

Analysis of biomechanics in athletes with disabilities: a systematic and narrative review

Análise da biomecânica em atletas com deficiência: uma revisão sistemática e narrativa

Jaqueline Lopes [1*]
Kamylla Albuquerque Guimarães [2†]
Simone Maria Lopes [3]
Sany Martins Pérego [4]
Claudia Andrade [1]

[1] Universidade Federal de Mato Grosso (UFMT), Cuiabá, MT, Brazil
[2] Centro Universitário do Vale do Araguaia (Univar), Barra das Garças, MT, Brazil
[3] Universidade Anhembi Morumbi (UAM), São Paulo, SP, Brazil
[4] Universidade de São Paulo (USP), São Paulo, SP, Brazil

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***Correspondence:** jaqueee-santosss@hotmail.com

Abstract

Introduction: Specifically in athletes with disabilities, investigations and biomechanical understanding seem to be even more relevant, as they provide data on how a certain type of disability limits sports practice and also describe parameters that allow the suggestion of relevant adaptations capable of guaranteeing a higher level comfort to practitioners. **Objective:** To describe patterns of biomechanical behavior during exercise in athletes with disabilities, and to discuss possible relationships between the type of disability and the sport practiced. **Methods:** This study performed a search in five electronic databases from the oldest records available until July 2020 using a search strategy that combined terms related to "athletes with disabilities" and "biomechanical analysis." Inclusion criteria: population (amateur or professional athletes with disabilities), intervention (sports practice), study design (observational), outcome (having evaluated biomechanics during sports practice). The biomechanical variables of interest included kinematic, kinetic, or electromyographic outcome measures. **Results:** Tewnty-six articles met the inclusion criteria (n = 705 participants). Biomechanical analysis showed that there is a greater inclination in the angle of the head and an increase in the kinematic variables in blind athletes, which result in less distance, speed, and performance; compensatory body patterns, reduced mooring strength, speed, joint amplitude, and reduced final performance are observed in amputated limbs of amputees; and there was a strong correlation between the subject's functional classification and kinematic parameters in wheelchair athletes, with this being proportional to the level of impairment. **Conclusion:** The outcomes demonstrated that the type of disability and the level of functional limitation are proportionally related to biomechanics in athletes with disabilities.

Keywords: Athletic injury. Athletic performance. Disability sport. Disabled person. Physical therapy specialty.

Resumo

Introdução: *Em atletas com deficiência, as investigações e o entendimento biomecânico parecem ser ainda mais relevantes ao fornecer dados sobre de que modo determinado tipo de deficiência limita a prática esportiva e, ainda, descrever parâmetros que permitam sugestão de adaptações pertinentes capazes de garantir maior nível de conforto aos praticantes.* ***Objetivo:*** *Descrever padrões de comportamento biomecânico durante o exercício em atletas com deficiência e discutir possíveis relações entre o tipo de deficiência e o esporte praticado.* ***Métodos:*** *Este estudo realizou uma busca em cinco bases de dados eletrônicas a partir dos registros mais antigos disponíveis até julho de 2020, utilizando uma estratégia de busca que combinou termos relacionados a "atletas com deficiência" e "análise biomecânica". Critérios de inclusão: população (atletas amadores ou profissionais com deficiência), intervenção (prática esportiva), desenho do estudo (observacional), resultado (ter avaliado a biomecânica durante a prática esportiva). As variáveis biomecânicas de interesse incluíram medidas de desfecho cinemáticas, cinéticas ou eletromiográficas.* ***Resultados:*** *Vinte e seis estudos atenderam aos critérios de inclusão (n = 705 participantes). Os resultados mostraram que há maior inclinação do ângulo da cabeça e aumento das variáveis cinemáticas em atletas cegos, resultando em menor distância, velocidade e desempenho; padrões corporais compensatórios, redução da força de amarração, velocidade, amplitude articular e desempenho final reduzido são observados em membros amputados de amputados; e parece haver relação entre a classificação funcional do sujeito e os parâmetros cinemáticos em atletas de cadeira de rodas, sendo esta proporcional ao grau de comprometimento.* ***Conclusão:*** *Os resultados demonstraram que o tipo de deficiência e o nível de limitação funcional estão proporcionalmente relacionados à biomecânica em atletas com deficiência.*

Palavras-chave: *Lesão atlética. Desempenho atlético. Esporte para deficiência. Pessoa com deficiência. Especialidade de fisioterapia.*

Introduction

Biomechanical analyses in sports sciences are important to improve performance and to prevent inappropriate movement patterns that increase the exposure to sports injuries.[1] Specifically in athletes with disabilities, investigations and biomechanical understanding seem to be even more relevant by providing data impact of the type of disability on sports in general, in terms of performance, taking into account the physical demand/technical-tactical specification, and also to describe parameters that allow the suggestion of pertinent adaptations capable of guaranteeing a greater level of comfort to practitioners.[2]

Recent studies have focused on analyzing sports movements and describing biomechanical elements in athletes with disabilities.[3] While some outcomes showed similarities between conventional and adapted sports, other outcomes showed significant differences, which need to be clarified and studied to better support the practical performance of these athletes.[2-5] As a result, athletes, coaches, and sports scientists benefit from the use of outcomes related to biomechanical understanding in adapted sports, even identifying possible patterns of disability that are more suitable for specific sports.

In this sense, previous review studies presented a general synthesis that shed a light on biomechanical aspects in Paralympic sports, covering all sports classified and their participants.[3,4] However, these studies did not use a systematic methodology, which may have limited the retrieval of studies on the topic. Moreover, these studies only included Paralympic sports in their analysis, which may have limited the exploration of different sports, if they were already addressed in the literature.

Furthermore, the systematic review studies conducted have focused only on exploring biomechanics in sports practiced by individuals with specific disabilities, such as amputees,[5] or with cerebral palsy,[6] not synthesizing and comparing findings between different sports and types of disabilities. For this reason, comprehensive systematic reviews need to be conducted to fill these gaps by providing comprehensive data on biomechanics during the sports practice by athletes with disabilities. Furthermore, the limitations seen in athletes with visual impairments, amputees and wheelchairs are different from each other, which makes each of these sports practices particular, resulting in specific biomechanical patterns. The sport practiced by the visually impaired, for example, tends to be performed by slow movements, while for amputees the height of the movements is generally smaller, and for wheelchair users agility may be limited due to the presence of a wheelchair to perform the movement.[2,3]

Thus, research involving biomechanical analysis in the parasports is essential to ensure the management of strategies that enable technical optimization, sports performance, injury prevention, and obtaining of evidence for supporting the classification in sports based on the level of functionality identified.[7] Hence, data that show a broad literature review on the biomechanical pattern in adapted sports can be useful and relevant for understanding the specific needs in parasports.

It is hypothesized that the lack of a limb and the use of a wheelchair, for example, would be responsible for generating extra compensatory patterns during sports practice, changing the verified biomechanical patterns. Therefore, this systematic review aimed to describe the patterns of behavior on biomechanical variables during exercise in athletes with disabilities and to discuss possible relationships between the type of disability and the sport practiced.

Methods

This systematic review study followed all the instructions presented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) to guarantee a high-quality methodological reproduction, and was duly registered in the International Prospective Register of Systematic Reviews (PROSPERO) under No. CRD42020212294 to guarantee transparency to the entire scientific community.[8]

Search strategy

The studies were searched in the following databases: PubMed/MEDLINE, EMBASE, SPORTDiscus, SciELO, and CENTRAL (Cochrane Central Register of Controlled Trials) from the oldest records until July 29, 2020. Moreover, a manual search was performed on the references of eligible studies to complement the electronic searches. For the elaboration of the search strategy used in the databases, the synonyms of the terms "disabled athletes," "sport," and "biomechanics" were crossed: 1. (disabled athletes) OR (disabled persons) OR (paralympic) OR (physical deficiency) OR (adapted sport) OR (para sport) OR (sports for persons with disabilities) OR (athlete amputee); 2. (sports) OR (sport medicine) OR (athlete) OR (athletes) OR (sport on wheels) OR (physical exercise); 3. (biomechanics) OR (sporting gesture) OR (motion assessment) OR (biomechanical evaluation) OR (mechanics of living organisms); 4. 1 AND 2 AND 3.

Eligibility criteria

The following inclusion criteria were considered: 1) population: amateur or professional athletes with disabilities; 2) intervention: sports practice; 3) study design: observational; 4) outcome: any biomechanical variable such as kinematics, speed, power, angle of inclination, among others. Case reports, case series, comments, editorials, book chapters, interviews, letters to the editor, and literature reviews were excluded.

No restrictions were applied as to the biomechanical evaluation method used, sex, age, year of publication, or language of the studies. All sports were considered eligible for inclusion, provided they were performed by athletes with disabilities.

Selection of studies, data extraction, and analysis

After completing the search in the selected databases, the titles found were grouped and saved in an electronic spreadsheet for identification and exclusion of duplicates. Thus, the studies were selected in stages (title, abstract, and full text) by peer review.

Then, the following relevant information about the studies was extracted: (1) general information (authors, year of publication, and study design), (2) characteristics of the population (sample size, distribution by sex, type of disability, age, and sport practiced), and (3) biomechanical evaluation methodology used and outcomes. When necessary, the authors of the studies were contacted to provide clarifications or access to raw data. This step was also conducted by two independent authors.

A narrative synthesis of the results was performed, instead of a meta-analysis, due to the methodological heterogeneity among the studies.

Quality evaluation

The included studies were evaluated for methodological quality using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies[9] adapted for characteristics of each type of study (details of the search strategy in Table 1).

The adapted tool comprised nine criteria, generating a final score for each study, classified as excellent (75 to 100%; very low risk of bias), good (50 to 74%; most methodological criteria met, low risk of bias), moderate (25 to 50%; some criteria met, possible risk), or poor (0 to 25%; few criteria were met, high risk of bias).

Table 1 - Quality appraisal of study methodology and reporting

Study, year	1	2	3	4	5	6	7	8	9	10
Gorton, 1987[14]	✓	✓	NR	✓	✓	✓	x	NR	x	5 (55.5%)
Ridgway et al., 1988[19]	✓	✓	NR	✓	✓	✓	x	NR	x	5 (55.5%)
Hutzler et al., 1995[27]	✓	✓	NR	✓	x	✓	x	✓	x	8 (88.8%)
Wang et al., 1995[31]	✓	✓	NR	✓	✓	✓	x	✓	x	8 (88.8%)
Goosey et al., 1997[21]	✓	✓	NR	✓	x	✓	x	✓	x	5 (55.5%)
van der Woude et al., 1998[28]	✓	✓	NR	x	x	✓	x	✓	✓	7 (77.7%)
Okawa et al., 1999[35]	✓	✓	NR	✓	✓	✓	x	✓	✓	7 (77.7%)
Chow et al., 2000[24]	✓	✓	NR	x	✓	✓	x	✓	x	5 (55.5%)
Nolan et al., 2006[16]	✓	x	NR	✓	x	✓	x	✓	x	4 (44.4%)
Chen et al., 2010[30]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Fung et al., 2010[20]	✓	✓	NR	x	x	✓	x	✓	x	4 (44.4%)
Sarro et al., 2010[23]	✓	x	NR	x	x	✓	x	✓	x	3 (33.3%)
Gastaldi et al., 2012[32]	✓	✓	NR	x	x	✓	x	✓	x	4 (44.4%)
Panoutsakopoulos et al., 2013[15]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Cavedon et al., 2014[25]	✓	✓	NR	✓	✓	✓	x	x	x	5 (55.5%)
Lee et al., 2014[11]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Taboga et al., 2016[17]	✓	x	NR	✓	✓	✓	x	✓	x	5 (55.5%)
Torralba-Jórdan et al., 2016[33]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Willwacher et al., 2016[18]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Bjerkefors et al., 2018[12]	✓	✓	NR	x	✓	✓	x	✓	x	5 (55.5%)
Haydon et al., 2018[26]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Junior et al., 2018[10]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Mason et al., 2018[22]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Warner et al., 2018[29]	✓	✓	NR	✓	✓	✓	✓	✓	✓	8 (88.8%)
Kertészné Német et al., 2019[13]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)
Padulles et al., 2019[34]	✓	✓	NR	✓	✓	✓	x	✓	x	6 (66.6%)

Note: 1 = Research question/objective clearly stated; 2 = Population clearly defined; 3 = Participants rate ≥ 50%; 4 = Participants recruited from similar populations; 5 = Variance or effect estimates reported; 6 = Outcome measures clearly defined; 7 = Blinded outcome assessors; 8 = Loss to follow-up ≤ 20%; 9 = Models adjusted for at least one confound; 10 = Items addressed or reported; NR = not reported.

Results

The search resulted in 4,328 records after excluding duplicates. Following the exclusions in stages (title, abstract, and full text), 44 titles were considered eligible. Of these, 11 studies were excluded due to their design and 7 for not having performed analyses under exercise conditions. Thus, 26 studies (Tables 2 and 3) met the inclusion criteria and were analyzed. The exclusion process is described in details in Figure 1.

Table 2 - Characteristics of the included studies (1987 - 2014)

Study, year	Characteristics of participants	Disability type	Sports practiced	Analysis methods	Variables analyzed	Movement analyzed	Outcomes
Gorton, 1987[14]	n = 26 26 men Age: NR	Blind and visually impaired	Athletics	Camcorders	Selected center of gravity, displacements, speeds, and joint angles	100 m race, during real competition	"The inclination of the head varied a lot. The anterior position of the head may be related to blindness."
Ridgway et al., 1988[19]	n = 31 31 men Age: NR	Wheelchair	Athletics	Camcorders	Cycle speed, cycle duration, cycle rate, cycle distance, and percentage of propulsion and recovery	800 m race	"In general, the highest speeds, rates, and distances of the cycle occurred in the classes with the highest functional impairments."
Hutzler et al., 1995[27]	n = 11 11 men Age: 30.3 ± 5.4 years	Wheelchair	Basketball	Electrically locked and controlled roller device	Power and speed	High-speed "Wingate" exercise test, lasting 30 s	"The speed variables of the subjects included in this study had a significant relationship with the power variables."
Wang et al., 1995[31]	n = 10 10 men Age: NR	Wheelchair	Athletics (Sprinters)	3-D cinematography with mirror	Speed, angulation, recovery	Running: four selected speeds were investigated	"As the speed increased, the actuation phase was executed more quickly, while the range of the pushing angle remained constant."
Goosey et al., 1997[21]	n = 23 13 men and 10 women Age: 18-41 years	Wheelchair	Athletics	Camcorders	Inclination angle, elbow angle and cycle dynamics, speed, and performance	800 m race	"Junior athletes adopted a more upright position and spent less time in contact with the rim (25%) than senior athletes. A moderate correlation was found between cycle distance and performance time (r = -0.68; p < 0.01). "
van der Woude et al., 1998[28]	n = 67 17 woman and 50 men Age: 29.1 ± 7.0 years	Wheelchair	Athletics	Computer-controlled ergometer	Propulsion and power production	30-second running test on a computer-controlled wheelchair ergometer	"The output powers were highly variable and seemed to be associated with the level of commitment."
Okawa et al., 1999[35]	n = 11 11 men Age: 20-46 years	Wheelchairs (paraplegia)	Marathon runners	Video camera	Push time, cycle time, total push time, and angular speed	Propulsion in a wheelchair until exhaustion, in the laboratory (for 5 min)	"Improvement in the total pulse angle must be achieved by extending the total pulse time and increasing the angular pulse speed."
Chow et al., 2000[24]	n = 17 17 men Age: 19-48 years	Wheelchair	Shot put	Video camera	Kinematic data (speed, release angle and height)	Each player made six attempts to throw the weight, and the best was recorded	"The measurements were smaller than in athletes without disabilities, so that all of them were significantly correlated with the functional classification and the measured distance (p < 0.05)."
Nolan et al., 2006[16]	n = 17 17 women Age: NR	Lower limb amputation (8 transfemoral and 9 transtibial)	Athletics (long jump)	Video camera (sagittal plane)	Center of mass height, vertical speed	Long jump at the 2004 Paralympic Games	"Transfemoral amputees had a higher center of mass height than transtibial amputees. And speed related to jumping performance."
Chen et al., 2010[30]	n = 7 5 men and 2 women Age: NR	Wheelchair	Runners	Video camera (2-D MaxTRAQ software was used using reflective markers)	Velocity	Running	"Angular and linear speeds increased at the wrist joint, indicating that the higher linear speed was transferred from the arm to the forearm and then from the hand during the propulsion of the wheelchair."
Fung et al., 2010[20]	n = 14 8 men and 6 women Age: NR	Wheelchair	Fencing	Camcorders	Maximum lunge speed, lunge angle, and fast return speed	Simulated test with fencing movements	"Two classes of functional impairments were assessed. The biomechanical data were similar for both classes ".
Sarro et al., 2010[23]	n = 10 10 men Age: 36.9 ± 5.7 years	Wheelchairs (spinal cord injury and quad amputation)	Rugby	Camcorders	Total distance traveled during the game; distance traveled during each quarter; distance covered in four different speed ranges	Rugby game	"There is a strong correlation between the functional classification of wheelchair rugby players and the distances covered during a game, especially at high speeds."
Gastaldi et al., 2012[32]	n = 50 35 men and 15 women Age: 36.9 ± 8.9 years	Paralympic athletes with different types of disabilities	Cross-country skiing	Video camera (high speed stereophotogrammetric without marker)	Kinematic biomechanical parameters and technical parameters	1-kilometer sprint, Paralympic Winter Games (2010)	"There was great variability in the sports gesture due to the residual functional capacities and sitting posture of each athlete. However, the polling cycles of disciplines classified into different classes have similar characteristics. "
Panoutsakopoulos et al., 2013[15]	n = 31 17 men and 14 women Age: 24.8 ± 6.4 years	Blind and visually impaired	Athletics	Stationary digital video camera	ADM, speed, jump, and distance	Speed test	"The distance and speed were shorter (p < 0.05) for the group with the greatest visual impairment."
Cavedon et al., 2014[25]	n = 43 43 men Age: 33.8 ± 9.02 years	Wheelchair	Tennis	Video camera (2D motion analysis)	Joint angles of the upper limbs and ball speed	Serve analysis	"Severity of impairment significantly (p < 0.05) affected post-impact ball velocity and shoulder angle at the instant of ball impact."

Note: NR = not reported.

Table 3 - Characteristics of the included studies (2014 - 2019)

Study, year	Characteristics of participants	Disability type	Sports practiced	Analysis methods	Variables analyzed	Movement analyzed	Outcomes
Lee et al., 2014[11]	n = 9 9 women Age: 16.1 ± 3.2 years	Amputee	Swimming	Camcorders	Mooring force, stroke rate, stroke phase durations, and inter-arm angle	30-second maximum effort crawl swim	"There was a relative decrease in the mooring force (this rate was higher in amputees); the angle between the arms and the duration of the relative phase remained constant. "
Taboga et al., 2016[17]	n = 11 7 men and 4 women Age: 26.7 ± 10.0 years	Lower limb amputation (transtibial)	Athletics (sprinters)	Video camera	Stride length, frequency, and speed	Running	"Amputee runners ran 3.9% slower with the affected leg compared to the normal leg (p < 0.05)."
Torralba-Jórdan et al., 2016[33]	n = 12 12 men Age: NR	Blind and visually impaired	Athletics (Long Jump)	Video cameras (Exilim F1, recording 2 at high speed)	Walking speed, step frequency, step length, contact time, flight time, and center of mass height	Competition during London Paralympic Games (2012)	"The increase in the space-time variables of the last stage of the race influences the result of the jump, decreasing performance."
Willwacher et al., 2016[18]	n = 154 103 men and 51 women Age: 20.8 ± 3.7 years	Lower limb amputation	Athletics (sprinters)	Digital force platforms	Performance, power, time, and speed	100-meter race	"The application of mid-lateral force had little influence on power. There was a non-significant reduction in performance in the amputee group."
Bjerkefors et al., 2018[12]	n = 41 13 women and 28 men Age: 35 ± 9 years	Amputees, spinal cord injury, spina bifida, and clubfoot	Canoeing	Camcorders (Qualisys Track Manager system; Visual 3D)	Joint angles were correlated with power	Ergometric paddle of high intensity kayak	"There were significant differences in RM between the able-bodied kayakers and the three para-kayak groups for the shoulders; trunk and pelvis; and legs during paddling.
Haydon et al., 2018[26]	n = 25 25 men Age: 30.5 ± 7.0 years	Wheelchair	Rugby	Video camera; and inertial measure	Kinematic data (joint angles, speed)	Five 5-meter sprints in a stationary position	"Significant differences in kinematic variables were observed between the classification groups, (p < 0.05)."
Junior et al., 2018[10]	n = 8 8 men Age: 25.0 ± 2.9 years	Amputee	Swimming	Video cameras (reflective markers)	Velocity, stroke length, and frequency	Six 200-meter sprints following an incremental protocol. The data were recorded at distances of 100 and 175 m	"To achieve higher speeds, swimmers with lower limb amputations need to increase the effort to maintain body alignment, and swimmers with upper limb amputations need to make up for the lack of the propulsive segment."
Mason et al., 2018[22]	n = 10 10 participants Age: 34 ± 5 years	Wheelchair	Rugby	Camcorders	Kinematic data on scapulothoracic movement in relation to performance	Two 3-minute exercise sessions on the wheelchair at two submaximal speeds (3 and 6 km/h)	"Participants with bilateral shoulder pain exhibited a scapula less turned upward during propulsion; however, great inter-individual variability in scapular kinematics was observed."
Warner et al., 2018[29]	n = 43 30 men and 13 women Age: 26.5 ± 6.7 years	Wheelchair	Sneakers	Clinical examination	Scapular kinematics	Raising and lowering of the humerus	"Wheelchair athletes had greater posterior scapular inclination during humeral elevation and lowering on the dominant side than on the non-dominant side. The dominant scapulae of tennis players in wheelchairs were significantly (p = 0.014) more turned upward."
Kertészné Német et al., 2019[13]	n = 13 13 men Age: 18-40 years	Amputees, spinal cord injury, spina bifida, and echinovaro foot	Canoeing	Video cameras (three-dimensional system Vicon - MX T40); and surface electromyography (EMG)	Joint angles, power, performance, and muscle activity	Ergometric paddling	"The upper limb ROM was not significantly different between disabled and non-disabled athletes (p ≥ 0.05). Muscle activities were significantly different between the group with and without disabilities (p ≤ 0.05)."
Padulles et al., 2019[34]	n = 11 11 participants Age: NR	Amputee (4 transtibial, 5 transfemoral, and 2 single amputees below the knee)	Athletics long jump	Video cameras (Four Exilim-F1)	Distance, time, stride frequency, speed, center of mass height, take-off stride angle, and stride length	Long jump	"77.8% of para-athletes take off with their legs supported by the prosthesis. The horizontal speed during the last three strides before takeoff was shown to have a high correlation with the official jump distance."

Note: NR = not reported.

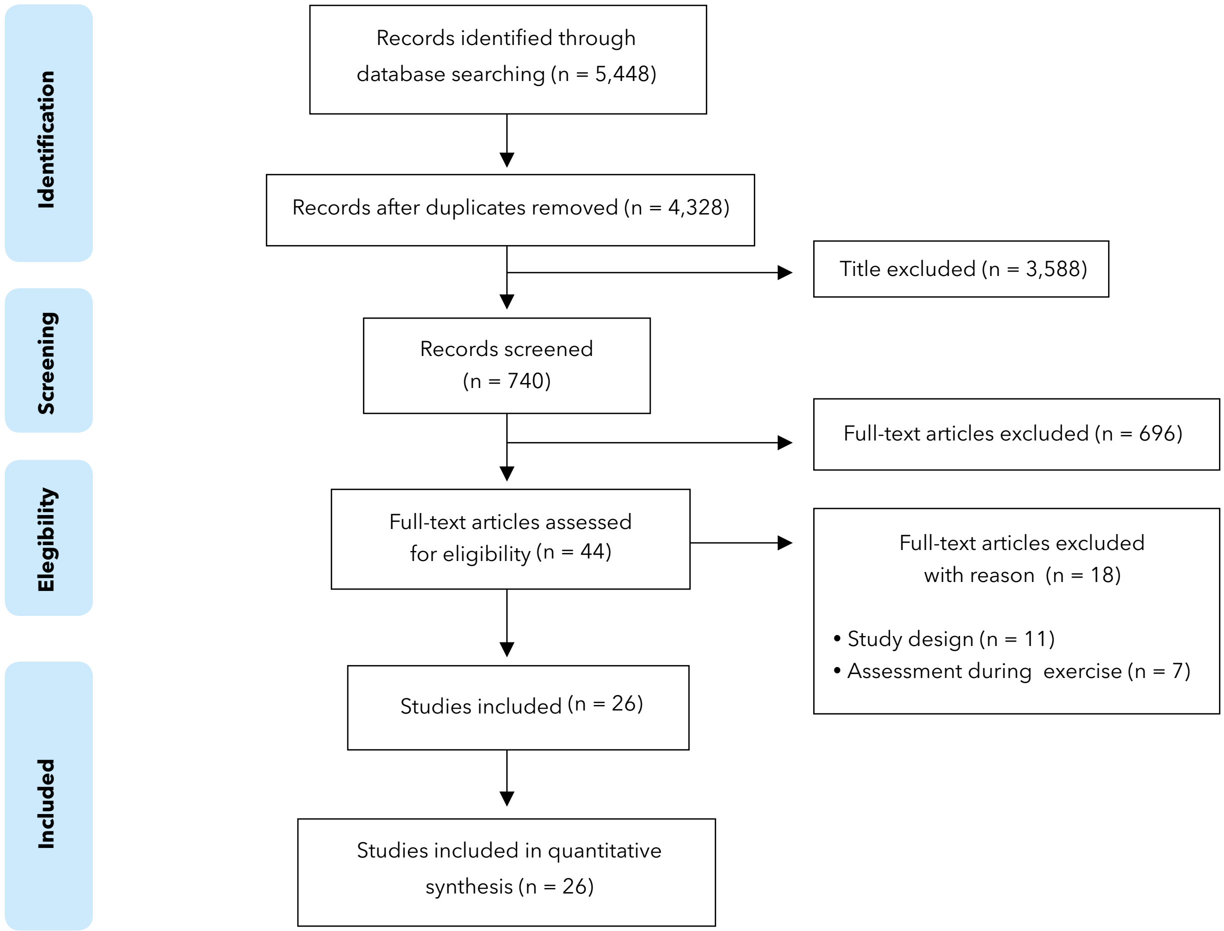

Figure 1 - Flowchart for selecting studies.

Study and participant characteristics

The selected articles included 7 to 154 participants, which resulted in a total of 705 participants,[10-35] comprising 513 men and 171 women, aged between 16 and 48 years. Twelve studies (46.15%) included only men,[10,13,14,19,23-27,31,33,35] two studies (7.69%) included only women,[11,16] ten studies included participants of both sexes (38.4%),[12,15,17,18,20,21,28,29,30,32] and two studies (7.69%) did not provide information on the sex of the participants.[22,34]

The articles were published between 1987 and 2019. The studies were conducted in different countries such as Australia,[26] Brazil,[23] China,[20,30] Germany,[18,27] Greece,[15] Hungary,[13] Italy,[25,32] Japan,[35] Netherlands,[28] Portugal,[10] Spain,[33,34] Sweden,[12,16] United Kingdom,[11,21,22,29] and United States.[14,17,19,24,31]

Types of disability of included participants

The studies analyzed the participants with the following disabilities and functional limitations: motor disabilities,[10] limb amputation,[11-13,16-18,23,32,34] spinal cord injury,[12,13,23,32,35] spina bifida,[12,13] clubfoot,[12,13] and blindness,[14,15,33] and some studies reported disabilities associated with the use and practice of sports in wheelchairs.[19,20-31,35]

Sports practiced

The studies analyzed ten different sports modalities, which included swimming,[10,11] canoeing,[12,13] fencing,[20] rugby,[22,23,26] shot put,[24] tennis,[25,29] basketball,[27] street running,[30,35] athletics,[14-19,21,28,31,33,34] and cross-country skiing.[32]

Biomechanical methods and results

The methods used to evaluate biomechanical variables included video cameras,[10-17,19-26,30-35] surface electromyography,[13] digital force platform,[18] electronically locked and controlled roller device,[27] computer-controlled ergometer,[28] and clinical examination.[29]

The biomechanical variables evaluated, in turn, included the following kinetic and kinematic measures: speed,[10,14-27,29-35] frequency,[10,11,17,19,29,32-34] length,[10,17,33] strength,[11,13,28,32] joint angulation,[11-15,20,21,24-26,31,34,35] power,[12,13,18,27] performance,[13,18,21,22] center of gravity,[14,16,33,34] distance,[15,19,23,34] jump,[15] time,[18,19,33-35] and propulsion.[19,28]

All studies performed analyses during the performance of sporting gestures in real or simulated scenarios. Some studies included a control group made up of athletes without disabilities, for comparison purposes,[11-15,18,29,30] whereas other studies did not.[10,16,17,19-28, 31-35]

The results of all included studies[10-35] showed that biomechanical patterns were mainly justified by the type of disability. Furthermore, all studies directly attributed the level of sports performance to the level of functional impairment of the participants.

Biomechanical outcomes

Blind and visually impaired

Three studies included blind and visually impaired athletes who practiced athletics.[14,15,33] These studies found a greater inclination in the head angle, which increased proportionally to the level of functional impairment and kinematic variables, which resulted in shorter distance, lower speed and, consequently, lower performance.

Amputee

Nine studies analyzed biomechanics in athletes with different levels of amputation.[10-13,16-18,32,34] Such analyses were performed in the following modalities: swimming, canoeing, athletics, and cross-country skiing.

The studies found the following biomechanical outcomes in the athlete profile: athletes used specific compensatory patterns to achieve higher speeds; there was a decrease in the mooring force; there was a decrease in speed, joint amplitude, and final performance were observed in amputated limbs when compared to healthy limbs; there was a decrease in center of mass height proportional to the level of the amputation; and there was a decrease in speed proportional to the distance of the jump. Kinematic parameters in healthy limbs did not appear to change significantly.

Whelchair

A total of 15 studies investigated athletes who play wheelchair sports.[19-32,35] They analyzed individual and collective sports including running, cross-country skiing, athletics, tennis, basketball, rugby, shot put, and fencing.

The three main findings observed in athletes in wheelchairs were as follows: 1) there seems to be a correlation between the athlete's functional classification with kinematic parameters, so that the values are proportional to the level of impairment; 2) shoulder problems seem to be common in these athletes, resulting in kinematic changes with a high variety in scapular movement, the causes and therapeutic needs of which must be checked individually; and 3) the reported changes in the shoulder joint complex resulted in impairments related to the speed, angulation, and impact of the ball.

Risk of bias assessment

The percentage score of the methodological quality of the studies varied between 44.4% and 88.8%, with the mean of 63.18%. Thus, five studies were classified as excellent (with low risk of bias), 17 studies as good (most of the methodological criteria met and low risk of bias), four studies as moderate (possible methodological risk present), and no study as poor (high risk of bias). All studies clearly reported the population included and the intended objectives. Information on the participants' rate higher than 50% was not reported clearly in any study whereas the blinding of the assessors was described by only one study (details of the methodological quality are shown in Table 1).

Discussion

This systematic review study aimed to describe specific biomechanical patterns during sports practice in athletes with disabilities. The main findings were as follows: 1) there is a greater inclination in the angle of the head and an increase in the kinematic variables in blind and visually impaired individuals, which resulted in lower distance and speed, and consequently, lower performance, which are all proportional to the level of impaired vision; 2) the main biomechanical changes in amputee athletes were the use of compensatory body patterns, decreased binding strength, decreased speed, decreased joint amplitude, and reduced final performance in amputated limbs when compared to healthy limbs; and decreased center of mass height proportional to the level of the amputation; and 3) the main findings in athletes who use wheelchairs demonstrated possible correlation between the functional classification and kinematic parameters, so that the values are proportional to the level of impairment found, and shoulder problems were common in these athletes, resulting in changes in scapular movement, which compromise the kinematics observed in this joint complex, during sports practice.

Some facts might explain the increase in kinematic variables and head tilt observed in athletes with visual impairments. So, first, in general, visually impaired subjects have adaptive weighting and greater care resources, since they basically depend on tactile feedback located on the plantar surface of the feet, for location in space[36] and also sound stimuli,[37] which explains the slower movement patterns. In addition, data related to kinematic values close to normal in athletes with visual impairment[36] may be related to the feeling of security, guaranteed by athletic experience and knowledge of practice place over the years. Finally, the aspect of adaptation to situations considering tactile and sound stimuli helps in the safety process related to sporting tasks.[38]

Another study on athletes who used wheelchairs also found that injuries in the upper limbs, especially the shoulder, are common since they use such joints repeatedly over the days to perform many types of activities, which generate mechanical stress in the region and are responsible for chronic musculoskeletal injury.[39] Moreover, in athletes in wheelchairs, the extensive variety of deficiencies associated with the different designs of the chairs, which generate individual adaptive biomechanical responses, should be analyzed. Thus, there is no single biomechanical pattern given the extensive variety of extrinsic and intrinsic factors that can be inferred in the movements observed.[39] Thus, the only common factor to athletes in wheelchairs is the excessive use of the upper limbs to perform functional activities of everyday life such as sports, leisure, social, and work activities, explaining the high incidence of injuries reported in the literature.

Moreover, athletes from different categories may also be exposed to different risk levels of injury. Reid et al.[40] found that individuals with less trunk control use muscles of the upper limbs with greater intensity to ensure maximum performance during sports practice. This might explain a higher incidence of injuries to upper limbs in this profile. Furthermore, as described, extrinsic issues related to sports, environment, and wheelchair associated with intrinsic issues involving the type of disability and level of functional impairment, resulted in unique biomechanical patterns determined by the need for adaptation in each case.

There are important patterns and characteristics that must be analyzed in amputee athletes when considering biomechanical analysis in sports movement. A previous study reported an increase in hip work in the amputated limb, which is the main cause of making running in amputees feasible.[41] This may involve a compensatory mechanism such as greater activity in the knee joint complex as an important secondary compensatory mechanism during running. From this perspective, the study by Buckley[41] stands out, in which he reported an increase in hip work in the amputated limb compared to the non-amputated limb; this possibly characterizes the main cause of viability of running in amputees, possibly due to a compensatory neural mechanism.[41] Additionally, the same study found that greater work on the knee joint complex also indicates an important secondary compensatory mechanism during the specific task of running. Still, a limitation observed in athletes with lower limb amputation refers to the difficulty of perfect fit between the prosthesis and the stump, which can generate friction and laxity,[42] compromising the execution of the sports movement to be performed.[43] Also, similarly to the other types of categories described, the greater the functional impairment, the more evident are the compensatory mechanisms verified,[44] which in turn tend to influence the subsequent performance.[45] Still, it seems logical that specific types of disabilities are more suitable for the practice of certain sports, due to the subject's possible functionality.[46] In relation to sex, it was found that many of the included studies were conducted in a sample combined by men and women, which made it impossible to extrapolate to which sex possible outcome trends were more applicable, and still made it difficult to compare results between men and woman in these cases. Thus, it is pertinent that future studies report data on men and women separately so that subgroup analyzes can be conducted and specific clinical recommendations can be formulated.

There are some limitations associated with this study that need to be presented so future studies can improve certain aspects. There was no standardization on the evaluation method and the presentation of the outcomes between the included studies. This fact restricts similar comparisons and in-depth discussions. Strengths are associated with the fact that there was no limitation regarding the language and year of publication, as well as the type of disability and sports, which allowed the inclusion of all the available data on the topic. Moreover, all items suggested for ensuring a high-quality methodological study were implemented.

Finally, the outcomes presented consist of basic initial support for the topic and require future research to substantiate consistent data. Despite this, given the considerable heterogeneity of the populations studied, methodologies and outcome variables within the included studies, caution is needed when interpreting or generalizing the results, especially as it is a relatively new area of research. It is important that future observational studies, as well as clinical trials, are carried out based on the observations and considerations presented to demonstrate quantitative evidence, increase the level of evidence on the topic, and support practical action.

Conclusion

This review provides readers with the first comprehensive systematic analytical synthesis on biomechanical analysis in athletes with disabilities, which comprised all sports and types of disabilities available in the literature. In addition, the results confirmed the initial hypothesis by demonstrating that the type of disability and functional limitation are directly related to the biomechanical pattern in athletes with disabilities. Such information is essential to support specific interventions based on the needs observed to optimize sports performance and reduce the incidence of sports injuries, ensuring safer levels for sports practice. Nevertheless, the findings of this study reiterate that balanced interpretations based on clinical reasoning are necessary for the applicability of current prospective evidence in a clinical environment.

Authors' contributions

JSSL designed the study, conducted the analyses, and wrote the manuscript. KAG, SML and SMP assisted in acquisition, analysis, and interpretation of data, and reviewed and edited the article. CMBA made substantial contribution including conception and design of the study, and a critical revision of the article. All authors read and approved the final version, except for KAG who sadly passed away (May 24, 2020).

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