Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Comparative Preseason Assessment of Ankle Range of Motion, Balance and Isometric Strength in Track and Field Para Athletes

Geronimo José Bouzas Sanchis
Universidade Federal de Minas Gerais
Renan Alves Resende
Universidade Federal de Minas Gerais
Paula de Farias Fernandes Martins
Universidade Federal de Minas Gerais
Marco Túlio de Mello
Universidade Federal de Minas Gerais
Yasser Alakhdar Mohmara
yasser.alakhdar@uv.es
University of Valencia
Andressa Silva
Universidade Federal de Minas Gerais

Research Article

Keywords:

Posted Date: March 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9013180/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Introduction: Compare the dorsiflexion range of motion, dynamic balance, and isometric strength of hip and knee extensors between limbs (dominant vs. non-dominant) and between impairment types in para athletes during the preseason.

Material and Methods: A Cross-sectional study was designed. Twenty-one Para athletes from track and field modalities were evaluated. Assessments were performed during the preseason and included the lunge test, Y-Balance test, and isometric strength testing of hip and knee extensors. The Shapiro-Wilk test was used to assess data normality. Paired t-test compared dominant and non-dominant limbs, and independent t-tests compared impairment types. Effect sizes were calculated using Cohen's d and the U3 statistic.

Results: Significant differences between impairment types were found for the lunge test (p<0,02) and Y-balance test (p<0,001), both with a small effect size and difference in non-dominant hip extensor isometric strength ($p < 0.01$) and asymmetry ($p < 0.01$), with a larger effect size.

Conclusion: Differences in hip extensor strength and functional test performance across impairment groups suggest asymmetries that may have biomechanical relevance for musculoskeletal injury risk in para athletes.

INTRODUCTION

In Paralympic athletics, para athletes with motor, visual, and intellectual impairments participate under a functional classification system [1]. Despite variations across events, track and field disciplines such as running and jumping exhibit a high incidence and prevalence of musculoskeletal injuries in the lower limbs in ambulant para athletes [2], frequently caused by repetitive movements during training and competition [3]. Among para athletes, the knee and ankle are the most frequently injured sites [3]. Chronic injuries are predominantly tendinopathies [4], while acute muscle injuries are more common in para athletes [2]. These injuries often impair performance, cause functional limitations [5], and may lead to prolonged absence from sports or even premature retirement.

Intrinsic risk factors for non-impaired athletes encompass previous injuries, older age, and male sex [6], deficits in specific muscle groups, and biomechanical alterations [6, 7]. Athletes with Achilles tendinopathy [8], patellofemoral pain [9], or ankle sprains [10] they frequently present with restricted ankle joint mobility, which may predispose them to these conditions. Additionally, balance impairments have been linked to patellofemoral tendinopathy [11] and patellofemoral pain [12] and ankle sprain [13]. Reduced strength in the knee and hip extensor muscles is another contributing factor associated with patellofemoral pain [14], patellar tendinopathy [11], and hamstring injuries.

Para athletes with intellectual and visual impairments frequently exhibit physical comorbidities such as postural balance impairments and reduced muscle strength [15]. Those with motor impairments

commonly exhibit restricted joint range of motion (ROM) [16], muscle weakness, and altered biomechanical adaptations to training loads [15, 17]. In addition, individuals demonstrate cerebral palsy demonstrate musculoskeletal alterations, including changes in tendon collagen organization and extracellular matrix structure [18]. These characteristics may contribute to transient tissue weakness, increasing susceptibility to cumulative load damage and the eventual development of clinically evident injuries [18].

Sports teams routinely assess musculoskeletal parameters and use physical performance tests to guide injury rehabilitation and evaluate athletes' injury risk profiles [19, 20]. These assessments should align with the specific demands of each sport [19]. Performance-based tests are rapid, low-tech, and easily administered [20], typically measuring muscle strength, balance, and joint ROM [16, 17]. The results of these assessments inform the implementation of preventive strategies by health professionals [17]. Notably, individuals with lower-limb motor impairments (e.g., hemiplegia, amputations) often present reduced ROM and strength in the affected limbs compared to non-impaired athletes [21], highlighting the impact of impairment type on musculoskeletal function.

Given the high prevalence and incidence of sport-related musculoskeletal injuries in athletics, along with the musculoskeletal consequences associated with different impairment types, it becomes essential to investigate preseason ROM, balance, and muscle strength in Para athletes. The present study aims to compare the dorsiflexion ROM, dynamic balance, and isometric strength of hip and knee extensors between limbs (dominant vs. non-dominant) and across impairment categories. These insights can support health professionals working with para athlete teams in designing targeted injury prevention programs and implementing precise strategies to mitigate injury risk. By understanding how impairment-specific factors (e.g., restricted mobility, strength deficits) interact with sport-specific demands, practitioners can identify modifiable risk factors and adapt interventions, tailor interventions to the unique needs of para athletes, and ultimately enhance both injury prevention and athletic performance.

METHODS

This cross-sectional study was conducted over three years (2022 to December 2024). We recruited para athletes from the track and field teams at the Sports Training Center of the Federal University of Minas Gerais (CTE/UFMG). The study adhered to the Declaration of Helsinki, and the project received approval from the Research Ethics Committee of the Universidade Federal de Minas Gerais (CAAE: 2718619.4.0000.5149).

Participants

The study employed a non-probabilistic, convenience-based sampling approach. Participants consisted of para athletes from the track and field teams at the CTE/UFMG (athletes with visual impairment [T11 to T13/F11 to F13], intellectual impairment [T20/F20], upper-limb impairment [T45 to T47/F45 to F46], and cerebral palsy [T35 to T38/F35 to F38]). Recruitment was conducted during the preseason period of

each year (January/February). Exclusion criteria included undergoing any surgical procedure within the six months before the initial assessment; presenting pain during activity or rest (scoring > 4/10 on the Visual Analog Scale [VAS]). If pain exceeding 4/10 was reported, the assessment was postponed by one week, and participants were excluded if pain persisted. Additionally, para athletes classified functionally within the F31–F34/T31–T34 categories, those with a clinical diagnosis of spinal cord injury, severe paraplegia, or any impairment preventing upright posture during assessments, were excluded.

Variables

Descriptive variables

Initially, descriptive data were collected, including age, gender, mass, height, type of impairment, and dominant limb. Individuals were categorized by type of impairment (1. Intellectual and visual impairment; 2. Motor impairment (lower/upper limb amputation, lower/upper limb malformation, short stature, diplegia, and hemiplegia).

Dorsiflexion Range of Motion – Lunge test

The Lunge test was utilized to evaluate ankle dorsiflexion ROM. A line was demarcated on the floor, and a vertical reference line was marked on the wall. The foot of the assessed limb was positioned on the floor line, perpendicular to the wall. Participants were instructed to advance the knee of the assessed limb forward until it contacted the wall line, while maintaining heel contact with the floor and avoiding trunk or pelvic rotations. An analog inclinometer was positioned 15 cm below the tibial tuberosity to measure the angle between the lower leg and the vertical axis [22]. Although, we calculated the asymmetry between the sides using the following equation: Non-dominant Side/ Dominant Side*100.

Dynamic Balance – Y-Balance Test

Dynamic balance of the lower limbs was assessed using the Y-Balance Test (YBT), which evaluates dynamic stability limits and asymmetric balance in three directions (anterior, posteromedial, and posterolateral) [23]. The testing grid was demarcated on the floor with white tape, forming three lines: one anterior and two posterior lines (posteromedial and posterolateral). The posterior lines were separated by a 90° angle and positioned at 135° relative to the anterior line. During the test, participants stood on one leg and used the contralateral lower limb to slide a reach indicator to the maximum achievable distance [23]. Para athletes completed three practice trials per limb for familiarization. Subsequently, three measurements were recorded in each direction (anterior, posteromedial, posterolateral) for both limbs.

For data analysis, the mean reach distance for each direction was first calculated. A composite score was then derived by dividing the mean reach distance of each direction by the participant's lower limb length and multiplying the result by 100. Although, we calculated the asymmetry between the sides using the following equation: Non-dominant Side/ Dominant Side*100.

Muscle strength

A handheld dynamometer (microFET®2, Hoggan Scientific, LLC, USA) was used for evaluating the isometric muscular strength of the hip, and knee extensors. Non-elastic straps were employed to stabilize participants and the dynamometer, thereby minimizing evaluator-induced force interference [24].

For hip extension torque assessment, participants were positioned in a prone position with the hip in neutral alignment across all planes, the knee of the assessed limb flexed to 90°, and the pelvis secured to the examination table via a strap. Participants were permitted to grasp the table with their upper limbs to stabilize the trunk, while the dynamometer was placed proximally to the popliteal fossa [11]. Verbal instructions prompted participants to “push as if attempting to lift the foot toward the ceiling.” For knee extension torque measurement, participants were positioned supine with the knee flexed to 30°, an angle selected to simulate the flexion required during jumping tasks [11]. The dynamometer was proximal to the midpoint between the lateral and medial malleoli, and participants were instructed to cross their arms over the chest and “push to extend the knee.”

During testing, each protocol included one practice trial followed by three experimental trials (5-second duration each), separated by 15-second rest intervals. The values were recorded in Newtons. Lever arms were defined as follows: the hip lever arm corresponded to the distance between the greater trochanter and lateral femoral epicondyle; the knee lever arm spanned from the lateral femoral epicondyle to the lateral malleolus; and the ankle lever arm extended from the calcaneus to the first metatarsophalangeal joint [11]. Limb symmetry was calculated as the ratio of dominant limb peak torque to non-dominant limb peak torque, multiplied by 100.

Procedures

Before data collection, a standardized training session was conducted between two experienced physiotherapists to ensure protocol consistency. Evaluator training comprised three theoretical and practical sessions focused on familiarization with assessment instruments and procedures. For the athletes who continued training throughout the three-year period, only the results from the final evaluation were used to avoid duplicate data from the same para athlete.

Before each evaluation session, participants completed a five-minute warm-up involving bodyweight exercises such as squats, lungs, upper-limb movements, and stationary jogging. Para athletes requiring modifications performed partial or assisted squats and lungs using a wall or chair for stability. Lower-limb movements were tailored to individual capabilities, emphasizing small, controlled motions or abbreviated ranges of motion to accommodate comfort and physical limitations. Clear verbal instructions, visual demonstrations, and tactile guidance were provided as needed. Rest periods were integrated to ensure participants could perform pain-free movements and at self-selected pacing.

Assessments began with ankle dorsiflexion flexibility testing, followed by YBT and the muscle isometric strength evaluation. Para athletes with visual impairments received tactile and verbal cues to facilitate task execution and directional orientation. Subsequent evaluations targeted isometric muscle strength. Throughout testing, standardized verbal encouragement (e.g., “Push as hard as possible!”) was administered to maximize effort.

Statistical Analysis

For statistical analysis, data normality was first assessed using the Shapiro-Wilk test. To evaluate differences between groups (type of impairment), parametric variables were analyzed with Student’s t-test, while non-parametric variables were examined via the Mann-Whitney U test. Differences between dominant and non-dominant limbs were assessed using the Wilcoxon test. Subsequently, Cohen’s D was calculated for variables exhibiting statistical differences to quantify effect size and is confidence interval (IC), followed by the U3 statistic to determine the percentage (%) difference between groups. A significant level of 5% ($\alpha = 0.05$) was adopted for all analysis.

RESULTS

A total of 22 para athletes were initially enrolled in the study. Four para athletes were excluded due to lower-limb impairments (classified as F32, F33, T33, and T34), and one additional participant was excluded for having less than one year of sports practice. Consequently, 17 Para athletes were included in the final analysis. Demographic characteristics, including sample size, means, standard deviations, and percentages, are detailed in Table 1. The participants were distributed across the following functional classifications: seven in T11, and one each in T12, T13, T37, T46, T47, F12, F20, F35, F37, and F38.

Table 1
– Demographic data of parathletes with number (n) of distribution and percentages (%).

				Sex		**Impairment**	
	Age	**BMI**	**Total**	**F**	**M**	**I/V**	**Mot.**
Sport	Mean (SD)	Mean (SD)	n (%)	n	n	n	n
Track	32.7 (± 11.7)	20.6 (± 2.2)	12 (70.6)	5	7	9	3
Field	21.3 (± 6.6)	19.7 (± 1.5)	5 (29.4)	1	4	2	3

Legend: SD: Standard Deviation; n: number; %: percentage; F: female; M: Male; I/V: Intellectual or Visual Impairment; Mot.: Motor Impairment.

Analysis of Table 2 revealed a Cohen’s d value of 0.13 (IC: − 0,91–1,02) for the *Lunge-D* variable, demonstrating a negligible difference between impairment groups (intellectual/visual impairment vs.

motor impairment). Cohen's U3 indicated that 55.2% of the intellectual/visual impairment group scored above the mean of the motor impairment group, with 94.8% overlap between the two distributions. For the YBT–D variable, a Cohen's D of 0.38 (IC: -0,59–1,35) suggested a small between-group difference. Cohen's U3 showed that 65.9% of the intellectual/visual impairment group scored above the motor impairment group's mean, with an overlap of 83.8% between distributions.

For the non-dominant hip extension muscle torque variable, a Cohen's D of 0.84 (IC: 0,17–1,84) indicated a large effect size between impairment groups (intellectual/visual impairment vs. motor impairment). Cohen's U3 revealed that 79.4% of the intellectual/visual impairment group scored above the mean of the motor impairment group. In contrast, hip extension strength asymmetry exhibited a Cohen's D of 2.54 (IC: 1,28–3,88), reflecting a very large clinical difference. Here, 98% of the intellectual/visual impairment group exceeded the motor impairment group's mean (U3), suggesting minimal distributional overlap.

Table 2
– Mean values of measured variables in the study, including ankle dorsiflexion ROM, dynamic balance, and hip/knee extensor isometric strength, stratified by impairment type, presented with corresponding means, standard deviations (SD), and p-values.

	Impairment			
	Visual/Intellectual	**Motor**		
Variable	**Mean (SD)**	**Mean (SD)**	**p-value**	**Cohen's D (IC)**
Dorsiflexion – D	35.6 (4,6)	36 (11,8)	0.02	0,13 (-0,91–1,02)
Dorsiflexion – ND	32.1 (9,9)	32.5 (13,8)	0.35	
Asymmetry - Dorsiflexion	90,9 (27,7)	96,6 (45,4)	0.31	
YBT – D	76.7 (4,7)	80.1 (12,9)	< 0.01	0,38 (-0,59–1,35)
YBT – ND	76.3 (5,2)	78.6 (12)	0.80	
Asymmetry - YBT	99,5 (4,6)	98,7 (8,2)	0.91	
T. knee – D	5.2 (0,9)	5.4 (1,2)	0.8	
T. knee – ND	6.1 (1,9)	4.1 (2,4)	0.2	
Asymmetry – Knee	115.2 (19,3)	72.6 (25,7)	0.7	
T. Hip. – D	4.0 (1,2)	4.3 (2,6)	0.06	
T. Hip – ND	4.1 (0,9)	2.7 (2,4)	< 0.01	0,84 (0,17–1,84)
Asymmetry – Hip	104.4 (15)	54.3 (24,6)	< 0.01	2,54 (1,28–3,88)

Legend: YBT: Y-Balance Test; T: Torque; D: Dominant; ND: Non-dominant; SD: Standard Deviation; IC: Confidence Interval.

DISCUSSION

The premise of this study was that ankle dorsiflexion ROM, dynamic balance performance, and hip/knee extensor strength would differ across impairment types in para athletes. To our knowledge, this is the first cross-sectional study to examine these variables in this population. We observed a statistically significant difference between impairment groups for dominant-side ankle dorsiflexion ROM, although with a negligible effect size, and for dominant-side YBT performance, which showed a small effect size. These findings indicate minimal functional differences between para athletes with intellectual/visual impairments and those with motor impairments during the preseason period. On the other hand, non-dominant hip extensor strength demonstrated a large effect size difference between impairment types, suggesting a meaningful disparity in muscular performance.

Regarding ankle dorsiflexion ROM, a statistically significant difference was observed on the dominant side between impairment types, although the effect size indicated no clinical relevance. In the literature, dorsiflexion values below 11° have been linked to Achilles tendinopathy [6] and patellar tendinopathy [11]. Conversely, other studies found no difference in dorsiflexion ROM between symptomatic and asymptomatic limbs [25]. When compared to normative data, the para athletes in our study exhibited ROM values like the general population (36° – 44°) rather than athletic populations (40°–50°), with no values indicative of functional limitation (< 30°) [26]. Previous studies have shown reduced dorsiflexion ROM in individuals with cerebral palsy [27], stroke [21, 28], and Parkinson's disease [29]. Notably, dorsiflexion values below 35° have been associated with increased Achilles tendon stress in able-bodied track and field athletes [30]. Although no clinically relevant differences were observed between impairment types, the values found in our sample (some below 35°) may suggest a potentially elevated risk for Achilles and patellar tendinopathy, as well as patellofemoral pain. These findings underscore the importance of incorporating targeted flexibility and load management strategies into preseason injury prevention protocols for para athletes.

In the YBT, para athletes with intellectual/visual impairments demonstrated lower dominant-side scores than those with motor impairments, although the effect size indicated only a small between-group difference, potentially influenced by the limited sample size. The YBT is a validated tool for identifying athletes at higher risk of lower-limb injury, with composite scores below 90% associated with a 3.5-fold increased risk of musculoskeletal injury [31]. However, while composite YBT scores may not distinguish military personnel with patellar tendinopathy from healthy controls, differences have been observed in the anterior reach direction [12]. In our study, regardless of impairment type, YBT composite scores suggested a high injury risk compared to normative benchmarks, with additional inter-impairment differences observed in dominant-side performance. These findings highlight the need for multidisciplinary teams to integrate preventive strategies focused on improving lateral balance and reach capacity into preseason conditioning programs for para athletes.

A statistically and clinically significant difference in hip extensor torque and asymmetry was observed between intellectual/visual impairment and motor impairment groups, whereas no significant

differences were found for knee extensors. To our knowledge, no previous studies have assessed hip extensor strength in para athletes, limiting direct comparisons. Hip extensor weakness may increase reliance on knee extensors to dissipate ground reaction forces during sports, potentially contributing to musculoskeletal conditions such as tendinopathy [11] and patellofemoral pain [32]. While able-bodied athletes with patellar tendinopathy and patellofemoral pain often exhibit reduced hip extensor strength [11]. Our findings differ from reports of knee extensor deficits in athletes with hemiplegic cerebral palsy [33] However, they align with results from para swimmers showing strength differences in the non-dominant limbs [17]. These results emphasize the need for sport-specific biomechanical interventions and targeted hip strengthening programs to mitigate injury risk in para athletes with motor impairments.

This study provides valuable insights into preseason physical performance variables among para athletes. However, some limitations should be considered. The small sample size may restrict the generalizability of findings to the broader Paralympic population, and chronic factors such as delayed-onset muscle fatigue could act as potential confounders. Furthermore, the analysis did not control for key covariates – including age and years of sport-specific practice – which may also affect the outcome measures. It is also important to acknowledge the inherent heterogeneity of the sample, which is not a limitation but a characteristic of adaptive sports modalities. Finally, grouping participants by impairment type represented an important methodological decision; while this classification may have influenced variables such as range of motion and muscle strength, it was the most practical approach to assemble comparable groups of para athletes for analysis.

Preseason assessments are essential for optimizing performance, reducing injury risk, and guiding tailored prevention strategies [19]. However, generic prevention protocols that overlook impairment-specific variations, as highlighted in this study, may be insufficient. We recommend integrating systematic assessments of the studied variables into preseason protocols, with particular emphasis on hip strength monitoring for para athletes with motor impairments. This approach would enable dynamic adjustments to prevention strategies, fostering comprehensive injury risk mitigation throughout the competitive season.

CONCLUSION

Our findings revealed negligible to small differences between impairment groups for ankle dorsiflexion ROM and dynamic balance. In contrast, hip extensor strength—particularly on the non-dominant side—demonstrated a large effect size, and hip extensor asymmetry exhibited a very large effect size between groups. These results indicate that, while flexibility and balance appear comparable across impairment categories, hip extensor strength and symmetry are markedly influenced by impairment type. Such discrepancies may have meaningful biomechanical implications, potentially contributing to altered load distribution and increased musculoskeletal injury risk. These insights reinforce the importance of incorporating impairment-specific considerations into preseason screening and targeted strength interventions to optimize injury prevention strategies in para athletes.

Declarations

Author Contribution

All authors of this manuscript have made substantial contributions as follows: Geronimo José Bouzas Sanchis - (1) conception and design of the study, and analysis and interpretation of data, (2) drafting the article, (3) final approval of the version to be submitted; Renan Alves Resende - (2) critically revising it for important intellectual content, (3) final approval of the version to be submitted; Paula Martins - (3) final approval of the version to be submitted; Juliana Ocarino - (2) critically revising it for important intellectual content, (3) final approval of the version to be submitted; Marco Tulio de Mello - - (3) final approval of the version to be submitted; Yasser Mohmara - (3) final approval of the version to be submitted; Andressa Silva - (3) final approval of the version to be submitted.

Acknowledgement

This study was supported by Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Conselho Nacional de Desenvolvimento Científico e Tecnológico (N. 444769/2023-4) (CNPQ), Fundação Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES); Centro de Estudos em Psicobiologia e Exercício (CEPE), Centro Multidisciplinar em Sonolência e Acidentes (CEMSA), Pró-reitora de Pesquisa (PRPq) - UFMG, Fundação de Apoio ao Ensino, Pesquisa e Extensão (FEPE/ UFMG), Centro de Treinamento Esportivo (CTE/EEFFTO/UFMG), Ministério do Esporte do Governo Federal (Brasília, Brazil — Protocol Numbers: 58000.008978/2018—37 and number: 71000.056251/2020— 49), Comitê Paralímpico Brasileiro (CPB), Academia Paralímpica Brasileira (APB).

DECLARATION OF INTEREST STATEMENT

We, the authors of this work, affirm that we have no conflicts of interest to declare regarding the research presented in this manuscript.

Each author hereby confirms that they have no financial or personal relationships with any individuals or organizations that could potentially influence the content or interpretation of this work.

We assert that this Declaration of Interest Statement accurately reflects the absence of any conflicts of interest among the authors involved in the preparation and publication of this manuscript.

Ethical Statement.

The study adhered to the Declaration of Helsinki, and the project received approval from the Research Ethics Committee of the Universidade Federal de Minas Gerais (CAAE: 2718619.4.0000.5149).

References

1. Pinheiro, L. S. P. *et al.* Prevalence and incidence of health problems and their characteristics in Brazilian para athletes: A one-season single-center prospective pilot study. *Disabil. Health J.* 17, (2024).
2. Pinheiro, L. *et al.* Prevalence and incidence of injuries in para athletes: a systematic review with meta-analysis and GRADE recommendations. *Br. J. Sports Med.* (2020).
3. Blauwet, C. A. *et al.* Risk of injuries in paralympic track and field differs by impairment and event discipline: A prospective cohort study at the London 2012 Paralympic Games. *American Journal of Sports Medicine* 44, 1455–1462 (2016).
4. Longo, U. G. *et al.* No influence of age, gender, weight, height, and impact profile in achilles tendinopathy in masters track and field athletes. *American Journal of Sports Medicine* 37, 1400–1405 (2009).
5. Silva, A. da *et al.* Musculoskeletal complaints and physiotherapeutic procedures in the brazilian paralympic delegation during the Paralympic Athetics World Championship in 2011. *Rev. bras. med. esporte* 19, 256–259 (2013).
6. Vlist, A. C. Van Der, Breda, S. J., Oei, E. H. G. & Verhaar, J. A. N. Clinical risk factors for Achilles tendinopathy: a systematic review. 1352–1361 (2019) doi:10.1136/bjsports-2018-099991.
7. Sancho, I., Malliaras, P., Barton, C., Willy, R. W. & Morrissey, D. Biomechanical alterations in individuals with Achilles tendinopathy during running and hopping: A systematic review with meta-analysis. *Gait Posture* 73, 189–201 (2019).
8. Hein, T., Janssen, P., Haupt, G. & Grau, S. Prospective analysis of intrinsic and extrinsic risk factors on the development of Achilles tendon pain in runners. *Journal Medicine Science Sports* 1–12 (2013) doi:10.1111/sms.12137.
9. Nakagawa, T. H., Moriya, E. T. U., Maciel, C. D. & Serrão, F. V. Trunk, pelvis, hip, and knee kinematics, hip strenght, and gluteal muscle activation during a silge-leg squat in males and females with and without Patellofemoral Pain Syndrome. *Journal of Orthopaedic & Sports Physical Therapy* 42, 491–501 (2012).
10. Denyer, J. R., Hewitt, N. L. A. & Mitchell, A. C. S. Foot structure and muscle reaction time to a simulated ankle sprain. *J. Athl. Train.* 48, 326–330 (2013).
11. Silva, R. S. *et al.* Lower Limb Strength and Flexibility in Athletes with and Without Patellar Tendinopathy. *Physical Therapy in Sport* https://doi.org/10.1016/j.ptsp.2015.12.001 (2016) doi: 10.1016/j.ptsp.2015.12.001.
12. Nakagawa, T. H., dos Santos, A. F., Lessi, G. C., Petersen, R. S. & Silva, R. S. Y-Balance Test Asymmetry and Frontal Plane Knee Projection Angle During Single-leg squat as Predictors of Patellofemoral Pain in Male Military Recruits. *Physical Therapy in Sport* 44, 121–127 (2020).
13. Hartley, E. M., Hoch, M. C. & Boling, M. C. Y-balance test performance and BMI are associated with ankle sprain injury in collegiate male athletes. *J. Sci. Med. Sport* 21, 676–680 (2018).
14. Neal, B. S. *et al.* Risk factors for patellofemoral pain: A systematic review and meta-analysis. *Br. J. Sports Med.* 53, 270–281 (2019).

15. Pinheiro, L. *et al.* Periodic health evaluation in Para athletes: a position statement based on expert consensus. *BMJ Open Sport Exerc. Med.* 10, e001946 (2024).
16. Sanchis, G. J. B. *et al.* Shoulder characteristics in para athletes: A comparative analysis of range of motion, posture, and muscle function. *Rehabilitacion (Madr).* 60, 100969 (2026).
17. Sanchis, G. J. B. *et al.* Season changes in performance of upper limbs and trunk in para swimmers. *Physical Therapy in Sport* 71, 31–35 (2025).
18. Gagliano, N. *et al.* Tendon structure and extracellular matrix components are affected by spasticity in cerebral palsy patients. *Muscles Ligaments Tendons J.* 3, 42–50 (2013).
19. Schwank, A. *et al.* 2022 Bern Consensus Statement on Shoulder Injury Prevention, Rehabilitation, and Return to Sport for Athletes at All Participation Levels. *Journal of Orthopaedic and Sports Physical Therapy* 52, 11–28 (2022).
20. Barbosa, G. M., Calixtre, L. B., Fonseca Fialho, H. R., Locks, F. & Kamonseki, D. H. Measurement properties of upper extremity physical performance tests in athletes: a systematic review. *Braz. J. Phys. Ther.* 28, (2024).
21. Ravichandran, H. & Janakiraman, B. The Effects of Ankle Joint Mobilization on Dorsiflexion Range and Gait Parameters in Chronic Stroke Survivors: A Systematic Review and Meta-analysis. *Journal of Stroke Medicine* 4, 15–24 (2021).
22. Xixirry, M. G., Riberto, M. & Manoel, L. S. Analysis of y balance test and dorsiflexion lunge test in professional and amateur soccer players. *Revista Brasileira de Medicina do Esporte* 25, 490–493 (2019).
23. Shaffer, L. T. C. S. W. *et al.* Y-Balance Test: A Reliability Study Involving Multiple Raters. *Mil. Med.* 178, (2013).
24. Scattone, R. S. & Serrão, F. V. Sex differences in trunk, pelvis, hip and knee kinematics and eccentric hip torque in adolescents. *Clinical Biomechanics* 29, 1063–1069 (2014).
25. Scattone Silva, R., Smitheman, H. P., Smith, A. K. & Silbernagel, K. G. Are static foot posture and ankle dorsiflexion range of motion associated with Achilles tendinopathy? A cross-sectional study. *Braz. J. Phys. Ther.* 26, 100466 (2022).
26. Powden, C. J., Hoch, J. M. & Hoch, M. C. Reliability and minimal detectable change of the weight-bearing lunge test: A systematic review. *Man. Ther.* 20, 524–532 (2015).
27. Maas, J. C. *et al.* Decrease in ankle–foot dorsiflexion range of motion is related to increased knee flexion during gait in children with spastic cerebral palsy. *Journal of Electromyography and Kinesiology* 25, 339–346 (2015).
28. Harlaar, J., Becher, J. G., Snijders, C. J. & Lankhorst, G. J. Passive stiffness characteristics of ankle plantar flexors in hemiplegia. *Clinical Biomechanics* 15, 261–270 (2000).
29. Smania, N. *et al.* Effect of Balance Training on Postural Instability in Patients with Idiopathic Parkinson's Disease. *Neurorehabil. Neural Repair* 24, 826–834 (2010).

30. Malliaras, P., Barton, C. J., Reeves, N. D. & Langberg, H. Achilles and Patellar Tendinopathy Loading Programmes. *Sports Medicine* 43, 267–286 (2013).
31. Mendonça, L. D., Ocarino, J. M., Bittencourt, N. F. N., Macedo, L. G. & Fonseca, S. T. Association of hip and foot factors with patellar tendinopathy (Jumper's Knee) in Athletes. *Journal of Orthopaedic and Sports Physical Therapy* 48, 676–684 (2018).
32. Prins, M. R. & van der Wurff, P. Females with patellofemoral pain syndrome have weak hip muscles: a systematic review. *Australian Journal of Physiotherapy* 55, 9–15 (2009).
33. Chiu, H.-C., Ada, L., Cherng, R.-J. & Chen, C. Asymmetry in Sensory-Motor Function between the Lower Limbs in Children with Hemiplegic Cerebral Palsy: An Observational Study. *Chinese Journal of Physiology* 66, 345–350 (2023).

Figures



Figure 1

Dorsiflexion Range of Motion – Lunge test



Figure 2

Dynamic Balance – Y-Balance Test



Figure 3

Isometric muscle strength of Hip extensors



Figure 4

Isometric Muscle strength of Knee extensors