

Article

sEMG Analysis of Upper Limb Muscles during Backhand Smash Using Badminton Rackets of Different Stiffness

Catarina M. Amaro ¹, Sérgio Nolasco ², Luis Roseiro ^{3,4}, Ana M. Amaro ^{3,*} and Maria António Castro ^{3,5}

¹ University of Coimbra, CIDAF-Research Unit for Sport and Physical Activity, Faculty of Sports Science and Physical Education, 3004-531 Coimbra, Portugal

² Department of Mechanical Engineering, University of Coimbra, 3004-531 Coimbra, Portugal

³ University of Coimbra, CEMMPRE-Centre for Mechanical Engineering, Materials and Processes, Department of Mechanical Engineering, 3030-788 Coimbra, Portugal

⁴ Polytechnic of Coimbra, Coimbra Institute of Engineering, 3030-199 Coimbra, Portugal

⁵ Sector of Physiotherapy, School of Health Sciences, Polytechnic of Leiria, 2411-901 Leiria, Portugal

* Correspondence: ana.amaro@dem.uc.pt; Tel.: +351-2397907001

Abstract: The analysis of racket stiffness effect on muscle activity during movement associated with badminton is essential for a better understanding of which badminton racket is better for the athletes to use. The present study aimed to evaluate the effect of racket stiffness on muscle activity and activation time of the upper limb muscles—biceps (Bicp), lateral head (TLat) and long head (TLong) of the triceps—when performing the backhand smash (BH) movement using two rackets with different levels of stiffness. A group of 6 volunteers, with an average age of 21.8 (± 4.5) years, and an average badminton practice time of 10.7 (± 5.3) years, performed 10 valid repetitions of the movement with each racket, and the muscle activity was collected using surface electromyography. Observing the results shows that the most excited muscle in the BH smash, in terms of (%MVC), is the TLat, regardless of the stiffness of the racket, which shows 56.9% for the Duora 33 and about 68.9% for the Duora 88, comparing with the Bicp and the TLong, respectively. Also, it was observed that the more rigid racket (Duora 88) showed a higher muscular activity for the Bicp and TLat muscles.

Keywords: electromyography; upper limb; rackets; stiffness



Citation: Amaro, C.M.; Nolasco, S.; Roseiro, L.; Amaro, A.M.; Castro, M.A. sEMG Analysis of Upper Limb Muscles during Backhand Smash Using Badminton Rackets of Different Stiffness. *Appl. Sci.* **2022**, *12*, 9483. <https://doi.org/10.3390/app12199483>

Academic Editors: Alessandro de Sire and Stefano Masiero

Received: 13 July 2022

Accepted: 19 September 2022

Published: 21 September 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Badminton is one of the most played sports globally, both at professional and amateur level [1,2]. In 1992 badminton was included in the Olympic Games, which further increased the number of participants in this modality [3]. According to the literature, this game has around 200 million athletes [3,4]. Compared to other racket sports, badminton is frequently considered to be the fastest, which implies that players have restricted time to complete specific movements [3,5,6]. In 2017, the official record for the fastest shot in a competition of 426 km/h was achieved, thanks to the Danish player Mads Kolding [7]. As badminton is a sport characterized by several changes of direction, jumps, accelerations, and sudden decelerations, high physical capacity is required from high-level players. Playing badminton requires the use of several muscles, such as the wrist flexors and extensors, the biceps and the triceps. Badminton is a physically demanding sport, so a significant number of injuries can occur. To play badminton it is necessary to have strength, endurance, muscular power, agility, speed, and precision [8]. During badminton practice, due to the repetitiveness of the exercises, such as the smash, fatigue progressively develops and a decrease in the forehand smash effect of the athletes is observed [9]. Joorgensen and Winge stated that the Badminton injury rate is 2.9 injuries per 1000 h [10]. The same authors described how badminton injuries have a higher occurrence rate in training, while for other racket sports the occurrence of injuries is mostly during games. Miyake et al. observed in their study that the proportion of injuries due to repetition of movement

was about 3 times greater than that due to trauma, both for matches and for games [11]. For Roman-Liu, musculoskeletal disorders (MSD's) are the consequence of the effects of extended periods of application of loads of various magnitudes [12]. MSDs can occur in the players' upper limbs due to the specificity of badminton's gestures, postures, and movements, along with the strength, effort, and hand-arm vibration induced in the upper limbs during practice. Risk factors for musculoskeletal injuries related to work are usually assessed in different ergonomic contexts [13,14]. According to Ferrara and Cohen, in racket sports, the upper muscles are the most used [15]. The continuous impact and the possibility of failed movements leads to increased stress over the musculoskeletal system and a rise in the number of injuries that can occur. Nhan et al. observed in their study that around 24.3% of badminton players' injuries occur on the upper limb [16].

In this sport, the most important aspect to consider is the racket, even before identifying the different movements under study [17]. The racket strings are located with a metal shield in the racket head, and the shaft connects the handle and the head. The handle area is held and controlled by the player, and its rigidity most affects the racket's performance. With this point in mind, this study aims to evaluate the influence of stiffness on muscular activity. Miller verified that racket stiffness is associated with tennis elbow and may be responsible for injuries in some badminton players [18].

The badminton smash, normally performed from the bottom of the field, is an offensive stroke with a downward trajectory [10,19]. The smash can be accomplished with a forehand (FH) grip, where the palm is pointing in the direction of the smash at the moment of impact with the shuttlecock [20]. According to Ramli et al. from a good body position, forehand shots can be reached by making whip-like movements with proximal control from the rotation of the trunk to the distal part with the rotation of the arm [21].

In the case of the smash movement in badminton, the upper part of the body is responsible for the acceleration of the racket. Zhang et al. argue that the rotation of the trunk is essential for maximum acceleration in the shot [22].

Surface electromyography (sEMG) can be used in sports as it allows for the study of neuromuscular patterns organized by the central nervous system during dynamic activities [23–25]. Electromyographic measurements are of great importance to test protocols and improving equipment for better sports performance. Evaluation of the electrical activity of a muscle is fundamental to assess the movement performance during different activities, as it can be used to guide the adequate and economic use of muscles, improve activity and prevent the risk of injury [26]. The study of neuromuscular patterns through EMG provides important information that can be used in sports to guide performance, injury prevention, management of muscle conditioning, skill improvement, and motor control [23].

In the present study, the most important muscles of the elbow and shoulder were assessed through surface electromyography (sEMG), namely the biceps (Bicp), the lateral head of the triceps (TLat), and the long head of the triceps (TLong). Biceps is the muscle responsible for flexing the elbow and supinating the forearm. It also acts as an accessory flexor of the shoulder as its long head originates from the scapula. The long head prevents superior movement of the humerus on the glenoid cavity, which is an important role during the movement of lifting the upper limb. The triceps muscle is responsible for elbow extension, and at the shoulder, through its long head, it also participates in abduction and extension. More precisely, TLat is normally recruited for movements that require occasional spikes in strength, while TLong is used when sustained force is required, or when synergistic control of the shoulder and elbow is required [27]. Both muscles, biceps and triceps, work together during the badminton smash to adjust the speed of the elbow motion and maintain balance so that the shuttlecock gains the intended velocity [28].

To the authors' knowledge, there have been no studies in the performance of badminton players' upper limb muscles, despite the commonality of upper limb badminton injuries [16]. This study, therefore, evaluates muscular activity in a group of volunteer badminton players with the goal of assessing the impact of the rackets' stiffness on the muscular activity and activation time during the smash movement, using two types of racket

of different stiffness. The findings of this study should help coaches, sports professionals and athletes choose the best racket according to the athlete's level, and to help prevent the occurrence of injuries.

2. Materials and Methods

The Declaration of Helsinki was used to carry out this work, to safeguard ethical principles for clinical research involving human beings, thus all procedures were approved by the local Ethics Committee (14_CEIPC2/2019). Before starting data collection, all volunteers were fully informed about this study and agreed by signing an informed consent form. To maintain anonymity, all data is confidential, and volunteers are identified by code numbers. To participate in this study, no volunteer could be under 18 years old, and they had to be a practitioner of the modality for at least 6 years and train at least 3 h a week. Athletes who had an injury in the last 6 months, who were using medication that could influence the musculoskeletal response, or who felt any muscle pain or discomfort were not allowed to participate in this study. Initially, the group was formed by eight athletes, four females and four males. However, before data collection, two female athletes were injured, and the group was reduced to six. The average and standard deviation of the volunteers characteristics were as follows—age: 21.8 ± 4.9 years, height: 175.2 ± 13.3 cm, weight: 66.5 ± 12.2 kg, wingspan: 171.8 ± 14.3 cm, and years of practice: 10.7 ± 5.8 . All volunteers were right handed.

Figure 1 shows a flow diagram of the experimental procedure. The 6 athletes each performed 10 backhand smashes per racket, and used two rackets of different stiffness, resulting in a total of 120 smashes. Surface electromyography was used to analyze the muscular activity during each backhand (BH) smash. Normally, this movement is used when the player is not in position to play a forehand shot, and it is used to earn time by forcing the other player to the back of the court. The two rackets used by all volunteers were Yonex Duora 33 and Yonex Duora 88. The frame and string were the same for both rackets, namely Yonex BG3, with a diameter of 0.74 mm and 125 N tension.

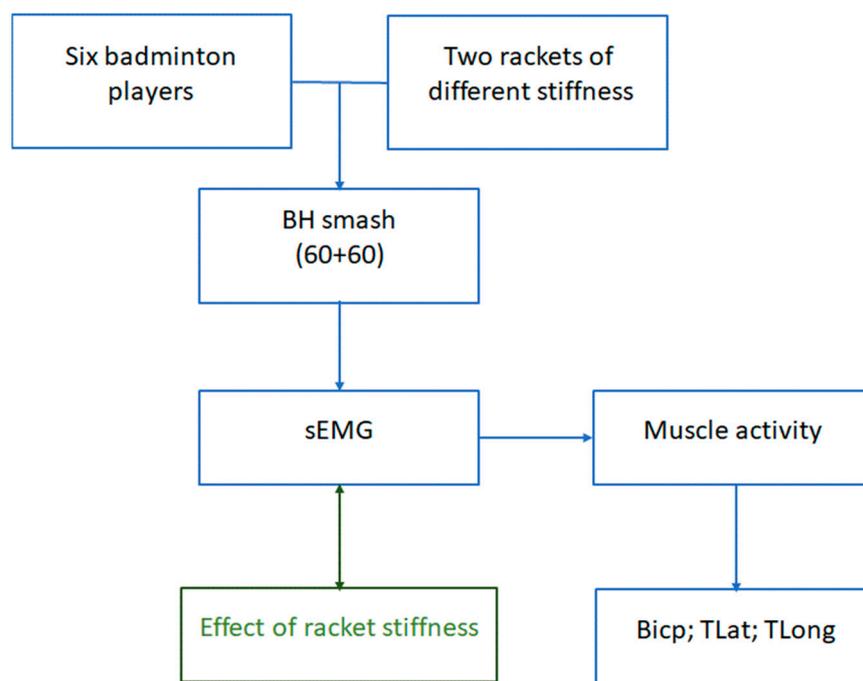


Figure 1. Flow diagram of the experimental procedure.

The Yonex Duora 33 (Figure 2) is a low-range racket that is usually used by less experienced players and is more flexible than the Yonex Duora 88 (Figure 3), which is a mid-range racket. The principal difference between these two rackets is the racket flex.

According to Phomsoupha et al., this racket type has more stiffness, and is therefore more normally used by athletes of an advanced level. We used the SnowPeak C1101 shuttlecocks for this study, which have been approved by the Badminton World Federation for international tournaments [29]. The feathers of the C1101 are Class A synthetic, and the shuttle head is made of natural cork with a weight of approximately 5 g.



Figure 2. Yonex Duora 33. Length: 675 ± 3 m; width: 189 ± 3 mm.



Figure 3. Yonex Duora 88. Length: 675 ± 3 m; width: 189 ± 3 mm.

Each athlete performed at 10 valid BH smashes with each racket, according to the protocol presented in Table 1.

Table 1. Protocol for the sEMG evaluation.

Athlete	Yonex Duora 33	Yonex Duora 88
Muscle warm-up		
	Executed 5 BH smashes	
Rest 30 s		
	Executed 5 BH smashes	
Rest 30 s		
		Executed 5 BH smashes
Rest 30 s		
		Executed 5 BH smashes

For the acquisition of data, sEMG BioSignalPlux equipment was used (Figure 4), which has a 1000 Hz frequency. AMBU BlueSensor N electrodes (AMBU, Ballerup, Denmark) were used, which are a compound of Ag-AgCl, pre-gelled, disk shaped, 10 mm in diameter, disposable, and adherent to the skin. BioPLUX telemetric equipment (PLUX, Lisbon, Portugal) with Bluetooth connectivity was used to record and amplify the EMG signals with the following characteristics [30]: gain (ratio between input and output signal): 1000; range: ± 1.5 mV; bandwidth: 25–500 Hz; input impedance: >100 GOhm.



Figure 4. Electromyographic instrumentation of the athletes.

Muscle activation was assessed using electrodes positioned on the most prominent muscular bellies of the Bicp, TLat, and TLong of the triceps, and the reference electrode was placed on the lateral third of the right clavicle (Figure 4). Before electrode placement, the skin was carefully prepared, according to the SENIAM recommendations [31]: hair removal, abrasion, and cleaning with alcohol to decrease the impedance of the interface between the skin and the electrode.

Electrodes were placed in parallel to the muscle fibers with a 20 mm center-to-center distance, according to SENIAM Project guidelines [31]. On the biceps, the electrodes were placed at one-third of the distance from the fossa cubit on the line between the medial acromion and the fossa cubit. On the triceps, they were placed halfway along the line from the posterior crista of the acromion (shoulder) to the olecranon (elbow) and at two finger widths medial and lateral to the line (TLong and TLat, respectively).

An isometric maximum voluntary contraction (%MVC) performed using manual muscle test procedures with verbal encouragement during the testing was used for amplitude normalization in the post-processing phase [32].

The EMG data were digitally filtered (25–400 Hz), full-wave rectified and smoothed through a low-pass filter (12 Hz, fourth-order Butterworth digital filter). For amplitude normalization, the peak 200 ms EMG signal of the (%MVC) was used as a reference. EMG processing was performed with a Matlab routine (version R2020b, Mathworks, Inc., Natick, MA, USA). The EMG signals were visually inspected before processing to ensure EMG signal quality.

To analyze the data statistics differences, with a significance level of 0.05, the Statistical Package for Social Science (SPSS) software 25.0 (IBM Corporation, Armonk, NY, USA) [33] was used. Descriptive statistics were reported as the mean and standard deviation of (%MVC) and activation time in seconds. The normality test of the data was performed using the Shapiro–Wilk test. The non-parametric Wilcoxon test was used to confirm the effect of racket stiffness on the studied variables. The significance level was set at 5%.

3. Results

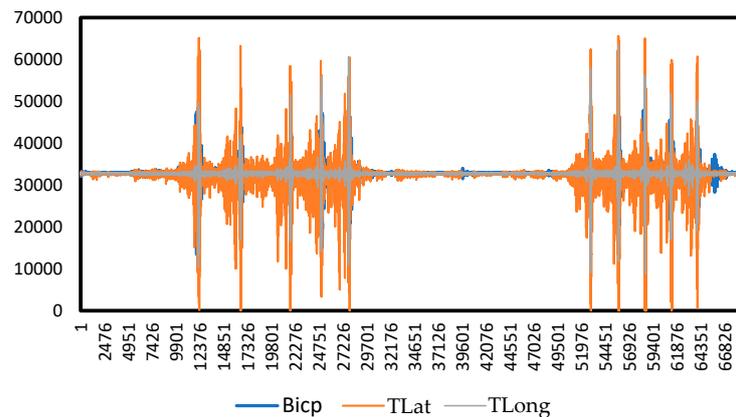
The average results (\bar{X}), standard deviation (SD), confidence interval, effect of the activation time (AT) in seconds, and the percentage of maximum voluntary contraction

(%MVC), as well as the comparisons according to different rackets, are shown in Table 2. The comparison between the studied muscles is also presented. Six significant values were collected ($p \leq 0.05$), each highlighted in Table 2 with an asterisk. Two of them refer to the intermuscular difference using the same racket when the activation time was evaluated.

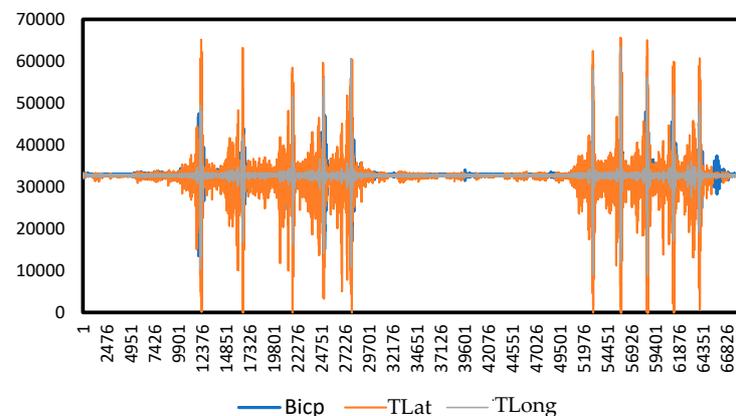
Table 2. %MVC and AT for each of the rackets and respective comparisons.

Muscle	Yonex Duora 33	CI 95%	Yonex Duora 88	CI 95%	Effect Size	p
	(n = 60) $\bar{X} \pm SD$		(n = 60) $\bar{X} \pm SD$			
AT (sec)	Bicp	0.72; 0.80	0.750 ± 0.121	0.71; 0.79	−0.057	0.600
	TLat	0.63; 0.69	0.621 ± 0.080	0.60; 0.65	−0.118	0.173
	TLong	0.52; 0.56	0.551 ± 0.065	0.53; 0.57	−0.331	0.116
	p	0.030 *	0.030 *			
%MVC	Bicp	54.74; 61.94	65.2 ± 16.3	61.12; 69.22	−0.454	0.028 *
	TLat	88.38; 95.28	98.2 ± 24.5	94.29; 102.78	−0.070	0.046 *
	TLong	63.92; 70.17	58.2 ± 12.3	56.04; 61.00	−0.195	0.249
	p	0.016 *	0.009 *			

Figure 5 shows sEMG raw signal for one of the athletes, considering both rackets.



(a)



(b)

Figure 5. sEMG raw signal for one of the athletes: (a) Duora 33; (b) Duora 88.

Figure 6 shows the average values of the normalized intermuscular amplitude (%MVC) and their standard deviation, comparing both rackets.

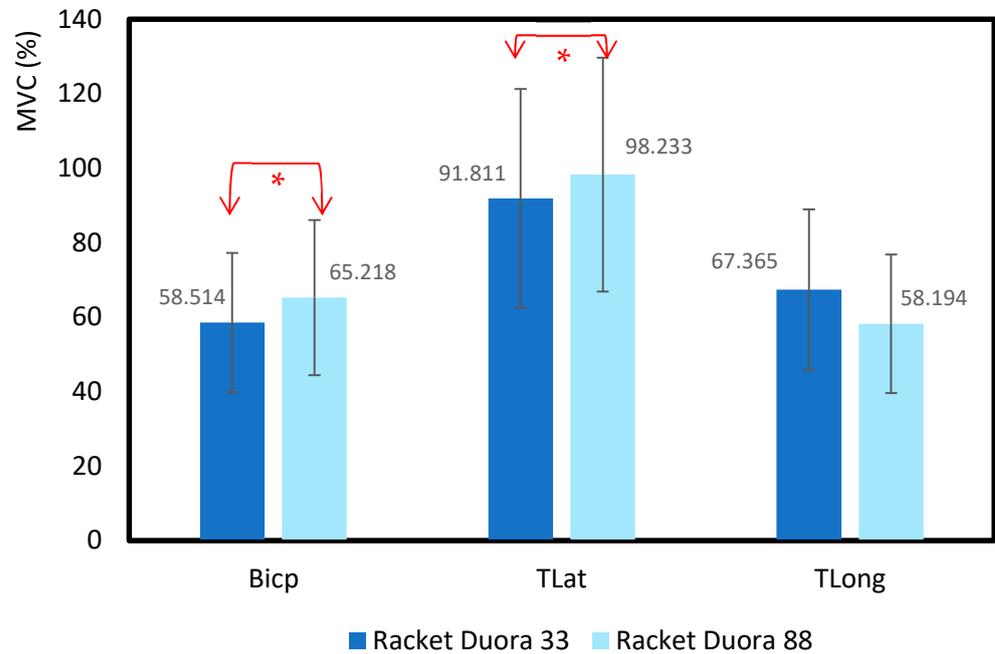


Figure 6. Average of the normalized intermuscular amplitude (%MVC) and their standard deviation. Statistically significant values are highlighted in the figure with an asterisk.

Figure 7 shows the average values of the activation time and the respective standard deviation for both of the rackets.

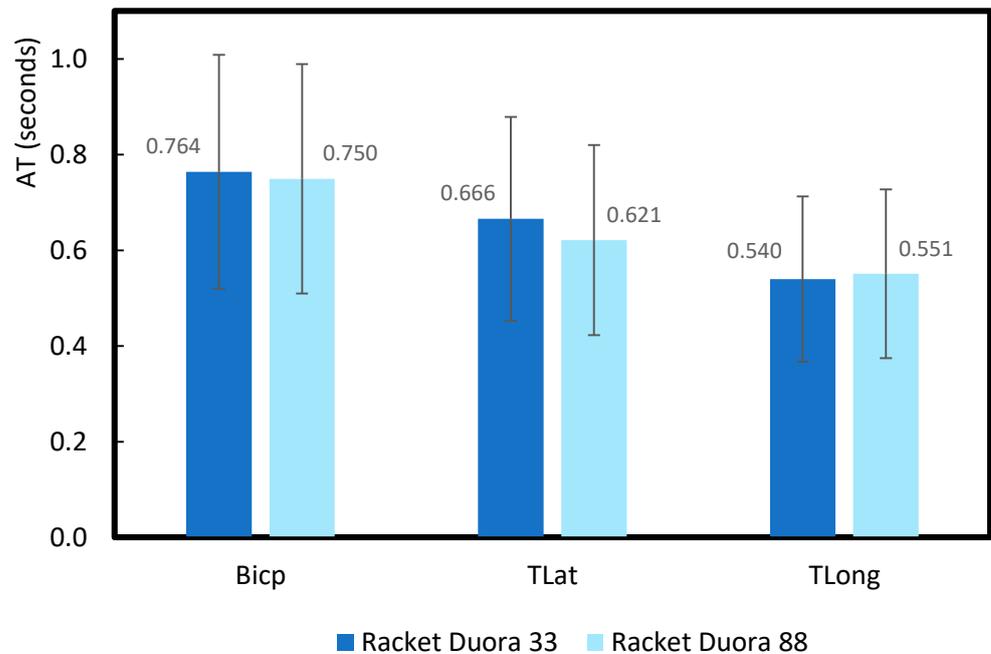


Figure 7. Average muscle activation time and standard deviation.

4. Discussion

Figure 5 shows that the most excited muscle during the backhand smash, for both rackets, is the TLat. It is also possible to verify the protocol adopted.

The muscle activation to the normalized amplitude when using both rackets was statistically different for the Bicip and the TLat. The remaining differences refer to intermuscular muscle activation when performing the smash with the same racket.

Table 2 shows that the AT for the TLong and Bicip is the same for both rackets, which indicates that the activation time does not depend on the racket in use, and rather it is a difference in recruitment coming from the movement performed.

Concerning %MVC muscle activation, statistically significant differences occur between Bicip and TLat for Yonex Duora 33, and between TLong and TLat for Yonex Duora 88. During the BH smash, the most excited muscle is the TLat, which is the muscle responsible for elbow extension through a concentric or eccentric contraction. This result is also corroborated by Sakurai and Ohtsuki in their study [28].

A different pattern of muscle activation was observed for Bicip and TLat (greater muscle activity) when performing the smash with the more rigid racket (Yonex Duora 88), although the opposite was observed for the TLong. The differences between the two rackets may be an indication that the vibration transmitted through the rackets influences the muscular activity of the used muscles, which is lower in the less rigid racket (Yonex Duora 33). This is a coherent result; since less energy needs to be dissipated, the muscle does not need to be so permeable to vibrations and may have a more intense contraction. This is an interesting result given that the fastest non-competitive smash was performed with a racket of high rigidity, the Yonex Nanoray Z-Speed, by Tan Boon Heong with a speed of 493 km/h in 2013, which corroborates this result. While flexible rackets bend forward when a shot is taken, losing accuracy, stiffer rackets have opposite characteristics, meaning they exert less force but are more accurate. According to our results, the racket with less rigidity promotes less muscle contraction. Thus, these results justify why beginner athletes prefer rackets with less rigidity. Usually, beginner athletes don't have the muscle strength that the more experienced athletes have developed through years of practice. Therefore, for beginning players who have low swing speed, less rigid rackets are better. On the other hand, the stiffer rackets are usually the most used for more experienced players with high swing speed.

Figure 6 shows that the most excited muscle is TLat, with Bicip and TLong being excited in a similar, but inferior way. The triceps, both TLat and TLong, are responsible for elbow extension, the predominant movement in the BH smash. TLat is responsible for the moments of higher intensity when compared to the other triceps head, which can justify such a higher activation of this muscle than the others. Bicip acts as an antagonist and TLong as a stabilizer in the whole smashing process.

TLat is the most energetic muscle for this swing as it is responsible for elbow extension and, therefore, strength production, and is also responsible for slowing down the motion by stretching and trying to resist the movement created in the forearm (eccentric contraction). This is an awarding factor for the volunteers studied, since Jaitner and Gawin [34] state that the faster the deceleration of the arm and forearm, the greater the energy transmitted to the shuttlecock in the BH smash, which is why it is an indicator of its performance.

Figure 7 shows that Bicip is active for longer during the BH smash, closely followed by TLat, with TLong being active for less time. The greater temporal activation of Bicip can be explained by the fact that it is the antagonist muscle in the extension of the elbow. This means that an activation intensity as high as TLat is not required, stretching over time to balance the elbow during deceleration. This finding is in line with Lucas-Osma and Collazos-Castro [27], who declare that TLat is specially recruited in moments of peak strength at the time of elbow extension, such as the BH smash. Comparatively, TLong is used in longer and less intense moments of force, and is associated with the stabilization that the shoulder performs during the shot movement.

5. Conclusions

Electromyography of the elbow muscles revealed that Bicip and TLat are greatly responsible for all the mechanics of the BH smash movement, aided by TLong. Bicip is the

muscle that remains active for the longest time, regardless of the stiffness of the racket in use. TLat is the muscle with higher activity in amplitude in terms of %MVP during the movement for both rackets.

In terms of racket rigidity, no differences were found in the duration of muscle activation, however, in terms of muscular intensity, the more rigid racket showed a higher muscular activity for the Bicip and TLat muscles. These results could be confirmed by performing further tests with rackets of other stiffness, such as Yonex Duora 55 and Yonex Duora 77.

Although the more flexible rackets are more accessible to athletes at a beginner level, their use involves greater intensity of muscle contraction, which can cause less experienced athletes with less developed technique to experience a greater constraint to their movement, and therefore, an increased risk of injury.

This work is a useful contribution to badminton practitioners, since it evaluated muscle activity in the upper limbs, as a function of racket stiffness. These results can help coaches predict the effect their athletes' rackets might have on their physical condition.

Author Contributions: L.R., M.A.C. and A.M.A. conceived and designed the study; C.M.A. and S.N. performed the tests, analyzed the results and helped to write the manuscript; L.R., A.M.A. and M.A.C., participated in the research work and helped to write the manuscript. C.M.A., S.N., L.R., M.A.C. and A.M.A. contributed to the acquisition, analysis, and interpretation of data, and helped to write the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Authors acknowledge the support of the Centre for Mechanical Engineering, Materials and Processes—CEMMPRE of the University of Coimbra, which is sponsored by Portuguese national funds provided by Fundação para a Ciência e Tecnologia (FCT) under the projects UIDB/00285/2020, LA/P/0112/2020 and the Mais Centro Program, Center Region Coordination Committee of EU through the European Regional Development Fund.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. El-Gizawy, H.; Akl, A.-R. Relationship Between reaction time and deception type during smash in badminton. *J. Sports Res.* **2014**, *1*, 49–56. [CrossRef]
2. Shariff, A.H.; George, J.; Ramlan, A.A. Musculoskeletal injuries among Malaysian badminton players. *Singap. Med. J.* **2009**, *50*, 1095–1097.
3. Phomsoupha, M.; Laffaye, G. The Science of Badminton: Game Characteristics, Anthropometry, Physiology, Visual Fitness and Biomechanics. *Sport Med.* **2015**, *45*, 473–495. [CrossRef]
4. Yu, L.; Mei, Q.; Mohamad, N.; Gu, Y.; Fernandez, J. An Exploratory Investigation of Patellofemoral Joint Loadings during Directional Lunges in Badminton. *Comput. Biol. Med.* **2021**, *132*, 104302. [CrossRef] [PubMed]
5. Ooi, C.H.; Tan, A.; Ahmad, A.; Kwong, K.W.; Sompong, R.; Mohd Ghazali, K.A.; Liew, S.L.; Chai, W.J.; Thompson, M.W. Physiological characteristics of elite and sub-elite badminton players. *J. Sports Sci.* **2009**, *27*, 1591–1599. [CrossRef]
6. Pardiwala, D.N.; Subbiah, K.; Rao, N.; Modi, R. Badminton Injuries in Elite Athletes: A Review of Epidemiology and Biomechanics. *Indian J. Orthop.* **2020**, *54*, 237–245. [CrossRef]
7. Fastest Badminton Hit in Competition (Male). 2017. Available online: [https://www.guinnessworldrecords.com/world-records/fastest-badminton-hit-in-competition-\(male\)](https://www.guinnessworldrecords.com/world-records/fastest-badminton-hit-in-competition-(male)) (accessed on 1 June 2020).
8. Song, X.; Peng, Y.; Hu, B.; Liu, W. Characterization of the fine hand movement in badminton by a smart glove. *Instrum. Sci. Technol.* **2020**, *48*, 443–458. [CrossRef]
9. Zhang, S. Effects of fatigue on biomechanics of forehand smash in badminton. *J. Vibroeng.* **2020**, *22*, 1826–1833. [CrossRef]
10. Jorgensen, U.; Winge, S. Epidemiology of badminton injuries. *Int. J. Sports Med.* **1987**, *8*, 379–382. [CrossRef]
11. Miyake, E.; Yatsunami, M.; Kurabayashi, J.; Teruya, K.; Sekine, Y.; Endo, T.; Nishida, R.; Takano, N.; Sato, S.; Kyung, H.J. A prospective epidemiological study of injuries in Japanese national tournament-level badminton players from junior high school to university. *Asian J. Sports Med.* **2016**, *7*, e29637. [CrossRef] [PubMed]

12. Roman-Liu, D. External load and the reaction of the musculoskeletal system—A conceptual model of the interaction. *Int. J. Ind. Ergon.* **2013**, *43*, 356–362. [[CrossRef](#)]
13. Seidel, D.H.; Heinrich, K.; Hermanns-Truxius, I.; Ellegast, R.P.; Barrero, L.H.; Rieger, M.A.; Steinhilber, B.; Weber, B. Assessment of work-related hand and elbow workloads using measurement-based TLV for HAL. *Appl. Ergon.* **2021**, *92*, 103310. [[CrossRef](#)]
14. Li, L.; Martin, T.; Xu, X. A novel vision-based real-time method for evaluating postural risk factors associated with musculoskeletal disorders. *Appl. Ergon.* **2020**, *87*, 103138. [[CrossRef](#)]
15. Ferrara, L.; Cohen, A. A Mechanical Study on Tennis Racquets to Investigate Design Factors that Contribute to Reduced Stress and Improved Vibrational Dampening. *Procedia Eng.* **2013**, *60*, 397–402. [[CrossRef](#)]
16. Nhan, D.T.; Walter, K.; Jay Lee, R. Epidemiological patterns of alternative racquet-sport injuries in the United States, 1997–2016. *Orthop. J. Sports Med.* **2018**, *6*, 2325967118786237. [[CrossRef](#)]
17. Vanasant, T.; Mingkhumlert, S.; Limroongreungrat, W. The effect of string tension on shuttlecock velocity. In Proceedings of the 31 International Conference on Biomechanics in Sports, Taipei, Taiwan, 7–11 July 2013.
18. Miller, S. Modern tennis rackets, balls, and surfaces. *Br. J. Sports Med.* **2006**, *40*, 401–405. [[CrossRef](#)]
19. Laffaye, G.; Phomsoupha, M.; Dor, F. Changes in the Game Characteristics of a Badminton Match: A Longitudinal Study through the Olympic Game Finals Analysis in Men's Singles. *J. Sports Sci. Med.* **2015**, *14*, 584–590.
20. Grice, T. *Badminton: Steps to Success*; Human Kinetics: Champaign, IL, USA, 2008.
21. Ramli, A.S.S.; Kamalden, T.F.T.; Sharir, R.; Harith, H.H.; Hanafi, M.; Gasibat, Q.; Samsudin, S. Mechanical Interaction within Badminton Forehand Shot Technique: A Review Paper. *Int. J. Kinesiol. Sports Sci.* **2021**, *9*, 28–34. [[CrossRef](#)]
22. Zhang, Z.; Li, S.; Wan, B.; Visentin, P.; Jiang, Q.; Dyck, M.; Li, H.; Shan, G. The Influence of X-Factor (Trunk Rotation) and Experience on the Quality of the Badminton Forehand Smash. *J. Hum. Kinet.* **2016**, *53*, 9–22. [[CrossRef](#)] [[PubMed](#)]
23. Marta, S.; Vaz, J.R.; Silva, L.; Castro, M.A.; Correia, P.P. Study and Interpretation of Neuromuscular Patterns in Golf. In *Applications, Challenges, and Advancements in Electromyography Signal Processing*; Naik, G., Ed.; IGI Global: Hershey, PA, USA, 2014; pp. 181–201.
24. de Sire, A.; Marotta, N.; Demeco, A.; Moggio, L.; Paola, P.; Marotta, M.; Iona, T.; Invernizzi, M.; Leigheb, M.; Ammendolia, A. Electromyographic Assessment of Anterior Cruciate Ligament Injury Risk in Male Tennis Players: Which Role for Visual Input? A Proof-of-Concept Study. *Diagnostics* **2021**, *11*, 997. [[CrossRef](#)] [[PubMed](#)]
25. Dinis, R.; Vaz, J.R.; Silva, L.; Marta, S.; Pezarat-Correia, P. Electromyographic and kinematic analysis of females with excessive medial knee displacement in the overhead squat. *J. Electromyogr. Kinesiol.* **2021**, *57*, 102530. [[CrossRef](#)]
26. Türker, H.; Sözen, H. Surface Electromyography in Sports and Exercise. In *Electrodiagnosis in New Frontiers of Clinical Research*; IntechOpen: London, UK, 2013.
27. Lucas-Osma, A.M.; Collazos-Castro, J.E. Compartmentalization in the triceps brachii motoneuron nucleus and its relation to muscle architecture. *J. Comp. Neurol.* **2009**, *20*, 226–239. [[CrossRef](#)]
28. Sakurai, S.; Ohtsuki, T. Muscle activity and accuracy of performance of the smash stroke in badminton with reference to skill and practice. *J. Sports Sci.* **2000**, *18*, 901–914. [[CrossRef](#)]
29. Phomsoupha, M.; Laffaye, G.; Cohen, C.; Clanet, C. How to use the elasticity of a badminton racket to increase its speed by 80%? *Comput. Methods Biomech. Biomed. Eng.* **2015**, *18*, 2028–2029. [[CrossRef](#)]
30. BioSignalsPlux. Electromyography. 2019. Available online: <https://www.biosignalsplux.com/en/> (accessed on 1 June 2020).
31. Hermens, H.J.; Freriks, B.; Merletti, R.; Stegeman, D.; Blok, J.; Rau, G.; Disselhorst-Klug, C.; Hägg, G. European Recommendations for Surface Electromyography. *Roessingh Res. Dev.* **1999**, *8*, 13–54.
32. Kendall, F.P.; McCreary, E.K.; Provan, P.G.; Rodgers, M. *Muscles: Testing and Function with Posture and Pain*; Williams & Wilkins: Philadelphia, PA, USA, 2005.
33. Ghasemi, A.; Zahediasl, S. Normality Tests for Statistical Analysis: A Guide for Non-Statisticians. *Int. J. Endocrinol. Metab.* **2012**, *10*, 486. [[CrossRef](#)]
34. Jaitner, T.; Gawin, W. A mobile measure device for the analysis of highly dynamic movement techniques. *Procedia Eng.* **2010**, *2*, 3005–3010. [[CrossRef](#)]