line with this, Rambely et al. explain that players who are able to produce high-speed smashes have completed a profitable rally, this is because a deadly attack requires a fast smash and power in the jump (Rambely, Osman, et al., 2005). Smash movements involve the upper body such as elbows, shoulders, wrists, and fingers (Barnamehei et al., 2018). In addition to involving the upper body, the smash also involves the lower limbs to maintain balance at the stage of the smash movement when swinging the racket (Hung et al., 2020). Several biomechanical analyzes of badminton forehand smash have been investigated in recent years. The main contributions to upper limb movement during overhead forehand smashes are the internal

Corresponding Author: SAPTA KUNTA PURNAMA, E-mail: saptakunta@staff.uns.ac.id

rotation velocity of the shoulder joint, elbow angular extension, and wrist falmar flexion (Rusdiana et al., 2021). Research by King et al (King et al., 2020) shows that proximal segment movement (shoulder and pelvis-thorax separation) is essential for developing greater distal linear velocities, which in turn leads to greater post-impact shuttlecock speed. Research by Hung et al (Hung et al., 2020) shows that in the smash condition, movement in the frontal plane increases, which results in higher loads on the joints in the lower limbs. Landing is affected by where the player hits the target area. In addition, the shuttlecock smash speed is related to the internal rotation of the shoulder which is deeper and the elbow is slightly extended when the racket contacts the shuttlecock. This shows that when contact occurs, the arm position has a role in developing a greater shuttlecock speed (Ramasamy et al., 2021). Some of the studies that have been described used a sample of badminton athletes, so the research results could not be applied to standing classification para-badminton athletes.

Therefore, it is necessary to analyze the biomechanics of the smash of the standing classification para-badminton athletes. It is very important for coaches and athletes to use the results of actual research as an effort to increase the efficiency of athlete performance, so that the exercises that are carried out must be carried out based on biomechanical analysis. Analysis of training technique using principles of biomechanics can provide key ideas for solving specific problems that arise in the process of improving technique, and is important for helping athletes on their way to achieving the highest level of technical skill. This is because the principles of biomechanics provide an understanding that the final result of an action is determined by the systemic unity at each stage of motor movement, so as to explain the cause-and-effect relationship between certain phases of motor action (Gamalii, et al., 2018). In line with this, Steininger et al. (Steininger et al., 2021) stated that developing skills required para-badminton players due to game specifications such as reduced playing area, fast sports, fast moving volume, and shuttlecock strikes. Therefore, this study aims to explain the biomechanics of the badminton forehand smash in standing classification disability players.

Methods

The research sample is Suryo Nugroho, a standing upper (SU5) para-badminton player who is 27 years old, weighs 65 kg, and height of 171 cm. The researcher used descriptive analysis method with a quantitative approach. This approach aims to explain badminton smash performance. The smash movements analyzed include the jump stage and the arm swing stage. The jump stages are jump start, take off, and top of jump. The arm swing stages are backswing, frontswing, contact, and follow through (Rambely, Osman, et al., 2005). The variables studied were angle, angular speed, shuttlecock speed and kinetic energy, force, power. The angle variables studied were the angles of the elbow, shoulder, arm, hip, knee, torso, hip, ankle.

The research was conducted by recording the jump smash movements made by the participants. Video recording is done because it can provide more accurate and practical information (Mota-Ribeiro & Bezerra de Almeida, 2020). Participants are given time to warm up (15 minutes) and get used to the test to be carried out (15 minutes). The test begins with a high serve feeder to the participant, then the participant performs a maximum jump smash and hits the shuttlecock that is aimed at the predetermined target area. 3 opportunities were given to participants (Ramasamy et al., 2021). The Canon EOS 1100D DSLR camera is positioned to record the kinematics of badminton smashes. The placement of the camera is in three positions. Camera 1 is mounted 1 meter on the right side of the participant and is perpendicular. This camera 1 aims to capture body movements in the side plane when doing badminton smashes. Camera 2 is installed near the target box which captures the path of the ball to the target box to determine a successful test to be analyzed as well as captures the movement of the feeder to determine the speed of the shuttlecock. Camera 3 is behind the subject to capture the tilted position of the body when performing a badminton smash (Figure 1).

It is important to be able to measure the execution of sports movements and in this case technology plays a role because it makes it possible to measure a movement. This will provide an objective method for describing, measuring, and evaluating human movement (Rucco et al., 2020). Therefore, motion analysis was performed using dartfish software, is a software that can be used to review video frame by frame (Palao et al., 2015). The results obtained are presented in tables and figures during the smash stage. For the results of angular velocity, shuttlecock speed and kinetic energy, force, and power have been calculated using Microsoft Excel.

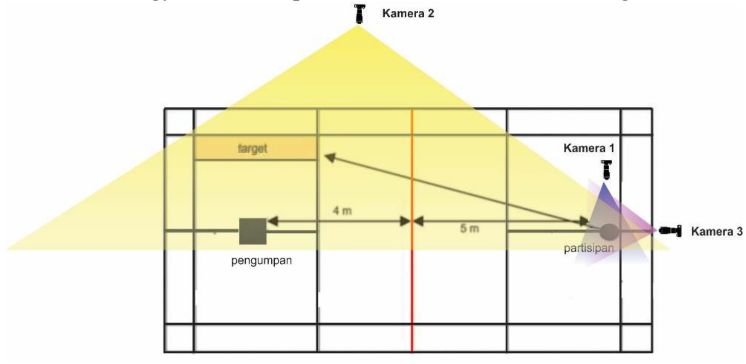

Figure 1. Field used for data collection with camera positioning and target area 3.88m x 0.4m

Result

Table 1. Description of shuttlecock track data on forehand smash

Stage	Variables	Test Result	Unit
Shuttlecock Track	Shuttlecock height (h_s)	2.95	m
	Shuttlecock speed after collision (v_{bs})	15.07	m/s
	The kinetic energy of the moving shuttlecock (EK)	0.62	J
	The depression angle of shuttlecock steepness (θ)	15.4	°

Table 1 explains that the height of the shuttlecock during flight is 2.95 m and the forehand smash that lands in the target area with a shuttlecock speed after the collision of 15.07 m/s and the steepness of the shuttlecock's trajectory with an angle of depression of 15.4° resulting from the kinetic energy of the moving shuttlecock of 0.62 J.

To produce a shuttlecock speed of 15.07 m/s, the forehand smash starts with a 0.43 m high jump done both when starting the jump and landing. The jump is carried out in 3 stages, namely jump start, take off, and top of jump. At the time of jump start, the shoulder tilt is 36.5°, the torso tilt is 36.7°, the flexion hip of 109.7°, the flexion knee of 101.6°, the hip position is at an angle of 51.5°, and the feet are 0.21 m wide. During take off, shoulder tilt is 49.9°, torso tilt is 15.5°, hip extension is 177.8°, knee extension is 177.9°, ankle tilt is 148.9°, force is 302.94 N and power is 342.63 J/s. During the top of jump, the shoulders are pulled back at an angle of 87.1°, the torso is also pulled back at an angle of 17.2°, the hip is extended at 177.8°, the knee is extended at 115.7°, the ankle is at an angle of 128.1°. The jump was carried out at a speed of 1.13 m/s (Table 2).

Table 2. Description of jump data on forehand smash

Stage		Variables	Test Result	Unit
Jump	Jump Start	Shoulder angle at jump start (θ_{bjs})	36.5	°
		Torso angle at jump start (θ_{tjs})	36.7	°
		Hip flexion angle at jump start (θ_{fhjs})	109.7	°
		Knee flexion angle at jump start (θ_{fkjs})	101.6	°
		Ankle angle at jump start (θ_{ajs})	72.4	°
		Hip angle at jump start (θ_{hjs})	51.5	°
		Leg width at jump start (s_{kjs})	0.21	m
	Take Off	Shoulder angle at take off (θ_{bto})	49.9	°
		Torso angle at take off (θ_{tto})	15.5	°
		Hip extension angle at take off (θ_{ehto})	177.8	°
		Knee extension angle at take off (θ_{ekto})	177.9	°
		Ankle angle at take off (θ_{ato})	148.9	°
		Force at take off (F_{to})	302.94	N
		Power at take off (P_{to})	342.63	J/s (Watt)
	Top of Jump	Shoulder angle at top of jump (θ_{btj})	87.1	°
		Torso angle at top of jump (θ_{ttj})	17.2	°
		Hip extension angle at top of jump (θ_{ehtj})	177.8	°
		Knee extension angle at top of jump (θ_{ektj})	115.7	°
		Ankle angle at top of jump (θ_{atj})	128.1	°
		Vertical speed at top of jump (v_{vtj})	1.13	m/s
		Maximum jump height at top of jump (h_{mjtj})	0.43	m

Table 3. Description of arm swing data on forehand smash

Stages		Variables	Test Result	Unit
Arm Swing	Backswing	Angle of elbow flexion of hitting arm during backswing (θ_{fsb})	33.1	°
	Frontswing	Shoulder angle of frontswing (θ_{bf})	164.6	°
		Angle of elbow extension of hitting arm during frontswing (θ_{esf})	148.3	°
		Frontswing time (Δt_f)	0.3	s
		Angular speed of frontswing ($\Delta\omega_f$)	10.80	rad/s
	Racket Contact with Shuttlecock	Tilt angle of hitting arm (θ_{klp})	115.2	°
		Pelvic tilt angle (θ_{kp})	10.3	°
		Shoulder tilt angle (θ_{kb})	45.9	°
		Arm swing force (F_{al})	0.31	N
		Arm swing power (P_{al})	4.69	J/s (Watt)
	Follow Through	Shoulder angle of follow through ($\Delta\theta_{bft}$)	27.4	°
		Follow through time (t_{ft})	0.2	S
		Angular speed of follow through (ω_{ft})	2.053	rad/s

After the jump, then rotate the shoulders externally while keeping the elbows bent, rotating the hips, and shoulders. Table 3 describes the forehand smash arm swing description.

Table 3 describes the swing arm data for the forehand smash which consists of backswing, frontswing, contact with the shuttlecock, and follow through. During the backswing, the elbow of the hitting arm is flexed 33.1°. During the frontswing, the shoulder is pulled back at an angle of 164.6°, the elbow of the hitting arm is extended 148.3°, the angular speed of the frontswing is 10.80 rad/s with a frontswing time of 0.3 seconds. When the racket contacts the shuttlecock, the arm tilt is 115.2°, the pelvic tilt angle is 10.3°, the Shoulder tilt angle is 45.9°, the arm swing force is 0.31 N, and the arm swing power is 4.69 J/s. At the time of follow-through, the shoulder was at an angle of 27.4°, the angular speed of follow-through was 2.053 rad/s with a follow-through time of 0.2 seconds.

Discussion

The series of jump movements on the forehand smash, the preparation starts from a standing position and bending the legs. During preparation, the body tries to store energy in the muscles. Then take off with structured and synchronized movements. When at the highest point, the shoulder followed by the hitting arm swings forward. Suryo Nugroho's forehand shuttlecock smash speed in this study was 15.07 m/s. This speed is much slower than the results of research by Ramasamy et al (Ramasamy et al., 2021), which showed an average shuttlecock smash speed of 97 ± 5 m/s for 19 elite Malaysian male badminton players. According to Ramasamy et al (Ramasamy et al., 2021), the speed of the shuttlecock smash is characterized by more inward turning of the shoulder and less elbow extension on contact. In this case, Suryo Nugroho's shoulder angle when hit is 164.6° and the elbow extension of the hitting arm is 148.3°. Meanwhile, the results of Ramasamy et al (Ramasamy et al., 2021) showed that the shoulder angle was 126.9 ± 5.3° and the extension angle was 63.8 ± 12.0°, smaller than the shoulder angle and extension of Suryo Nugroho.

Tsai et al (Tsai & Chang, 1998) showed a shuttlecock speed of 62.5 m/s for elite players and 54.2 m/s for college players. This speed is also much higher than Suryo Nugroho's shuttlecock speed. Tsai et al (1998) explained that the faster shuttlecock speed comes from the elbow angular speed, which is 793 deg/sec for elite players and 569 deg/sec for colledge players, while Suryo Nugroho's elbow angular speed is 10.80 rad/s.

In addition to angle, shuttlecock speed is also generated from the magnitude force to transfer kinetic energy from the body to the shuttlecock during swinging motion. Nakano et al (Nakano et al., 2020), explained that the amount of energy transferred is affected by the combined forces on the shoulder, elbow, and wrist (arm swing force) meaning that more energy transferred from the body to the arm is associated with a shorter time between jump and swing action, with a short time so that the speed increases. In this study, the magnitude of the shuttlecock's kinetic energy is 0.62 J, which is transferred by the arm swing force of 0.31 N.

Empirically, the jump smash produces a bigger hit because of the air action-reaction between the upper and lower limbs (Li et al., 2017). At the completion of upper extremity movements, coordination and connection with lower extremities is required. Arora et al (Arora et al., 2021) explained that when a player extends the leg to jump, the knee extensor acts eccentrically, increasing the resultant force after flexion. During this phase, the lower leg muscles work concentrically, pushing hard against the ground and increasing the force. In this study, Suryo Nugroho bent with a knee flexion angle of 101.6° then stretched his knee with a knee extension angle of 177.9° capable of producing a force of 302.94 N. On the other hand, the final quality of the forehand smash stroke is influenced by the upper and lower body power (Z. Zhang et al., 2016). In this study, the upper limb power, namely arm swing, was 4.69 J/s. At the start of the smash move, players will lower their bodies to conserve energy and to release their power during the jump action stage. In this study, Suryo Nugroho's power when jumps is 342.63 J/s.

A positive correlation was found between the two HCMJ (height countermovement jump) and HSPJ (height spike jump) regarding VmaxWJ (velocity with jump smash) in males; height of shuttlecock impact in jump smash (HWJ) and HSPJ for women; proved the importance of jumping ability in badminton smash (Ferreira et al., 2020). Suryo Nugroho showed an excellent jump smash technique and reached a height of 0.43 m to reach a shuttlecock as high as 2.95 m. The results of this study are supported by Rambely et al. (Rambely, Wan Abas, et al., 2005) explaining that during the smash action, the jump is performed when the arm swings from back to front. The purpose of the jump is to jump higher and contact with the shuttlecock occurs at a higher position so that the shuttlecock's trajectory will be very steep. In this study the steepness of the shuttlecock with an angle of 15.4°.

The jumps made by Suryo Nugroho used both feet both when jumping and landing. Although the results of the analysis of Rambely et al (Rambely, Wan Abas, et al., 2005) explained that the jump used the majority of players using a one-legged jumping technique both left and right with a percentage of 44% and 41.7% respectively, while only 10.7% used both legs. However, injuries can occur to the knees and ankles due to loss of balance when using the one-legged jumping technique. In this case, Sahabuddin et al (2021) explained that injuries may occur due to inadequate movement of the hip and knee joints, causing not only reduced shock absorption but also increased risk of lower limb injury. Such as excessive dynamic knee valgus (DKV) which is characterized by knee valgus, contralateral pelvic drop, internal hip rotation, and shift of the center of mass away from the stance leg. DKV is primarily caused by hip abductor weakness, which causes non-contact injuries such as patellofemoral pain syndrome and anterior cruciate ligament (ACL) injuries.

Conclusions

Based on the data analysis that has been done, it can be concluded that the shuttlecock speed of Suryo Nugroho's forehand smash is 15.07 m/s. This speed is indicated by the shoulder angle of 164.6°, the elbow extension angle of the hitting arm of 148.3°, the frontswing angle of 10.80 rad/s, the kinetic energy of the moving shuttlecock of 0.62 J transferred by the arm swing force of 0.31 N and the arm swing power of 4.69 J/ s. At the beginning of the forehand smash, Suryo Nugroho jumps using both feet with a knee flexion angle of 101.6° and a knee extension angle of 177.9° producing a force of 302.94 N and a power of 342.63 J/s. Suryo Nugroho's jump height was 0.43 m to reach the shuttlecock as high as 2.95 m and resulted in a steep shuttlecock trajectory with a depression angle of 15.4°.

References

Arora, C., Singh, P., & Varghese, V. (2021). Biomechanics of core musculature on upper extremity performance in basketball players. J. Bodyw. Mov. Ther., 27, 127–133. https://doi.org/10.1016/j.jbmt.2021.02.023

Barnamehei, H., Ghomsheh, F. T., Cherati, A. S., & Pouladian, M. (2018). Upper limb neuromuscular activities and synergies comparison between elite and nonelite athletics in badminton overhead forehand smash. Appl. Bionics Biomech., 2018. https://doi.org/10.1155/2018/6067807

BWF. (n.d.). Rankings _ BWF Fansite. https://bwfbadminton.com/rankings/?id=14 diakses pada 1 November 2022 12.45 WIB

BWF. (2020). PARA BADMINTON GENERAL COMPETITION.

Ferreira, A., Górski, M., & Gajewski, J. (2020). Gender differences and relationships between upper extremity muscle strength, lower limb power and shuttle velocity in forehand smash and jump smash in Badminton. Acta Bioeng. Biomech., 22, 1–16. https://doi.org/10.37190/ABB-01643-2020-02

Gamalii, V., Potop, V., Lytvynenko, Y., & Shevchuk, O. (2018). Practical use of biomechanical principles of movement organization in the analysis of human motor action. J. Physc. Edu. Sport, 18, 874-877.

Hoffmann, D., Brixius, K., & Vogi, T. (2018). Racket sports teaching implementations in physical education – a status quo analysis of German primary schools. J. Physc. Edu. Sport, 18, 867-873.

Hung, M. H., Chang, C. Y., Lin, K. C., Hung, C. L., & Ho, C. S. (2020). The Applications of Landing Strategies in Badminton Footwork Training on a Backhand Side Lateral Jump Smash. J. Hum. Kinet., 73, 19–31. https://doi.org/10.2478/hukin-2020-0002

King, M., Towler, H., Dillon, R., & McErlain-Naylor, S. (2020). A correlational analysis of shuttlecock speed kinematic determinants in the badminton jump smash. Appl. Sci., 10, 1–14. https://doi.org/10.3390/app10041248

Li, S., Zhang, Z., Wan, B., Wilde, B., & Shan, G. (2017). The relevance of body positioning and its training effect on badminton smash. J. Sports Sci., 35, 310–316. https://doi.org/10.1080/02640414.2016.1164332

Mota-Ribeiro, W., & Bezerra de Almeida, M. (2020). Performance analysis in wheelchair para-badminton matches. Int. J. Racket. Sports. Sci., 2, 22-31.

Nakano, N., Fukashiro, S., & Yoshioka, S. (2020). The effect of increased shooting distance on energy flow in basketball jump shot. Sport. Biomech., 19, 366–381. https://doi.org/10.1080/14763141.2018.1480728

Palao, J. M., Hastie, P. A., Cruz, P. G., & Ortega, E. (2015). The impact of video technology on student performance in physical education. Technol. Pedagog. Educ, 24, 51–63. https://doi.org/10.1080/1475939X.2013.813404

Ramasamy, Y., Usman, J., Sundar, V., Towler, H., & King, M. (2021). Kinetic and kinematic determinants of shuttlecock speed in the forehand jump smash performed by elite male Malaysian badminton players. Sport. Biomech., 00, 1–16. https://doi.org/10.1080/14763141.2021.1877336

Rambely, A. S., Osman, N. A. A., Usman, J., & Wan Abas, W. A. B. (2005). The contribution of upper limb joints in the development of racket velocity in the Badminton Smash. Isbs, 2005, 422–426.

Rambely, A. S., Wan Abas, W. A. B. (2005). The analysis of the Jumping Smash in the Game of Badminton. Isbs, 1, 671–674.

Rucco, R., Ascione, A., & Palma, D. D. (2020). Motion analysis in sport training: the link bertween technology and pedagogy. J. Physc. Edu. Sport, 20, 2337-2341.

Rusdiana, A., Abdullah, M. R., Syahid, A. M., Haryono, T., & Kurniawan, T. (2021). Badminton overhand backhand and forehand smashes: a biomechanical analysis approach. J. Physc. Edu. Sport, 21, 1722-1727.

Sahabuddin, F. N. A., Jamaludin, N. I., Bahari, M. L. H. S., Najib, R. K. M. R. A., & Shaharudin, S. (2021). Lower limb biomechanics during drop vertical jump at different heights among university athletes. J. Physc. Edu. Sport, 21, 1829-1835.

Steininger, R. N., Strapasson, A. M., Cardoso, V. D., & Gaya, A. C. A. (2021). Para-Badminton: aptidão física relacionada ao desempenho de atletas brasileiros em cadeira de rodas. Lecturas: Educación Física y Deportes, 26, 123–136. https://doi.org/10.46642/efd.v26i281.2346

Strapasson, A. M., Verônica, K., Fonseca, O., Luiza, M., Alves, T., Haegele, J. A., & Duarte, E. (2019).

Iniciação ao Para-Badminton através do programa de ensino “Shuttle Time” teaching program. Conexões, 17, e019031–e019031. https://doi.org/10.20396/conex.v17i0.8655265

Strapasson, A. M., de Moura Simim, M. A., Chiminazzo, J. G. C., Leonardi, T. J., & Paes, R. R. (2021). Are technical and timing components in Para-Badminton classifications different?. Int. J. Racket. Sports. Sci., 3, 22-27.

Tsai, C.-L., & Chang, S.-S. (1998). Biomechanical Analysis of Differences in the Badminton Smash And Jump Smash Between Taiwan Elite And Collegiate Players. XVI Int. Symp. Biomech. Sport., 259–262.

Zhang, B., Li, F., & Jiang, W. (2013). Mixed Doubles Match Technical and Tactical Analysis of World Badminton Champion Based on Mathematical Statistics. Adv. Phys. Educ., 03, 154–157. https://doi.org/10.4236/ape.2013.34025

Zhang, Z., Li, S., Wan, B., Visentin, P., Jiang, Q., Dyck, M., Li, H., & Shan, G. (2016). The Influence of X-Factor (Trunk Rotation) and Experience on the Quality of the Badminton Forehand Smash. J. Hum. Kinet., 53, 9–22. https://doi.org/10.1515/hukin-2016-0006