Open Access

OBM Neurobiology

Original Research

Is Wheelchair Basketball a Symmetric or Asymmetric Sport?

Giacomo Farì [1, 2, *], Enrica Chiaia Noya [2], Laura Dell'Anna [2], Vincenzo Ricci [3], Francesco Quarta [4], Laura Masiero [5], Andrea Bernetti [1], Marisa Megna [2], Maurizio Ranieri [2]

1. Department of Experimental Medicine (Di.Me.S), University of Salento, 73100 Lecce, Italy; E-Mails: giacomo.fari@unisalento.it; andrea.bernetti@unisalento.it
2. Department of Translational Biomedicine and Neuroscience (DiBraiN), Aldo Moro University, Bari, Italy; E-Mails: enrica.chiaianoya@gmail.com; lauradellanna@gmail.com; marisa.megna@uniba.it; maurizio.ranieri@uniba.it
3. Physical and Rehabilitation Medicine Unit, Luigi Sacco University Hospital, ASST Fatebenefratelli-Sacco, Milan, Italy; E-Mail: ricci.vincenzo@asst-fbf-sacco.it
4. Department of Biological and Environmental Science and Technologies (Di.S.Te.B.A.), University of Salento, Lecce, Italy; E-Mail: francesco.quarta6@studenti.unisalento.it
5. Department of Statistical Science, University of Padova, Padova, Italy; E-Mail: laura.masiero.3@gmail.com

* **Correspondence:** Giacomo Farì; E-Mail: giacomo.fari@unisalento.it

Academic Editor: Virginia Barone

Special Issue: The New Frontiers of Neurological Rehabilitation: Sport, New Technologies and Advancements in Traditional Therapies

OBM Neurobiology
2024, volume 8, issue 2
doi:10.21926/obm.neurobiol.2402227

Received: January 16, 2024
Accepted: June 18, 2024
Published: June 25, 2024

Abstract

Wheelchair basketball (WB) is a health and inclusion opportunity for people with disabilities. In the scientific literature, no evidence defines WB as a symmetrical or asymmetrical sport; however, it would be helpful to deepen this aspect because it could improve the quality of training programs and consequently speed up WB performance. In WB, the biomechanical role of the shoulders is crucial. Therefore, the symmetry index and the activation of the bilateral supraspinatus and biceps brachii muscles were investigated to establish, with specific WB tests, whether it is a symmetrical or asymmetrical sport. Ten professional athletes were enrolled in this cross-sectional study. Each athlete was assessed by executing three tests on the field: sprint test, figure 8 test with the ball, and test without the ball. The symmetry index and muscle recruitment of the right and left supraspinatus and biceps brachii muscles were evaluated with a surface electromyograph. In all three tests, there was a positive correlation between muscle activations of the right and left supraspinatus muscles (sprint test: p-value 0.004; figure 8 without the ball: p-value 0.016; figure 8 with ball: p-value 0.009), while no correlation emerged between the muscle activities of the two brachial biceps (sprint test: p-value 0.155; figure 8 without ball: p-value 0.291, figure 8 with ball: p-value 0.9). There was a negative correlation between right biceps brachii muscle recruitment and performance in the figure 8 test without the ball and between right and left supraspinatus muscle recruitment and performance in the figure 8 test with the ball. Finally, no correlation was found between the symmetry index of the supraspinatus and brachial biceps muscles and the performance in the three tests. A p-value < 0.05 was considered significant for all tests. A higher and more symmetrical shoulder muscle recruitment does not lead to a better performance. WB could be regarded as an asymmetrical sport, particularly in sport-specific gestures, where technical skills are more important than muscle strength. Therefore, training should not aim to implement strength and symmetry but to improve the refinement and technical peculiarity of the athletic gesture.

Keywords
Wheelchair; basketball; muscles; rehabilitation; training; sport

1. Introduction

Wheelchair basketball (WB) is an increasingly popular sport. Over the last decade, Paralympic sports, particularly WB, have steadily gained interest [1, 2]. Born in the USA at the end of the 40s as a rehabilitation activity for veterans of the Second World War [3], WB today represents an excellent opportunity for physical activity, rehabilitation, and integration for people with disabilities [4]. Fundamental to increasing motor skills, WB also improves the emotional state of people who practice it [5]. Moreover, this sport is an excellent occasion for social inclusion and integration since one of its distinctive features is that athletes and amateurs with different disabilities share the playing court thanks to the classification system that assigns each player a score from 1 to 4.5 based on residual functional abilities and trunk stability [6]. In literature, upper limb muscle strength and aerobic and anaerobic capacity play a significant role in athletic performance among WB athletes with different classification scores [7].

Moreover, shoulder pain in WB players is an important topic [8], as it is an ongoing problem when it comes to injuries related to this sport [9]. It is so relevant that Yildirim et al. proposed a rating scale specifically dedicated to shoulder pain assessment in these athletes [10] and also attempted to investigate the connection between shoulder pain and trunk control in this activity [11]. Ultimately, Wilroy et al. created a 6-week intervention program to enhance sports performance and reduce the risk factors that increase susceptibility to pain or shoulder injury [12].

Considering the necessity to move in a wheelchair, in WB, the concept of symmetry of the sporting gesture revolves around the trunk and shoulders, which are also the anatomical districts most affected by sport-related overuse injuries [9]. In fact, during a WB match or training session, shoulders are constantly overloaded due to the need to move quickly, change direction, pass, and throw the ball. The most involved muscles during these gestures are supraspinatus and biceps brachii [13]. The supraspinatus is an abduction starter, while the biceps guarantee the flexion and supination of the forearm. Thus, it is intuitive that these movements are fundamental in the practice of a wheelchair sport and specifically in WB, which is one of the most demanding sports in terms of wheelchair mobility performance compared to other sports such as wheelchair tennis and wheelchair rugby [14]. To better understand the role carried out by these muscles, a deeper explanation of wheelchair propulsion is needed. The propulsion cycle is made up of two phases: the push phase, also called the force production phase, when hands and rims are in contact, and the recovery phase, also called the non-propulsive phase, when the hands and rims are not in contact each other [15]. The push phase synergy is primarily influenced by muscles engaged in external rotation, shoulder flexion, and scapular protraction. The recovery phase is mainly dominated by muscles involving extension, abduction, internal rotation, and scapular retraction. According to a previous study conducted to analyze muscle activity during wheelchair propulsion using EMG, supraspinatus displayed a high peak activity during the push phase. However, its activity is relevant in both phases. Supraspinatus is involved in external rotation during the push phase and abduction during the recovery phase. As previously declared, another critical muscle involved in wheelchair propulsion is the biceps, activated in the late recovery phase and reaching its peak activity during the last part of the backswing. Moreover, the biceps continue activity until the hand reaches the top dead center on the handrail [16].

Despite the interest in WB in scientific literature increasing in the last few years, the topic of symmetry or asymmetry is still studied exclusively among able-bodied basketball players [17, 18]. In WB, symmetry represents a recent and underexplored topic that only a few studies have considered. According to Maloney, sports can be categorized into different groups, with bilateral sports further divided into symmetric or asymmetric sports based on sporting asymmetries, defined as bilateral differences in specific sport-related parameters [19]. Regarding WB, Ferro et al. found asymmetry in wrist peak acceleration during a 20 m sprint test using inertial measurement systems, and this result was not associated with the classification score [20]. Another research aimed to evaluate the interlimb asymmetry of forces developed during an upper limb Wingate aerobic test in a WB player population, finding that forces were asymmetric for most participants [21].

Although these studies provided valuable contributions, there is still a lack of knowledge on this topic, an essential field of interest that could give new perspectives for training and prevention strategies.

2. Materials and Methods

This study aims to investigate whether WB is a symmetrical or asymmetrical sport and, more specifically, to analyze the activity of the shoulder muscles during specific field tests to examine if muscle engagement develops in bilateral differences.

An observational cross-sectional study was carried out.

Ten professional athletes were enrolled in the study. They all belonged to an Italian team competing in the second championship of the Italian Wheelchair Basketball Federation (FIPIC). The tests were conducted during the competitive phase of the same championship when the total training volume ranged from six to eight hours per week. All these players had been practicing WB at a competitive level for at least two years.

Each athlete was asked to read and sign the informed consent containing all the information and objectives of the study. Demographic data, somatic structures' information (sex, age, height, weight, dominant upper limb), and medical diagnosis for motor impairment were collected. The athletes were homogeneous in terms of disability since they all suffered from paraparesis and predominantly used wheelchairs in daily life activities. None of them had suffered recent injuries or had current musculoskeletal diseases.

To assess muscular activation, a surface electromyograph (mDurance®-mDurance Solutions SL, Granada, Spain) was simultaneously used to record and analyze the supraspinatus and biceps brachii muscles activation measured as Root Mean Square (RMS) expressed in microvolts [22, 23]. Two-channel bipolar sensors for recording the superficial muscle activity were positioned on the proximal 2/3 of the supraspinatus muscle and the distal third of the brachial biceps bilaterally [24].

All participants performed three field tests taken from a field battery of tests considered valid and reliable for WB players [25]. The three tests considered for this assessment, which were already used in previous studies [26], were taken to consider sport-specific gestures of WB, such as speed, wheelchair maneuverability, and wheelchair ball handling. Specifically, the field battery was conducted as follows:

Sprint test: this test consists of a 20-meter sprint in a straight line to evaluate speed. At the starting signal, the athlete sprints, covering a distance of 20 meters in a straight line in the shortest time possible. Two attempts were made, and only the best one was recorded.

Figure 8 test without the ball: this test evaluates the maneuverability of the wheelchair. At the starting signal, the athlete moves between two cones, located 5 meters from each other and equidistant from the halfway line, drawing a figure 8. The number of laps completed in 1 minute was recorded (rpm).

Figure 8 test with the ball: this test evaluates wheelchair maneuverability and WB motor skills. At the starting signal, the athlete moves between the same cones as above, drawing a figure 8 and handling the ball according to the current rules of the International Wheelchair Basketball Federation. The number of laps completed in 1 minute is recorded (rpm).

The tests were explained to the athletes before execution, ensuring each player warmed up for 5 minutes before each test and rested for 5 minutes immediately after. All the WB players were asked to wear the straps to make the test execution safe and homogeneous.

Ethical approval was granted by the Institutional Review Board of the Department of Biological and Environmental Sciences and Technologies of the University of Salento (approval number 2/2023). The principles of the Declaration of Helsinki performed all the procedures. Each athlete was asked to read and sign the informed consent containing all the information and objectives of the study.

2.1 Statistical Analysis

Data were analyzed with RStudio, a free statistical software environment for statistical computing and graphics.

Univariate linear regressions were used to appraise confounders, but none were found. The τ test (Tau test), a non-parametric hypothesis test for statistical dependence based on the τ coefficient (Kendall's τ), was used to assess a possible association between the variables. It is a particular case of a more general correlation coefficient, given that it does not rely on assumptions about the evaluated variables' distributions. This study chose the τ test because of the non-normality of the variables' distributions. Under the null hypothesis of independence between two variables, the sampling distribution of τ has an expected value of zero. The null hypothesis of the absence of correlation cannot be accepted when the p-value associated with τ is <0.05.

3. Results

Ten athletes were enrolled in the study, whose demographic characteristics are summarized in Table 1.

Table 1 Demographic characteristics of the sample.

Variable	Values
Sex; no. (%)	
Male	9 (90.0)
Female	1 (10.0)
Age (y); mean ± SD	35.5 ± 13.5 (15-53)
Height (m); mean ± SD (range)	1.68 ± 0.1 (1.55-1.79)
Weight (kg); mean ± SD (range)	70.4 ± 10.2 (55-85)
BMI; mean ± SD (range)	24.75 ± 1.33 (22.89-26.83)
Dominant upper limb; no. (%)	
Right	5 (50.0)
Left	5 (50.0)

Abbreviations: kg, kilogram; m, meter; SD, standard deviation; BMI, Body Mass Index.

In all three tests, a statistically significant positive correlation was found (p-value < 0.05) in the comparison between the RMS of the right supraspinatus and the RMS of the left supraspinatus. As the right supraspinatus RMS increases, the left supraspinatus RMS (p-value 0.004 for sprint test; p-value 0.016 for figure 8 test without ball 2; p-value 0.009 for figure 8 test with ball). All the RMS scores are expressed in microvolts. These findings are graphically described in Figure 1.

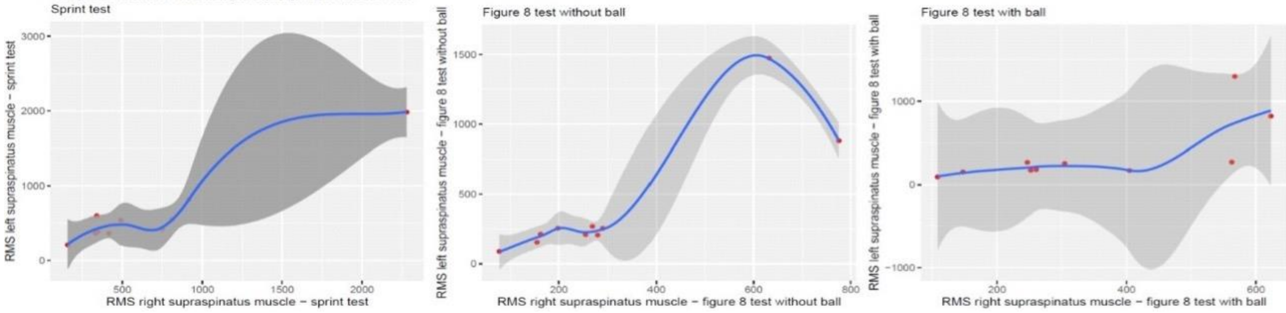

Figure 1 Comparison between left and right supraspinatus RMS in the three tests (RMS is expressed in microvolts).

The same comparison was repeated for the right and left biceps brachii muscles but, in this case, the correlation was weakly positive or negative, therefore not statistically significant (p-value 0.155 for sprint test; p-value 0.291 for figure 8 test without ball, p-value 0.9 for figure 8 test with ball).

Then, a comparison between the right and left supraspinatus RMS and the right and left biceps brachii RMS and the performance of the athletes in the three tests was performed.

There is a negative correlation between the right biceps brachii RMS and the performance in the figure 8 test without the ball and between the right and left supraspinatus RMS and the performance in the figure 8 test with the ball; therefore, when the muscle activation increases the related performance decreases. These findings are graphically described in Figure 2.

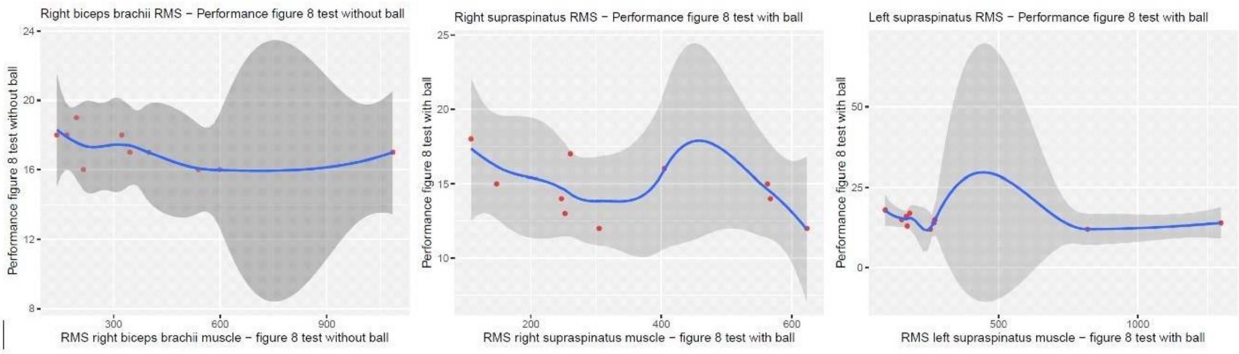

Figure 2 Comparison between right and left supraspinatus RMS (microvolts) and performance and between right biceps brachii RMS (microvolts) and performance in WB tests - significant correlations.

No further correlations were highlighted between the RMS of these muscles and the athletes' performance in the remaining evaluations. No statistically significant association emerged between the symmetry index of the supraspinatus and biceps brachii muscles and the performance in the three tests mentioned above.

4. Discussion

These results show that a more significant asymmetry in shoulder muscle recruitment guarantees a better WB-specific gesture and, therefore, a more effective performance. Thus, a training program focused on improving the refinement and technical precision of the athletic gesture may be the key to enhancing athletic WB players' performance.

An object showing exact correspondence between its left and right sides is defined as symmetrical [27]. Although to our eyes, the human body may appear symmetrical about a vertical axis because we have two arms, two legs, two eyes, and so on, in reality, it is not. Humans naturally prefer one side of their body when asked to perform a motor task [28, 29] and maintain an asymmetric posture for a long time, which can influence phenotypic plasticity [30]. Therefore, asymmetry appears part of human nature, behavior, and sporting activities [31, 32].

Practicing a sport is a highly complex activity that requires excellent physical ability and is sometimes characterized by asymmetric muscle activation, which is functional to better athletic sport-specific performance.

Many sports are characterized by rapid sequences of asymmetric gestures that combine strength and motor refinement, such as in football or golf, which are considered intrinsically asymmetric [33, 34]. However, WB has never been defined as a symmetrical or asymmetrical sport. It is unknown whether training athletes as if it were symmetrical or not to improve sport-specific performances is more beneficial.

From the analysis of the collected data, it emerged that, both in the sprint and figure 8 tests with and without the ball, the RMS of the right supraspinatus and that of the left one increase together, so the muscle activation seems symmetrical. However, the exact correspondence was not found in the muscular recruitment of the biceps brachii, so it would seem that the muscular activation of the two biceps is not symmetrical.

The difference between the muscle recruitment of the supraspinatus and the biceps could be justified because the supraspinatus is involved in load work, while the biceps are in precision and technical gesture activities. Consequently, the biceps are called to adapt, second by second and in a different way for each side, to perform fine movements [35]. Myers et al. demonstrated that biceps are muscles involved in rapid and precise athletic gestures [36]. Particularly concerning WB, athletes are called to activate the upper limbs differently than able-bodied athletes in carrying out specific gestures such as ball shooting [37]. The need to maintain a functional movement of all the joints of the upper limb despite motor limitations means that the fulcrum of the refined movement is not the shoulder alone but the shoulder-elbow complex, which, therefore, requires a more significant and delicate involvement of the biceps.

On the contrary, in wheelchair sports and the daily living of wheelchair users, the supraspinatus muscles are essential for strength activities, such as the movement of propulsion, since they guarantee the start of abduction and external rotation movements and allow control the shoulder range of motion (ROM) [38]. These muscles play an essential role in shoulder joint stability. Consequently, they are the first target in the rehabilitation protocols dedicated to WB players when they suffer from shoulder pain, primarily aiming to improve shoulder ROM and increase strength in activities such as linear sprinting [39].

In particular, the negative correlation between the right biceps brachii RMS and the performance in figure 8 test without ball and between the right and left supraspinatus RMS and the performance in figure 8 test with ball demonstrates that when an athlete is asked to perform a complex and sport-specific gesture, such as in figure 8 tests, shoulder muscles recruitment will be reduced compared to explosive strength tests, such as the sprint test. This further supports the hypothesis that technical gestures in WB require refined and precise movements to the detriment of strength. For this same reason, we consider the absence of correlation between SI of the supraspinatus and biceps brachii muscles and performance in the three exercises. All these findings demonstrate that a symmetrical activation of the shoulder muscles could not influence performance in WB athletes, like in other sports. Haugen et al. investigated possible associations between kinematic asymmetry and injury prevalence. They did not find any correlation [40] with the paper of Exell et al., which stated that strength imbalances are joint and task-specific [41]. Upon a more critical reading of these findings, however, it seems more correct to assume that an increased and symmetrical shoulder muscle recruitment does not translate into a better gesture in WB, which is a sport that requires extreme agility and specific muscle activation, that must change from side to side in every moment of the game. During a match, in a few seconds, a player can be called upon to receive and pass the ball, move quickly in a short space, and attempt to shoot with the greatest possible precision. So, these activities require a remarkable ability to work asymmetrically with the upper limbs and are more frequent than strength activities, which are also essential but less recurring.

So, the question we asked in the title was only intended to spur the curiosity of researchers in the field, and clearly, it is not easy to give a final answer. Nevertheless, our findings may be engaging in promoting new attention to asymmetric training for WB athletes' upper limbs to improve technique. Traditional training and rehabilitation protocols for WB players are based on shoulder symmetrical exercises that aim at enhancing strength without particular attention to the fluidity and agility of the gesture [12, 42]. On the contrary, future protocols should be more personalized and selective in muscle training while also taking advantage of increasingly precise detection tools such as inertial sensors [43] and surface electromyographs [39].

The need to improve an athlete's sporting performance is common to all sports, in which training must simultaneously increase performance and reduce the risk of injury [44, 45]. This necessity is even more significant in WB since players are persons with disability and often daily wheelchair users. For them, this sport is primarily an opportunity for rehabilitation. Therefore, training sessions must be aimed at improving performance without running the risk of overloading the musculoskeletal system with symmetrical workloads in the gym, which could be harmful and not very useful and involve unnecessary energy disposal. In fact, by perfecting their movements, athletes can minimize inefficiencies and make their sporting actions more advantageous and practical, enhancing their performance. Knowing the importance of the asymmetry of shoulder muscle activation and making technique prevail over strength could guide future training protocols for WB, as for other wheelchair sports with similar performance demands. This study has some limitations. First, the small sample size is because WB competitive athletes are few and are often busy with sports competitions, so involving them in scientific research isn't easy.

Moreover, the symmetry index and the RMS of only two shoulder muscles were investigated, while WB gestures involve many upper limbs and trunk muscles. This choice was made because supraspinatus and biceps are the most important in WB gestures, according to the available literature [46-48]. Finally, we did not distinguish the athletes concerning their essential medical diagnosis. Still, in this specific sample, it was not significant since the disabling outcome of these pathologies was the same for all players, i.e., paraplegia. Consequently, the motor disability was the same for all athletes.

5. Conclusions

Greater and symmetrical muscle recruitment does not translate into a better WB performance. On the contrary, an asymmetrical, rapid, and precise activation of the muscle involved in sport-specific gestures seems more valuable and functional for WB performance. WB is a complex sport in which technical skills may be more important than muscular strength and often imposes asymmetric gestures.

Further studies are necessary to delve into these results, which are still preliminary, aiming for increasingly effective and safe training programs for WB players.

Acknowledgments

The authors would like to thank the Italian Wheelchair Basketball Federation (FIPIC) for the support in the athletes' enrollment in this study.

Author Contributions

GF: contributed to conception, design of the study, data collection and analysis, and wrote the draft of the manuscript. ECN and LDA: contributed to conception, data collection and design of the study. AB and VR: contributed to manuscript revision. MR and MM: supervised the study. LM: contributed to data analysis. All authors discussed the results and contributed to the final manuscript.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Competing Interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement

The datasets used and analysed during the current study will be made available upon reasonable request to the corresponding author, G.F. giacomo.fari@unisalento.it

References

1. Gil-Agudo A, Del Ama-Espinosa A, Crespo-Ruiz B. Wheelchair basketball quantification. Phys Med Rehabil Clin. 2010; 21: 141-156.
2. Farì G, Fiore P, Ricci V, Zonno A, Joksimovic M, Petruzzella D, et al. The impact of the COVID-19 pandemic on outdoor physical activities for people with disabilities, including the risks for psychophysical well-being. Sustainability. 2023; 15: 1436.
3. Farì G, Megna M, Fiore P, Ranieri M, Marvulli R, Bonavolontà V, et al. Real-time muscle activity and joint range of motion monitor to improve shoulder pain rehabilitation in wheelchair basketball players: A non-randomized clinical study. Clin Pract. 2022; 12: 1092-1101.
4. Petrigna L, Pajaujiene S, Musumeci G. Physical fitness assessment in wheelchair basketball: A mini-review. Front Sports Act Living. 2022; 4: 1035570.
5. Farì G. Sports for people with disabilities: A way for rehabilitation and social inclusion. J Back Musculoskelet Rehabil. 2023; 36: 1217-1218.
6. Macchiarola D, Megna M, Quarta F, Bianchi FP, Cipriano R, Andrani M, et al. With or without straps? A pilot study to investigate whether restraint devices affect the wheelchair basketball players' performance. Prosthet Orthot Int. 2023; 47: 519-524.
7. Soylu Ç, Yıldırım NÜ, Akalan C, Akınoğlu B, Kocahan T. The relationship between athletic performance and physiological characteristics in wheelchair basketball athletes. Res Q Exerc Sport. 2021; 92: 639-650.
8. Tsunoda K, Mutsuzaki H, Hotta K, Tachibana K, Shimizu Y, Fukaya T, et al. Correlates of shoulder pain in wheelchair basketball players from the Japanese national team: A cross-sectional study. J Back Musculoskelet Rehabil. 2016; 29: 795-800.

9. Farì G, Macchiarola D, Quarta F, Bianchi FP, Caforio L, Cutti AG, et al. Epidemiology of injuries in wheelchair basketball: Trauma versus overuse mechanism and prevention rehabilitative strategies. J Prosthet Orthot. 2023; 35: 32-37.
10. Yıldırım NÜ, Büyüköztürk Ş, Bayramlar K, Özengin N, Külünkoğlu BA, Çoban Ö. Developing a shoulder pain scale for wheelchair basketball players. J Back Musculoskelet Rehabil. 2019; 32: 479-485.
11. Yildirim NU, Comert E, Ozengin N. Shoulder pain: A comparison of wheelchair basketball players with trunk control and without trunk control. J Back Musculoskelet Rehabil. 2010; 23: 55-61.
12. Wilroy J, Hibberd E. Evaluation of a shoulder injury prevention program in wheelchair basketball. J Sport Rehabil. 2018; 27: 554-559.
13. Farì G, Latino F, Tafuri F, Dell'Anna L, Raele MV, Fai A, et al. Shoulder pain biomechanics, rehabilitation and prevention in wheelchair basketball players: A narrative review. Biomechanics. 2023; 3: 362-376.
14. van der Slikke RM, Berger MA, Bregman DJ, Veeger DH. Wearable wheelchair mobility performance measurement in basketball, rugby, and tennis: Lessons for classification and training. Sensors. 2020; 20: 3518.
15. Theisen D, Daly D. Wheelchair propulsion biomechanics: Implications for wheelchair sports. Sports Med. 2001; 31: 339-367.
16. Mulroy SJ, Gronley JK, Newsam CJ, Perry J. Electromyographic activity of shoulder muscles during wheelchair propulsion by paraplegic persons. Arch Phys Med Rehabil. 1996; 77: 187-193.
17. Fort-Vanmeerhaeghe A, Benet-Vigo A, Montalvo A, Arboix A, Buscà B, Arboix-Alió J. Relationship between performance and inter-limb asymmetries using flywheel resistance device in elite youth female basketball players. Biology. 2022; 11: 812.
18. Poliszczuk T, Mańkowska M, Poliszczuk D, Wiśniewski A. Symmetry and asymmetry of reaction time and body tissue composition of upper limbs in young female basketball players. Pediatr Endocrinol Diabetes Metab. 2013; 19: 132-136.
19. Maloney SJ. The relationship between asymmetry and athletic performance: A critical review. J Strength Cond Res. 2019; 33: 2579-2593.
20. Ferro A, Pérez-Tejero J, Garrido G, Villacieros J. Relationship between sprint capacity and acceleration of wrists in wheelchair basketball players: Design and reliability of a new protocol. Int J Environ Res Public Health. 2021; 18: 10380.
21. Brassart F, Faupin A, Hays A, Bakatchina S, Alberca I, Watelain E, et al. Upper limb cranking asymmetry during a Wingate anaerobic test in wheelchair basketball players. Scand J Med Sci Sports. 2023; 33: 1473-1485.
22. Calabrò RS, Filoni S, Billeri L, Balletta T, Cannavò A, Militi A, et al. Robotic rehabilitation in spinal cord injury: A pilot study on end-effectors and neurophysiological outcomes. Ann Biomed Eng. 2021; 49: 732-745.
23. Farì G, Megna M, Ranieri M, Agostini F, Ricci V, Bianchi FP, et al. Could the improvement of supraspinatus muscle activity speed up shoulder pain rehabilitation outcomes in wheelchair basketball players? Int J Environ Res Public Health. 2022; 20: 255.
24. Molina-Molina A, Ruiz-Malagón EJ, Carrillo-Pérez F, Roche-Seruendo LE, Damas M, Banos O, et al. Validation of mDurance, a wearable surface electromyography system for muscle activity assessment. Front Physiol. 2020; 11: 606287.
25. Vanlandewijck YC, Daly DJ, Theisen DM. Field test evaluation of aerobic, anaerobic, and

wheelchair basketball skill performances. Int J Sports Med. 1999; 20: 548-554.
26. Ferreira da Silva CM, de Sá KS, Bauermann A, Borges M, de Castro Amorim M, Rossato M, et al. Wheelchair skill tests in wheelchair Basketball: A systematic review. PloS One. 2022; 17: e0276946.
27. Van Valen L. A study of fluctuating asymmetry. Evolution. 1962; 16: 125-142.
28. Howells H, Thiebaut de Schotten M, Dell'Acqua F, Beyh A, Zappalà G, Leslie A, et al. Frontoparietal tracts linked to lateralized hand preference and manual specialization. Cereb Cortex. 2018; 28: 1-13.
29. Afonso J, Bessa C, Pinto F, Ribeiro D, Moura B, Rocha T, et al. Asymmetry as a foundational and functional requirement in human movement: From daily activities to sports performance. Singapore: Springer Nature; 2020.
30. Fullin A, Caravaggi P, Lus G, Melone MA, Sampaolo S, Lucariello A. Long-term effects of asymmetrical posture in boxing assessed by baropodometry. J Sports Med Phys Fit. 2021; 62: 350-355.
31. Bishop C. Interlimb asymmetries: Are thresholds a usable concept? Strength Cond J. 2021; 43: 32-36.
32. Fohanno V, Nordez A, Smith R, Colloud F. Asymmetry in elite rowers: Effect of ergometer design and stroke rate. Sports Biomech. 2015; 14: 310-322.
33. McLean BD, Tumilty DM. Left-right asymmetry in two types of soccer kick. Br J Sports Med. 1993; 27: 260-262.
34. Cole MH, Grimshaw PN. The biomechanics of the modern golf swing: Implications for lower back injuries. Sports Med. 2016; 46: 339-351.
35. Landin D, Thompson M, Jackson MR. Actions of the biceps brachii at the shoulder: A review. J Clin Med Res. 2017; 9: 667-670.
36. Myers JM, Lephart SM, Rodosky MW, Ju YY, Fu F. Role of the biceps brachii during throwing: An EMG Study. Proceedings of the 49th Annual Meeting of the Orthopaedic Research Society; 2003 February 2-5; New Orleans, LA, USA. Rosemont: Orthopaedic Research Society.
37. Nunome H, Doyo W, Sakurai S, Ikegmai Y, Yabe K. A kinematic study of the upper-limb motion of wheelchair basketball shooting in tetraplegic adults. J Rehabil Res Dev. 2002; 39: 63-71.
38. Finley MA, Rasch EK, Keyser RE, Rodgers MM. The biomechanics of wheelchair propulsion in individuals with and without upper-limb impairment. J Rehabil Res Dev. 2004; 41: 385-395.
39. Farì G, Quarta F, Longo SC, Masiero L, Ricci V, Coraci D, et al. How does classification score affect falls in wheelchair basketball? A video-based cross-sectional study on the Italian national team during the European Para Championships 2023. Phys Ther Sport. 2024; 67: 77-82.
40. Haugen T, Danielsen J, McGhie D, Sandbakk Ø, Ettema G. Kinematic stride cycle asymmetry is not associated with sprint performance and injury prevalence in athletic sprinters. Scand J Med Sci Sports. 2018; 28: 1001-1008.
41. Exell T, Irwin G, Gittoes M, Kerwin D. Strength and performance asymmetry during maximal velocity sprint running. Scand J Med Sci Sports. 2017; 27: 1273-1282.
42. Rum L, Sten O, Vendrame E, Belluscio V, Camomilla V, Vannozzi G, et al. Wearable sensors in sports for persons with disability: A systematic review. Sensors. 2021; 21: 1858.
43. Notarnicola A, Covelli I, Maccagnano G, Marvulli R, Mastromauro L, Ianieri G, et al. Extracorporeal shockwave therapy on muscle tissue: The effects on healthy athletes. J Biol Regul Homeost Agents. 2018; 32: 185-193.

44. Farì G, Notarnicola A, Covelli I, Moretti B. Epidemiology of injuries in water board sports: Trauma versus overuse injury. J Sports Med Phys Fit. 2021; 61: 707-711.
45. Farì G, Santagati D, Macchiarola D, Ricci V, Di Paolo S, Caforio L, et al. Musculoskeletal pain related to surfing practice: Which role for sports rehabilitation strategies? A cross-sectional study. J Back Musculoskelet Rehabil. 2022; 35: 911-917.
46. Akınoğlu B, Kocahan T. Characteristics of upper extremity's muscle strength in Turkish national wheelchair basketball players team. J Exerc Rehabil. 2017; 13: 62-67.
47. García-Gómez S, Pérez-Tejero J, Hoozemans M, Barakat R. Effect of a home-based exercise program on shoulder pain and range of motion in elite wheelchair basketball players: A non-randomized controlled trial. Sports. 2019; 7: 180.
48. Veeger TT, De Witte AM, Berger MA, van der Slikke RM, Veeger DH, Hoozemans MJ. Improving mobility performance in wheelchair basketball. J Sport Rehabil. 2019; 28: 59-66.