SPORT BIOMECHANICS BEFORE AND AFTER THE RIO 2016 PARALYMPIC GAMES

BIOMECÂNICA DO ESPORTE ANTES E DEPOIS DOS JOGOS PARALIMPÍCOS RIO 2016

BIOMECÁNICA DEL DEPORTE ANTES Y DESPUÉS DE LOS JUEGOS PARALÍMPICOS RIO 2016

Review Article
Artigo de Revisão
Artículo de Revisión

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ABSTRACT

Introduction: Events such as the Paralympic Games leave a series of legacies in the host societies. This is also applicable to the development of associated scientific knowledge, particularly in the field of sports biomechanics. Objective: The objective of this study is to investigate the Brazilian scientific production in the field of biomechanics in Paralympic sports during the cycle that preceded and followed the Rio 2016 Paralympic Games. Additionally, the study aims to provide insights for future research endeavors. Methods: The search was conducted on the Lattes Platform, utilizing the filters "Assunto" and "Doutores" and the keywords "Paralímpico" and "Paralympic." In total, 723 authors were identified who published articles related to the topic. Subsequently, the curricula were accessed, and the articles were sorted and identified, resulting in 37 articles that met all inclusion criteria. Results: The results indicate that: a) Brazil witnessed an increase in the number of publications after London 2012; b) The majority of these productions (87%) originate from Public Institutions; c) There was a greater participation of other regions of Brazil in the production of knowledge in the area after Rio 2016; d) Individual modalities such as powerlifting and athletics were the most researched, despite Brazil's reference status in some collective modalities; e) Women remain a minority, both as participants in research and as authors of publications; f) The productions demonstrate high levels of quality; g) The most commonly used research techniques in biomechanics were kinematics and dynamometry. Conclusion: The field of biomechanics in Paralympic sports has significantly benefited from the legacy generated by the Rio 2016 Paralympics. As future challenges for researchers, the following aspects stand out: maintaining the quality of productions, expanding studies to include collective modalities, increasing the participation of other federated entities in the production of knowledge in this field, promoting greater gender equity, and incorporating new research techniques in biomechanics. ***Level of Evidence II; Review Study.***

Keywords: Para-Athletes; Biomechanical Phenomena; Sports for Persons with Disabilities.

RESUMO

Introdução: Eventos como os Jogos Paralímpicos deixam uma série de legados nas sociedades que as sediam. Não seria diferente quando se trata do desenvolvimento do conhecimento científico associado, em especial a biomecânica do esporte. Objetivo: Investigar a produção científica brasileira produzida em biomecânica no esporte paralímpico no ciclo que antecedeu e sucedeu os Jogos Paralímpicos Rio 2016, além de fornecer insights para novos estudos. Métodos: Foram realizadas buscas na Plataforma Lattes, sendo habilitados os filtros "Assunto" e "Doutores", com as palavras-chave "Paralímpico" e "Paralympic". Ao todo, foram encontrados 723 autores que publicaram artigo(s) relacionado(s) com o tema. Após acessar os currículos, os artigos foram triados e identificados, resultando em 37 artigos que preencheram todos os critérios de inclusão. Resultados: Os resultados mostram que a) Após Londres-2012, o Brasil tem aumentado o número de publicações; b) Grande parte das produções (87%) são oriundas de Instituições Públicas, c) Após Rio-2016 houve uma maior participação de outras regiões do Brasil na produção do conhecimento na área, d) Apesar do Brasil ser referência em algumas modalidades coletivas, modalidades individuais como o powerlifting e o atletismo, são as mais pesquisadas, e) Mulheres ainda são minoria, tanto como participantes das pesquisas quanto na autoria das publicações, f) As produções atingem elevados extratos de qualidade, g) As técnicas de pesquisa em biomecânica mais utilizadas foram a cinemática e dinamometria. Conclusão: A biomecânica no esporte paralímpico tem se valido do legado gerado pelas paralimpíadas Rio-2016. Como desafios futuros para os pesquisadores, destacam-se: manutenção da qualidade das produções, ampliação dos estudos para as modalidades coletivas, aumento da participação de outros entes federados na produção do conhecimento na área, promoção de uma maior equidade de gênero e incorporação de novas técnicas de pesquisa em biomecânica. ***Nível de Evidência II; Estudo de Revisão****.*

Descritores: *Paratletas; Fenômenos Biomecânicos; Esportes para Pessoas com Deficiência.*

Associate Editor responsible for the review process: André Pedrinelli

RESUMEN

Introducción: Eventos como los Juegos Paralímpicos dejan una serie de legados en las sociedades anfitrionas. Esto también es aplicable al desarrollo de conocimiento científico asociado, especialmente en el campo de la biomecánica deportiva. Objetivo: El objetivo de este estudio es investigar la producción científica brasileña en el campo de la biomecánica en deportes paralímpicos durante el ciclo que precedió y siguió a los Juegos Paralímpicos de Río 2016. Además, el estudio tiene como propósito brindar ideas para futuros esfuerzos de investigación. Métodos: La búsqueda se realizó en la Plataforma Lattes, utilizando los filtros " Assunto " y "Doutores" y las palabras clave "Paralímpico" y "Paralympic". En total, se identificaron 723 autores que publicaron artículos relacionados con el tema. Posteriormente, se accedió a los currículos y se clasificaron e identificaron los artículos, lo que resultó en 37 artículos que cumplieron con todos los criterios de inclusión. Resultados: Los resultados indican que: a) Brasil experimentó un aumento en el número de publicaciones después de Londres 2012; b) La mayoría de estas producciones (87%) provienen de Instituciones Públicas; c) Después de Río 2016, hubo una mayor participación de otras regiones de Brasil en la producción de conocimiento en el área; d) Las modalidades individuales, como levantamiento de pesas y atletismo, fueron las más investigadas, a pesar del estatus de referencia de Brasil en algunas modalidades colectivas; e) Las mujeres siguen siendo una minoría, tanto como participantes en investigaciones como autoras de publicaciones; f) Las producciones demuestran altos niveles de calidad; g) Las técnicas de investigación más utilizadas en biomecánica fueron la cinemática y la dinamometría. Conclusión: El campo de la biomecánica en deportes paralímpicos ha sido significativamente beneficiado por el legado generado por los Juegos Paralímpicos de Río 2016. Como desafíos futuros para los investigadores, se destacan los siguientes aspectos: mantener la calidad de las producciones, ampliar los estudios para incluir modalidades colectivas, aumentar la participación de otras entidades federadas en la producción del conocimiento en este campo, promover una mayor equidad de género e incorporar nuevas técnicas de investigación en biomecánica. ***Nivel de Evidencia II; Estudio de Revisión.***

Descriptores: *Paratletas; Fenómenos Biomecánicos; Deportes para Personas con Discapacidad.*

DOI: http://dx.doi.org/10.1590/1517-8692202430022022_0001i Article received on 01/25/2022 accepted on 05/25/2023

INTRODUCTION

In the Tokyo-2020 Paralympics, Brazil obtained the same number of medals as in Rio-2016 (72 medals), but surpassed the number of golds (22 medals). In the same year, Brazil made history by winning the 100th gold medal in Paralympic Games, reaching a total of 109 medals.[1] The evolution of Brazilian Paralympic sport took a big leap after the creation of the Brazilian Paralympic Committee (CPB) in 1995, which started the organization and planning of the sport as we know it, and since Beijing-2008 it has figured among the *Top-10* Paralympic Powers. Another factor that has contributed to the evolution of Brazilian performance is the close relationship between the CPB and Universities, especially public ones, through the creation of Reference Centers, Paralympic Seminars, and International Paralympic Congresses. These strategies, in addition to being important to expand the access of parathletes to training sites, also contribute to the formation of human resources and dissemination of scientific knowledge produced on the subject. Part of this scientific knowledge produced in the context of Paralympic sport has been used to improve the training routines of these athletes, reflecting in the improvement in sports performance.[2,3]

According to the Brazilian Academy of Sciences,[4] 95% of all Brazilian scientific production is developed by public institutions, which depend largely on public funding. However, resources destined to science and technology have suffered successive budget cuts that affect the evolution of scientific knowledge in all areas,[5] including in sport sciences. In this context, we find biomechanics of sport, an area of activity of biomechanics, which can be defined as the application of the laws of mechanics to living organisms and biological tissues.[6] Biomechanics is part of the mandatory curriculum of the main Physical Education courses in Brazil.

Traditionally, biomechanics of sport uses research techniques that involve kinemetry, dynamometry, anthropometry, and electromyography,[7] in isolation or in association way, in order to approach different forms of human movement. However, in recent years, Brazilian researchers working with sports biomechanics have included infrared thermography[8,9] and ultrasonography[10] as techniques to assess thermal regulation and muscle architecture, respectively, and their relationships with aspects such as strength production and muscle fatigue, among others. Knowing the importance of research in sports science to generate applied knowledge and in the qualification of professionals who will work in sport, it is imagined that Brazil, as a Paralympic power, is also generating an important volume of scientific knowledge on this theme. However, to date, no studies were found in the literature that grouped Brazilian scientific production involving biomechanics in Paralympic sport.

Therefore, in the current study we describe the Brazilian scientific production on biomechanics in Paralympic sport published in the cycles that preceded and followed the Rio-2016 Paralympic Games. We hypothesized that the Rio-2016 Paralympic Games left legacies, including in the scientific culture around parasport, especially in biomechanics, and that this has persisted, despite the difficulties facing Brazilian science in recent years.

MATERIALS AND METHODS

Selection of articles

Considering that the study was restricted to Brazilian scientific production, we chose to carry out the search on the Lattes Platform. Two searches were performed on September 26, 2021, with the "Subject" and "Doctors" filters being enabled on the platform. Initially, the keyword "*Paralímpico*" was used, with 393 authors being found. In the second search, the keyword used was "*Paralympic*", with 330 authors being found. In all, 723 authors were found with a publication related to the topic. Of note, the Lattes Platform does not allow the use of more advanced search algorithms. Next, the evaluators (YBH) and (KSGS) accessed all the curriculums, in which the articles were screened and identified.

The inclusion criteria adopted were: a) the 1st author was required to be Brazilian; b) articles needed to involve Paralympic modalities; c) a biomechanics research technique was required to have been used in the articles; d) being published in international journals; and e) being

published between January 2012 and September 2021. After reading the titles of the articles, they were *downloaded* to the *Mendeley®* reference manager, where duplicate articles were removed. The summaries of all the identified articles were read in order to confirm the proximity to the topic (biomechanics and Paralympic sport). If there were doubts among the evaluators, a third evaluator (MR) was consulted. A total of 37 articles met the inclusion criteria, and their details are described in Table 1.

RESULTS AND DISCUSSION

Chronology of the publications

The largest number of articles published involving biomechanics in Paralympic sports occurred in the year of the Rio-2016[11-17] and Tokyo-2020 Paralympics,[18-24] when the games were planned in Japan (the Paralympics were held in 2021 due to the COVID-19 Pandemic), both with seven

Table 1. Overview of studies in biomechanics and Paralympic sports.

Authors	Institution	Objective	Modality	Athletes	Biomechanical instrumentation	Biomechanical parameters evaluated	Conclusions
Aidar et al.[29]	UFS	Evaluate sticking point strength indicators in Paralympic powerlifting athletes.	Powerlifting	12 men	Linear transducer Load cell Electromyograph	Maximum Isometric Force (MIF) Rate of Force Development (RFD) Time to reach the MIF (TMIF) Velocity (Vel) Dynamic time (DT) EMG	The MIF, RFD, TMIF, and Vel. tend to be harmed at the beginning and after the sticking point.
Bernardina et al.[37]	UFMG	Quantify the asymmetries in bench press performance at different submaximal intensities using FANOVA.	Powerlifting	8 men 2 women	2D Kinematics	Mean velocity (MV) at 50 and 90% 1RM	FANOVA analysis is able to identify asymmetries in the different phases of the movement.
Resende et al.[30]	UFS	Evaluate the effect of different types of warm ups on the strength and skin temperature of Paralympic powerlifting athletes.	Powerlifting	15 men	Thermographic camera Linear transducer Force sensor	Skin temperature Dynamic and static force (Impulse, variability, and peak torque)	The types of warm-up studied do not seem to interfere in the performance of Paralympic powerlifting athletes. However, thermal images showed that traditional warm-ups better meet the expected objectives for this preparation phase.
Ribeiro Neto et al.[28]	SARAH Network	To verify the relationships between the medicine ball throw (MBT) and the field tests of mobility performance in wheelchair basketball and the peak torque of the shoulder and trunk in male and female WCB beginners.	Wheelchair basketball	19 men 18 women	Isokinetic dynamometer	Concentric peak torque Voluntary isometric peak torque	The MBT, a simple and feasible test, can be used to estimate and determine the wheelchair mobility performance of female and male WCB beginners.
Teles et al.[31]	UFS	Analyze dynamic and static strength indicators, at different intensities, on the performance of athletes with and without spinal cord injury.	Powerlifting	9 men (LM) 10 men (other disabilities)	Linear transducer Load cell Electromyograph	Maximum Isometric Force (MIF) Rate of Force Development (RFD) Time to reach MIF (TMIF) Impulse Fatigue Index (FI) Variability Mean propulsive velocity (MPV) Maximum velocity (Velmax) Power (W) sEMG	Static and dynamic strength indicators are similar in Paralympic weightlifters with spinal cord injury and other disabilities.
Dos Santos et al.[18]	UFS	Evaluate the use of different grip widths on powerlifting performance.	Powerlifting	12 men	Calipers Load cell Electromyograph	Mean propulsive velocity (MPV) Maximum Isometric Force (MIF) Time to reach MIF (TMIF) sEMG	At 25% of 1RM and with grip at 1.5 BAD, the highest MIF and MPV occurred. With 1.5 BAD a smaller TMIF was needed to reach 30%, 50%, and 100% of the MIF.
Fischer et al.[19]	UFSC	Compare the bioenergetic and biomechanical parameters of athletes with quadriplegia and paraplegia at submaximal speeds.	Handcycle	15 men 2 women	Power meter (crank)	Velocity (Vel) Mechanical power (W) Mechanical efficiency (ME%) Metabolic Power (MP)	Tetraplegics presented lower aerobic performance but similar metabolic costs compared to paraplegics at submaximal velocities.
Fraga et al.[20]	UFS	To evaluate the effect of ibuprofen ingestion in post-training recovery on muscle injury indicators, body temperature, and muscle power.	Powerlifting	8 men	Load cell Thermographic camera	Maximum Isometric Force (MIF) Rate of Force Development (RFD) Skin temperature (Temp)	The effect of ibuprofen in preventing the normal decrease in muscle temperature during post-exercise recovery could potentially be indicative of a delay in the anti-inflammatory response.

Loturco et al.[21]	NAR	Investigate the association between the ideal power load in the exercises bench press, shoulder press, and prone bench pull and acceleration and performances in wheelchair basketball players.	Wheelchair basketball	11 men	Photocell Linear transducer	Sprint Velocity (Vsprint) Acceleration (Accel) Load (L) Mean propulsive velocity (MPV)	Players who produce more power in certain strength-power exercises are also able to accelerate faster and reach higher speeds over short distances (5, 10, and 20 m).
Ribeiro Neto et al.[22]	SARAH Network	Verify the differences in total load, bar path in the sagittal plane, and mean bar velocity between the arched and flat bench press techniques in beginners (BG) and experienced (EG) Paralympic lifters.	Powerlifting	28 men 15 women	60 Hz camera	Full load Mean velocity Displacement: vertical, horizontal, and resultant Total Distance	The total load, bar path in the sagittal plane, and mean bar velocity were not significantly different between the arched and flat techniques for experienced athletes and powerlifting beginners during the eccentric and concentric phases of the movement.
Sampaio et al.[23]	UFS	To analyze the effect of creatine supplementation (Cr) on peak torque (PT) and fatigue rate in bodybuilding Paralympic athletes.	Powerlifting	8 men	Load cell	Force (Kgf) Force (N) Peak torque (PT) Rate of force development (RFD) Maximum isometric strength (time)	Creatine supplementation has a positive effect on the performance of Paralympic powerlifting athletes, reducing the fatigue index and maintaining strength levels as well as PT.
Weber et al.[24]	UEL	Propose field tests to estimate the anaerobic power of wheelchair basketball athletes.	Wheelchair basketball	11 men	Balance Bioelectrical impedance Manual dynamometer Cycle ergometer	Anthropometry Handgrip strength Peak power Mean power	The combination of field tests and anthropometric measurements seems to be appropriate to determine the anaerobic power of basketball wheelchair athletes in the lower classes.
Coswig et al.[44]	UFPA	Evaluate the reliability of MyJump2 app measurements to assess vertical jump performance.	7-a-side soccer	40 men	Contact platform Jump app	Jump height Flight time	The MyJump2 app features high validity and reliability to measure the jump height and flight time of squat jumps and countermovement jumps in soccer athletes with cerebral palsy.
Feitosa et al.[47]	UECE	Evaluate the kinematic, coordinative, and efficiency parameters measured in VO2max in swimmers with physical disabilities; Correlate these biomechanical parameters with time for a maximum test of 200 m.	Swimming	7 men 4 women	3D Kinematics	Stroke rate (SR) Stroke length (SL) Mean swimming speed (SS) Intracyclic velocity variation (IVV)	Swimmers with less significant impact of physical disability on specific swimming tasks had higher SL, SS, and propulsion efficiency. In general, the catch-up arm coordination model was adopted.
Kons et al.[48]	UFSC	Evaluate the postural and neuromuscular control of judo athletes with and without visual impairment.	Judo	2 men	Manual dynamometer Force platform	Center of pressure (COP) Manual pressing force (FPM) Jump height (Alt.) Power (W) Maximum force (MF) Força de pressão manual (FPM)	The athlete with visual impairment showed greater balance in neutral and anteroposterior positions. The visually impaired athlete performed better in the squat jump, but lower performance in jumping against movement and handgrip strength test.
Loturco et al.[25]	NAR	To analyze the relationships between different load intensities and movement speeds in bench press exercise.	Powerlifting	8 men 8 male little people 5 women	Linear transducer	Mean velocity (MVel) Mean propulsive velocity (MPV) Peak velocity (PV)	The load-velocity relationship is strong and accurate in Paralympic lifters, especially at higher load intensities (≥70% 1RM). These athletes can perform 1RM tests at velocities lower than those previously reported in the literature.
Machado et al.[32]	UNICAMP	Evaluate peak torque and fatigue index in simulated wheelchair propulsion.	Rugby	6 men	Isokinetic dynamometer	Peak torque (PT) Fatigue index (FI)	Athletes do not show differences in PT and TI between limbs.
Monezi et al.[33]	UNICAMP	Analyze time-motion of goalball players in official attacks considering the player's position, execution technique, and attack phases.	Goalball	16 men	60Hz camera	Distance covered by player Time spent Mean player velocity Maximum player velocity	Wingers made most of the shots and had higher values in all of the variables compared to centers, both in the preparation and attacking phases. The swing and throwing between the legs techniques presented higher values than the frontal technique in both attack phases.

Oliveira et al.[42]	UFRJ	Analyze the dermatoglyphic and body composition characteristics.	5-a-side soccer	13 men	Skinfold Compass Calipers Balance	Anthropometry	The study found similarities between wings and goalkeepers, as well as between defense and pivots for most variables. The somatotypical profile presented by the athletes indicated the predominance of the muscular component in all tactical positions played in the game.
Simim[46]	UFC	To investigate the demands (i.e., distances covered and acute physiological responses) of the amputee soccer match game (AS) and its impact on muscle endurance and power.	7-a-side soccer	16 men	GPS Accelerometer	Total distance Relative distance Mean velocity Maximum velocity Jump height Force production (absolute and relative)	Small differences were found between the first and second half for the total distance covered and in various speed categories, in addition, all neuromuscular performance measures decreased after the match.
Antunes et al.[39]	UFSC	Evaluate power parameters, muscle imbalance and asymmetry indices in sprinters with cerebral palsy from different functional classes.	Athletics	4 men	Isokinetic dynamometer Force platform	Concentric peak torque Eccentric peak torque Conventional ratio Functional ratio Asymmetry index Jump height Peak power	Athletes with more severe cerebral palsy presented lower jumping performance and torque production of the knee extensors and flexors, in addition to presenting greater asymmetries between the limbs. Considering the results of athlete T37, it seems that training for a longer period could reverse part of the neuromuscular impairments caused by cerebral palsy.
Loturco et al.[2]	NAR	Describe the variations in the power performance of judokas in three consecutive training cycles in preparation for the ParaPan American Games, the World Championship, and the Paralympic Games.	Judo	11 men	Contact platform Linear transducer	Jump height Mean propulsive power	The power of the lower limbs gradually increased throughout the training period, reaching its maximum value immediately before the Paralympic Games. In addition, in this phase, the judokas produced the greatest power outputs in the PB and PBP exercises; and (3) equally, the best performances in the SJ and CMJ tests were achieved in this period.
Gorla et al.[11]	UNICAMP	Investigate the effects of wheelchair rugby training on body composition.	Wheelchair rugby	13 men	Densitometer (Dexa)	Body composition in the arms Body composition in the trunk Body composition in the legs Body composition in the whole body	Regular training increased lean mass and bone mass in the arms and decreased fat mass throughout the body.
Lemos et al.[12]	UNIFESP	Compare the body composition obtained by air displacement plethysmography (ADP) and skinfolds (SF).	Athletics Goalball Swimming	33 men 37 women	Skinfold Compass Air Displacement Plethysmograph	Fat percentage Body density	ADP and SF body composition analyses show similar results, except for swimmers.
Loturco et al.[13]	NAR	Compare the muscle power and maximum isometric strength capabilities of Olympic and Paralympic judokas.	Judo	14 men 14 women	Contact platform Linear transducer Force platform	Mean propulsive power Maximum isometric strength	Visually impaired Olympic and Paralympic judokas have similar levels of maximum isometric strength, but muscle strength performance is superior in Olympic athletes.
Loturco et al.[14]	NAR	To test the effects of wearing compression garments on performance related to speed and power in visually impaired elite sprinters.	Athletics	2 men 6 women	Contact platform Linear transducer Photocell	Unloaded Squat Jump (SJ) Loaded Squat Jump (JS) Speed at distances of 20m Speed at distances of 70m	The acute increase in vertical jumping skill should be explored in preparing Paralympic sprinters during strength training sessions. However, the chronic effects on Paralympic athletes wearing compression garments need to be further tested in order to support their use as a specific training aid.
Pereira et al.[15]	NAR	Compare the physical performance of visually impaired Paralympic sprinters and their guides in jumping and sprint tests.	Athletics	3 men 7 women 10 male guides	Contact platform Measuring tape Photocell	Jump height (CMJ and SJ) Distance of 5 jumps with the right leg Jumping distance with the left leg 10m speed 50m speed	Guides performed better than visually impaired sprinters in the power and speed tests, and the net differences were greater in jumping ability. Furthermore, only visually impaired sprinters showed significant correlations between the results of the vertical jump (SJ and CMJ) and the speed in the 50 m sprint.

Santos et al.[16]	USP	Identify differences in trunk muscle strength and balance between the various classes and determine whether trunk muscle strength and balance correlate with the current classification.	Wheelchair basketball	42 men	Isokinetic dynamometer	Extensor peak torque Flexor torque peak Dynamic balance	The current observation-based classification system reasonably captures deficits in trunk muscle strength and balance in players.
Sousa et al.[17]	UFRJ	Analyze the dermatoglyphic profile and handgrip strength of the finalists of the Brazilian Championship of Paracanoe 2012.	Para Canoeing	19 men	Manual dynamometer	Manual handgrip strength	The groups presented very interesting characteristics for the practice of paracanoeing and, therefore, allow the application of the data directly in the training for a more specific and individualized approach.
Loturco et al.[26]	NAR	Estimate the magnitude of variability and progression in actual performance in competitive vertical jump and field testing. Investigate the relationships between loaded and unloaded vertical jump test results and actual competitive results of sprint performance.	Athletics	7 men 8 women	Contact platform Linear transducer	Jump height (CMJ and SJ) Mean propulsive power	Vertical jump tests, under loaded and unloaded conditions, can be good predictors of the running performance of athletes, especially when combined in a multiple linear regression equation.
Medeiros et al.[44]	UNIFESP	To investigate the relationship between body composition and sports performance 6 months after training.	Swimming	12 men 5 women	Air Displacement Plethysmograph	Lean mass Fat mass Density Time in 50m	A 6-month training period reduced fat mass and increased lean body mass. These factors were associated with sports performance, measured by the 50 m freestyle swim.
Silva et al.[39]	UFMG	Assess and monitor the torque of knee extensors and flexors and the reports of complaints over 1 year.	Athletics	10 men 4 women	Isokinetic dynamometer	Peak torque (60º/s, 180º/s and 300º/s)	The torque of the flexor and extensor muscles of the right and left knee showed a gradual increase between assessments. The torque of the flexor and extensor muscles of the right and left knee showed a gradual increase between assessments. At the same time, a relationship between muscle imbalance and knee and thigh complaints was found in all three assessments after 1 year.
Borges et al.[37]	UFRN	Analyze the percentage of muscle activation at different intensities in the bench press.	Powerlifting	6 men	Electromyograph	$_{S}$EMG (Serratus anterior, triceps, biceps, anterior deltoid and pectoralis major)	Muscle activation of the pectoralis major, anterior deltoids, serratus anterior, biceps and triceps during bench press performance was greater with increased intensity.
Campos et al.[33]	UNICAMP	To characterize cardiorespiratory responses and motor performance of soccer 5 athletes after 14 weeks of training.	5-a-side soccer	7 men	Skinfold Compass Stopwatch Photocells Measuring tape	Fat percentage Fat free mass Peak power Mean power Fatigue index Agility Jump distance	The performance of athletes from the Brazilian Paralympic Team is inferior to that of professional players, the cardiorespiratory and motor performance is superior to that of semi-professional futsal athletes.
Zoppi[34]	UNICAMP	To determine the physiological and performance improvements of Brazilian Paralympic rowers during a training season.	Para Rowing	8 men	Scale	Anthropometry	Adaptive rowers fully tolerated the training process, which allowed them to achieve a high level of training for physiological and performance improvements.
Campos et al.[35]	UNICAMP	To analyze the effects of 16 weeks of training on physical fitness parameters and body composition in athletes.	5-a-side soccer	6 men	Skinfold compass Photocells Measuring tape	Fat percentage Maximum power Mean power Minimum power Fatigue index	The 5-a-side soccer training showed a trend towards parameters that are related to rapid recovery and execution of intense stimuli, due to organic adaptations generated by the training process.
Squarcini et al.[40]	UESB	Determine endogenous circadian rhythm period of isometric and isokinetic strength and simple reaction time of totally blind people.	Athletics	6 men 4 women	Manual dynamometer Spine dynamometer Isokinetic dynamometer Thermometer	Body temperature Spine isometric strength Isometric strength in dominant and non-dominant hand Peak torque (60º/sec)	The circadian rhythms of force and simple reaction time of totally blind people are within their free-running periods.

UFS (Federal University of Sergipe); UFMG (Federal University of Minas Gerais); UFSC (Federal University of Santa Catarina); NAR (São Paulo Nucleus of High Performance in Sport); UNICAMP (State University of Campinas); UEL (State University of Londrina); UFPA (Federal University of Pará); UECE (State University of Ceará); UFRJ (Federal University of Rio de Janeiro); UFC (Federal University of Ceará); USP (University of São Paulo); UNIFESP (Federal University of São Paulo); UFRN (Federal University of Rio Grande do Norte); UESB (State University of Southwest Bahia).

publications. It is interesting to note that in the year of the London-2012 Paralympics, no scientific articles were found that addressed the topic, but, up until Tokyo-2020, in this edition of the Paralympic Games (London-2012) Brazil had the record for gold medals. Figure 1A presents the number of medals in the last three Paralympic cycles. Interestingly, the increase in the achievement of gold medals coincided with the advance in the publication of scientific articles involving biomechanics and parasports, as can be seen in Figure 1B.

Regionality of publications

Regarding the origin of the publications (Figure 1C), with the exception of those produced by the São Paulo Nucleus of High Performance in Sport (NAR)[13,14,21,25,15,26] and the Sarah Network of Rehabilitation Hospitals,[21,27] the first author of all other publications was linked to one of the 13 (87%) Public Universities reported, totaling 28 published articles. UFS[18,20,23,28-30] and UNICAMP[11,31-35] are noteworthy for being public institutions with the highest number of articles published, with six articles from each institution. However, the largest number of publications per institution was produced by NAR, with seven articles published. Thus, the importance of Public Universities for the production of knowledge involving Paralympic sport and biomechanics is evident. It is noteworthy that in the cycle that preceded the Rio-2016 Paralympic Games, a large part of the publications came from institutions located in the Southeast region, especially in the state of São Paulo. In the cycle started after Rio-2016, we observed that institutions in the Southeast region continued to produce much of the knowledge in parasport biomechanics, but there was greater participation from the South, Northeast, North, and Midwest regions, as can be seen in Figure 1D, indicating a geographic expansion in the production of knowledge on the subject.

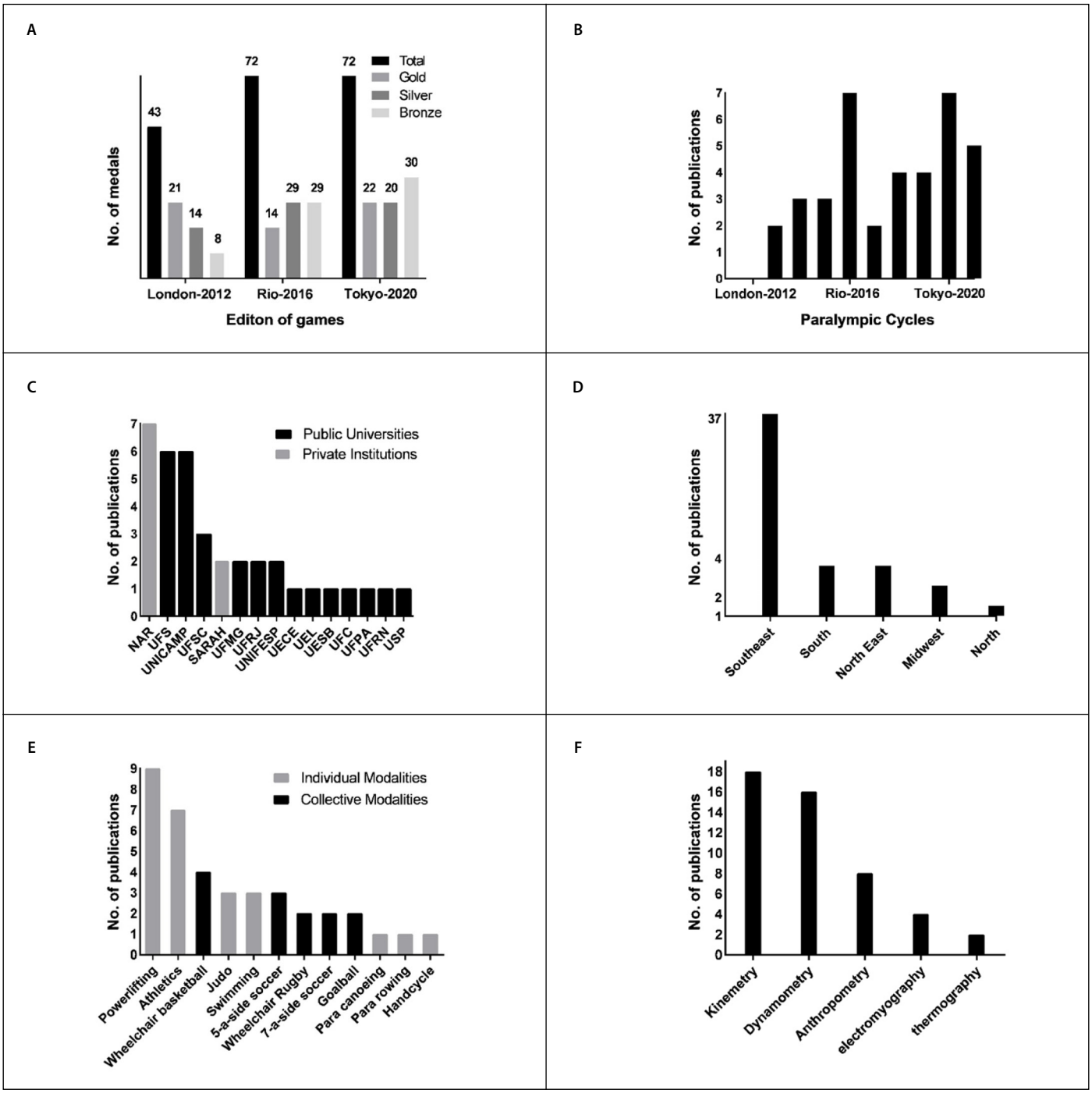

Figure 1. Characterization of the articles.

Modalities investigated

Among the Paralympic sports, *powerlifting*[18,22,23,25,28-30,36,37] and athletics[12,14,15,26,38-40] generated the greatest quantity of publications in the field of sports biomechanics, both individual modalities. Among the collective sports, wheelchair basketball gave rise to most publications,[16,21,24,27] as can be seen in Figure 1E. It is interesting to note that despite Brazil being considered the country of soccer, having won in Tokyo-2020 the 5th gold medal in a row in the 5-a-side soccer modality and having research groups consolidated in the study of biomechanics of soccer, only three studies investigated the biomechanical aspects of this modality.[33,35,41] These data indicate that Brazil has great potential to study the biomechanics of sport in collective Paralympic modalities, since we have trained human resources for this.

Female representation

In all, 626 parathletes were included in the 37 publications. Of these, 495 (79%) were men and only 131 (21%) were women. When compared in percentage terms with the 259 members of the Brazilian delegation who attended the Paralympic Games in Tokyo-2020, the percentage of women increased to 40% (103). Female participation is even greater when looking at the medals table, as 45% of the total medals won in Tokyo-2020 were by women. We know that female participation in sport has been encouraged and has been growing in recent years,[42] however, great disparity is still observed in relation to male parathletes as research participants. In this sense, our suggestion is that future research considers greater participation of female parathletes. It is noteworthy that the lack of female representation also occurred in the first authorship of the articles used in this review, being present in only 16% of the analyzed articles.

Quality of the publications

Despite the fact that Qualis CAPES is in the process of being reformulated in the period 2019-2022, we chose to assess the quality of journals through the WebQualis 2013-2016 list available on the Sucupira Platform, in force at the time of our study. Of the 37 articles published, 29 were inserted in journals of superior impact (A1, A2, B1), with 15 articles in Qualis A1,[11-13,16,18,22,24,25,26,27,36,39,40,43,44] six in Qualis A2[2,15,21,23,32,45], and eight in Qualis B1.[17,20,30,34,35,38,46,47] It is interesting to note that, due to the heterogeneity of the sample groups, we expected a greater number of publications in the *"Case Studies"* format. However, we observed only 2 publications[38,47] in this format, both in Qualis B1 journals. In this sense, we believe that given the variety of disabilities, more case studies with parathletes involving individual modalities and biomechanical parameters could be published.

Research techniques in biomechanics

Figure 1F shows the most commonly used research techniques in the studies. We found 3D[46] and 2D kinematics,[36] in addition to photocells,[14,15,21,33,35] contact platforms[2,13-15,26,43], and linear transducers.[2,13,14,21,25,26,28-30] We observed the use of dynamometry in publications involving measurements with force platforms,[13,38,47] load cells,[18,20,23,28,30] and isokinetic,[16,27,31,38-40] manual,[17,24,40,47] and lumbar dynamometers,[40] It is interesting to note that we did not find any studies that evaluated pressure distribution in parathletes.

Four studies[18,28,30,37] reported using electromyography, all of which involved analysis of muscles of the trunk or upper limbs. Our search reported only two studies that used infrared thermography[20,29] and no studies reported the use of ultrasound in the context of sports biomechanics. Considering that people with spinal cord injury, depending on the level of injury, tend to present alterations in thermoregulation,[48,49] the use of infrared thermography could be an important analysis tool in athletes in sports such as wheelchair rugby and wheelchair basketball, in addition to, of course, athletics. On the other hand, many disabilities result in chronic alterations in muscle-tendon properties[50] that could be identified by means of ultrasonography. In this sense, we reinforce the need to expand the use of other research techniques in biomechanics beyond the methods traditionally used.

Our study has some limitations, such as the uncertainty of having found all the publications that could be part of the inclusion criteria. This is due to the Lattes Platform's own search limitations, which make it impossible to cross-check keywords. However, the search on this platform is an easily accessible way for coaches and athletes to seek researchers and studies in the area that could be useful to them in their training routines. Thus, to the best of our knowledge, we believe that this work is the first to map Brazilian scientific production involving biomechanics in Paralympic sport in the cycle that preceded and followed the Rio-2016 Paralympic Games.

CONCLUSION

Our results enable us to conclude that: a) Scientific production involving biomechanics of Paralympic sport showed an increase in the Paralympic cycle that preceded Rio-2016, remaining high in the subsequent Paralympic cycle; b) Rio-2016 marked an expansion to other Brazilian regions of groups studying biomechanics in Paralympic sport; c) Public universities lead scientific production in the area; d) The main focus of the studies is still individual modalities; e) Women still face difficulties in being included in research (participation and authorship) involving biomechanics in parasport; f) Publications involving the subject reach high impact journals; g) Kinematics and dynamometry are the most commonly used measurement techniques in biomechanics in the publications, but new *insights* can be obtained with the inclusion of more measurement techniques.

ACKNOWLEDGMENTS

This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Financial Code 001 and the Amazonas State Research Support Foundation (FAPEAM).

All authors declare no potential conflict of interest related to this article

AUTHORS' CONTRIBUTIONS: Each author contributed individually and significantly to the development of this article. HYB: data analysis and paper writing; CSAA: data analysis and critical review of intellectual content; SKSG: data analysis and critical review of intellectual content; CFP: essay writing and critical review of intellectual content; RM: writing of the work and final approval of the version of the manuscript to be published.

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