ORIGINAL ARTICLE

Relationship between hip rotational range of motion and isokinetic lower limb strength in elite male alpine skiers

Yupeng Yang. *Graduate School. Harbin Sport University. Heilongjiang Province, China.*
Ying Li. *School of Sports Science and Health. Harbin Sport University. Heilongjiang Province, China.*
Mengqi Liu. *Graduate School. Harbin Sport University. Heilongjiang Province, China.*
Qinghe Liu. *Graduate School. Harbin Sport University. Heilongjiang Province, China.*
Lisha Tian. *Graduate School. Harbin Sport University. Heilongjiang Province, China.*
Ying Qin. *School of Sports Science and Health. Harbin Sport University. Heilongjiang Province, China.*
Mi Zheng **.** *School of Sports Science and Health. Harbin Sport University. Heilongjiang Province, China.*

ABSTRACT

This study aims to clarify the intrinsic relationship between the hip joint range of motion and the isokinetic strength of the hip and knee joints among outstanding male alpine skiers. Twenty-one national-level male alpine skiers were selected for this study. The internal and external rotations of the hip joint in prone and weighted positions were evaluated, along with the total range of motion. The maximum torque, peak power, and other hip and knee joint flexion and extension indicators were measured at angular velocities of 60°/sec and 180°/sec. The results of this study show: (1) There is a negative correlation between the hip joint rotation range in prone and weighted positions and the hip extension and flexion indices in the 60°/sec test; (2) The external rotation angle of the hip joint in the weighted position has a positive correlation with the explosive power of the hip and knee joints in the 180°/sec test; (3) The internal rotation range of the hip joint measured in the prone position has a negative correlation with the total work of hip extension and flexion at 180°/sec and 60°/sec. The results of this study indicate that when evaluating the athletic qualities of alpine skiers, the angular velocity differences between the hip joint range of motion and lower limb muscle strength must be taken into consideration. The range of external rotation angle of the hip joint in the weighted position can be used as an important indicator for evaluating the explosive power of the hip and knee joints. In addition, during training, priority should be given to the dynamic balance of hip joint flexibility and stability.

Keywords: Biomechanics, Alpine skiing, Hip joint range of motion, Lower limb isokinetic muscle strength, Correlation analysis.

Cite this article as:
Yang, Y., Li, Y., Liu, M., Liu, Q., Tian, L., Qin, Y., & Zheng, M. (2026). Relationship between hip rotational range of motion and isokinetic lower limb strength in elite male alpine skiers. *Journal of Human Sport and Exercise, 21*(1), 255-266. https://doi.org/10.55860/xgkwbf29

Corresponding author. *School of Sports Science and Health. Harbin Sport University. Heilongjiang Province, China.*
E-mail: zhengmi0207@163.com
Submitted for publication September 08, 2025.
Accepted for publication October 24, 2025.
Published November 18, 2025.
Journal of Human Sport and Exercise. ISSN 1988-5202.

doi: https://doi.org/10.55860/xgkwbf29

INTRODUCTION

Robust lower body strength is essential for the performance and efficacy of alpine skiers, as the specific technical manoeuvres in this sport predominantly depend on the control and power exertion of the lower body musculature. During turns, athletes must employ hip and knee flexion/extension and adduction/abduction to regulate the angle of the skis and alter direction. The swift contraction of the quadriceps, hamstrings, and gluteal muscles directly influences the fluidity of the turn and the capacity to sustain speed (Hébert-Losier et al., 2014). In challenging snow conditions, lower limb muscle strength is essential for executing precise manoeuvres like propulsion and swift directional shifts. Insufficient strength might result in movement distortion and rhythm disruption, ultimately affecting competition outcomes (Turnbull et al., 2009).

All joints in the human body exhibit varying degrees of flexibility and stability. The technical manoeuvres in alpine skiing underscore the significance of hip joint mobility in this discipline. The hip joint, a ball-and-socket joint, possesses an anatomical configuration that renders it the most flexible joint in the lower limbs, allowing for six degrees of freedom of movement. The range of motion in hip flexion, extension, adduction, abduction, and rotation directly influences the starting length and angle of force generation of core muscle groups, including the quadriceps, gluteus maximus, and hamstrings. Consequently, the mobility of the hip joint and the strength of the lower limb muscles are intricately connected. In alpine skiing, athletes possessing excellent hip joint mobility provide a robust basis for effectively utilizing their lower body strength, while substantial lower body strength contributes to joint stability during full range of motion activities.

Prior research has predominantly concentrated on the correlation between range of motion (ROM) and muscular strength output in isolated joints, overlooking the distinct responses of lower limb multi-joint coordination systems at varying velocities (Baumgart et al., 2021). Moreover, whereas current research has thoroughly investigated the relationship between hip flexion/extension range of motion and lower limb strength, limited studies have addressed the correlation between hip internal rotation range of motion and isometric lower limb strength (Donno et al., 2025; Heinrich et al., 2022). Recent biomechanical studies indicate that the hip joint, as the central component of the lower limb kinetic chain, transmits directional changes in its range of motion through the myofascial chain to distal joints, thereby affecting the efficiency of knee extensor explosive force output (Malfait et al., 2016). The existing literature does not clarify the relationship between hip joint range of motion measurement methods in various positions and isometric muscle strength in the hip and knee joints of the lower limbs. This study utilized the weight-bearing and prone positions to assess hip joint range of motion (ROM). The measurement in the prone position is increasingly utilized in clinical assessments (Takeda & Furukawa, 2022), The assessment of hip joint range of motion in a weight-bearing position more accurately reflects the movement patterns of the hip joint during human activity than assessments conducted in other positions. The assessment of isokinetic strength was conducted at varying angular velocities (60°/s and 180°/s) for the hip and knee joints, demonstrating the intrinsic relationship between hip rotational range of motion and the isokinetic strength of both the hip and knee joints. This offers theoretical justification for the optimization of training strategies and the improvement of competitive performance in alpine skiing athletes.

MATERIALS AND METHODS

Subject of study

This research involved the recruitment of 21 male athletes from the national first-level alpine skiing team as subjects. Table 1 presents their comprehensive basic information. Inclusion criteria: Individuals aged 18 to 25 years who have completed over five years of professional training and hold an athlete grade certificate.

Exclusion criteria include: (1) lower limb orthopaedic diseases and soft tissue injuries that have not healed within the last six months; (2) inability to cooperate in the completion of the experimental process.

Table 1. Basic information of subjects.

Age	Height	Weight	Years of training
20.8 ± 1.18	177.2 ± 5.00	73.3 ± 18.54	5.05 ± 1.24

Test process

ROM measurement

To maintain the accuracy of experimental measurements, all range of motion assessments for participants were performed by the same certified physical therapist. Participants were positioned in prone and weight-bearing orientations during measurement, with the range of motion for hip internal rotation, external rotation, and total rotation documented for each position. The equipment utilized included an iPhone 13 smartphone (iOS 17.3), an XW-W01 smartphone mount, a physical therapy bed, and the Bubble Level and Clinometer smartphone application (Whyte et al., 2021). This application has been utilized in various studies to assess lower limb joint range of motion, with established reliability and validity for research purposes (E. Miley et al., 2019; E. N. Miley et al., 2022; Whyte et al., 2021).

In the prone position, the subject lies on the treatment bed with the pelvis secured by a restraint strap to inhibit rotation. The knee joint of the test leg is flexed at 90°, whereas the non-test leg remains extended and flat on the bed (Charlton et al., 2015). The examiner positions the smartphone at the tibial tubercle, calibrates it to the neutral position of the hip joint utilizing the Clinometer software, stabilizes the pelvis with one hand, and secures the ankle with the other hand. The test leg undergoes passive internal and external rotation around the hip joint axis until it attains its end-range resistance position. The assistant measures the angle difference between the initial and final positions to determine the range of motion, repeating the procedure three times in each direction and calculating the average value.

The subject adopts a half-kneeling position during the measurement of weight-bearing positions. The test leg is flexed at the knee to 90° and supports at least 80% of body weight, whereas the contralateral leg supports less than 20% of body weight and is positioned on a weighing scale for measurement purposes. The subject ensures trunk stability by grasping a chair with both hands (Aefsky et al., 2016). The therapist positions the pelvis horizontally, ensuring alignment of the sagittal plane of the test leg. The subject actively rotates the hip joint both internally and externally to its maximum range, while maintaining a neutral ankle position and avoiding trunk compensation. The therapist observes and documents the maximum rotation angle for each of the three repetitions, calculating the average value thereafter.

Isokinetic muscle strength test

This research employed a multi-joint isokinetic muscle strength testing system (CON-TREX-MJ, PHYSIOMED, Germany), utilizing angular velocities of 60°/s and 180°/s to perform flexion-extension assessments on the hip and knee joints of the subjects. Before testing, the calibration of the equipment was confirmed, and the participants' body positions were adjusted to ensure alignment of the joint axes with the equipment axes, with limbs immobilized to prevent compensation. Participants initially executed three sets of maximum effort flexion and extension movements at a velocity of 60°/s, with rest intervals of 30 to 60 seconds between sets. Following a 2-minute rest interval, the test was conducted again at 180°/s, with three further sets performed. The system recorded metrics including maximum torque, peak power, average power, and total work automatically. Data were systematically organized and stored subsequent to the test.

Statistical methods

The research employed SPSS 27.0 software for statistical analysis. Descriptive statistics were employed to analyse basic information regarding the study subjects, including age, height, weight, and years of training, through frequency analysis. Continuous variables were presented as mean ± standard deviation (Mean ± SD). Correlation Analysis: Data conforming to the criteria for normal distribution were subjected to Pearson correlation analysis, represented as ($\bar{x}$ ± s). Spearman rank correlation analysis was employed for data that did not satisfy the criteria for normal distribution. In all analyses, a *p*-value of less than .05 was deemed statistically significant.

RESULTS

Rapid angular velocity (180°/s)

The constant velocity 180°/s test showed that Prone-HTR was highly significantly positively correlated with PP-KE (r = 0.374, $p < .01$), MP-KE (r = 0.337, $p < .01$), and TW-KE (r = 0.354, $p < .01$). Prone-HIR showed significant negative correlations with TW-HE and TW-HF (r = -0.346, $p < .01$; r = -0.347, $p < .01$) (Figure 1A).

WB-HER showed significant positive correlations with MP-K (r = 0.381, $p < .05$), TW-K (r = 0.392, $p < .05$), MP-H (r = 0.425, $p < .01$), and TW-H (r = 0.477, $p < .01$) (Figure 1B). WB-HT showed a strong positive correlation with TW-HF (r = 0.432, $p < .01$).

Slow angular velocity (60°/s)

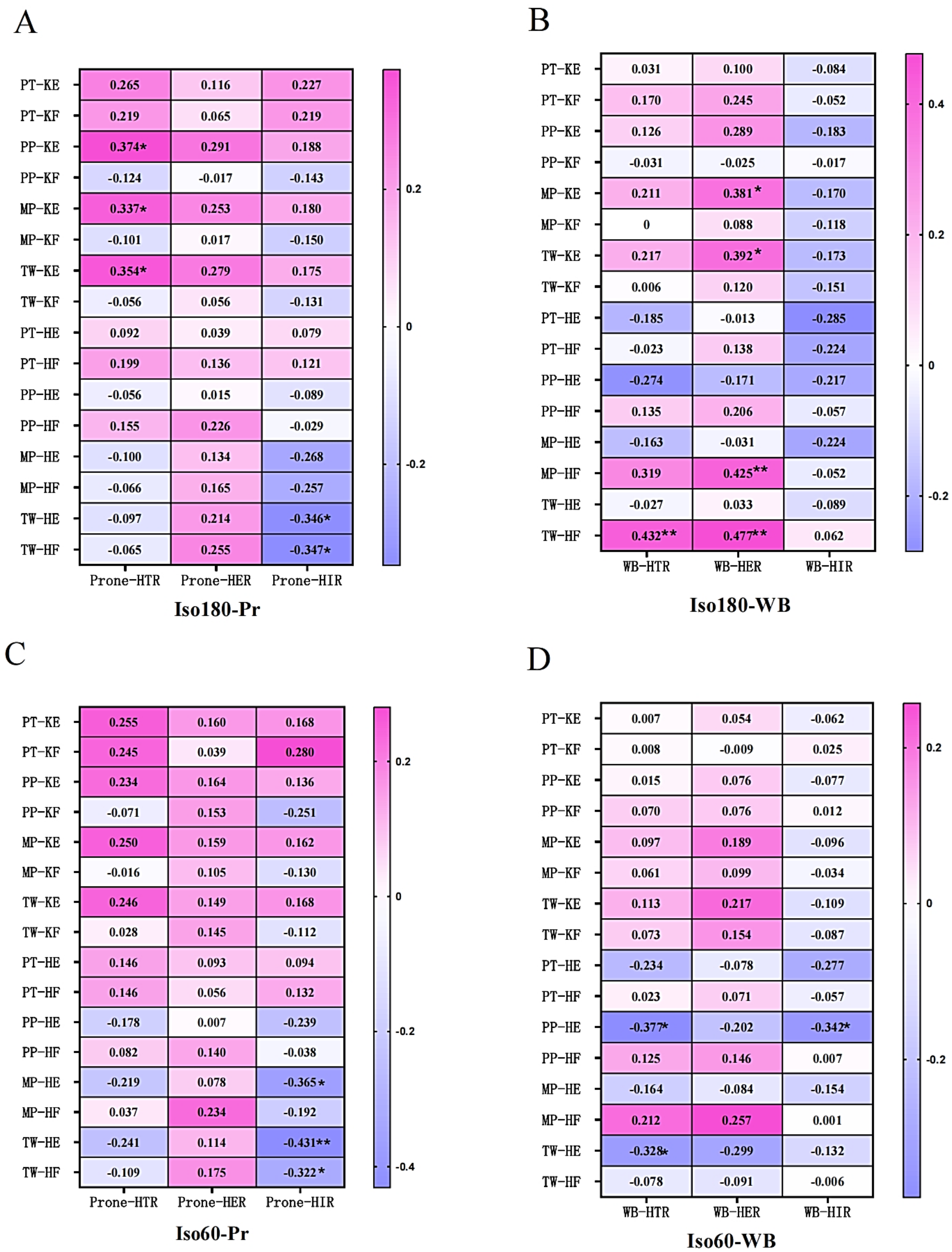
In the constant speed 60°/s test, the prone-HIR prone position hip internal rotation range of motion was significantly negatively correlated with the total work of the TW-HE hip extensor muscles (r = -0.431, $p < .01$), the total work of the TW-HF hip flexor muscles (r = -0.322, $p < .05$), and MP-HE hip extensor average power (r = -0.365, $p < .01$) (Figure 1C).

WB-HTR loaded hip joint total range of motion was significantly negatively correlated with TW-HE hip extensor total work (r = -0.328, $p < .05$), PP-HE hip extensor peak power (r = -0.377, $p < .01$) showed a significant negative correlation, and WB-HIR loaded hip internal rotation range of motion showed a significant negative correlation with PP-HE hip extensor peak power (r = -0.342, $p < .01$) (Figure 1D).

DISCUSSION AND CONCLUSIONS

Hip joint range of motion and lower limb isokinetic muscle strength are velocity-dependent

Testing at a slow angular velocity of 60°/s highlights the peak muscle force output. This study's results demonstrate a significant negative correlation between hip range of motion measurements in both prone and loaded positions and indicators of hip extensors and flexors. This indicates that during slow-speed hip movements, enhanced flexibility results in diminished stability, irrespective of the hip's anatomical or functional position. This significantly decreases the force output efficiency of the hip flexors and extensors. Aefsky et al., (2016) discovered in their study that slow isokinetic movements engage a greater proportion of the load range, necessitating muscles to withstand constant resistance, whereby joint stability emerges as a critical limiting factor in force output. In alpine skiing, athletes executing straight downhill movements primarily engage in isometric or slow concentric contractions of the lower limb muscle groups. This necessitates the continuous exertion of force by the active muscle groups to maintain slight flexion of both the hip and knee joints, thereby counteracting vibrations from the snow surface and stabilizing the support chain.



Note. A: Heat map analysis of the correlation between isokinetic testing at 180°/s and prone hip joint range of motion; B: Heat map showing the correlation analysis between constant speed testing at 180°/s and hip joint rotation range of motion under load; C: Heat map analysis of the correlation between isokinetic testing at 60°/s and hip joint rotation range of motion in the prone position; DHeat map showing the correlation analysis between isokinetic testing at 60°/s and hip joint range of motion under load; Prone-HIR: Prone Hip Internal Rotation Range of Motion; Prone-HER：Prone Hip External Rotation Range of Motion; Prone-HTR: Prone Hip Total Rotation Range of Motion; WB-HIR: Weight-Bearing Hip Internal Rotation ROM; WB-HER: Weight-Bearing Hip External Rotation ROM; WB-HTR: Weight-Bearing Hip Total Rotation ROM; PT-KE: Peak Knee Extensor Torque; PT-KF: Peak Knee Flexor Torque; PP-KE: Peak Power of Knee Extensors; PP-KF: Peak Power of Knee Flexors; MP-KE: Mean Power of Knee Extensors; MP-KF: Mean Power of Knee Flexors; TW-KE: Total Work of Knee Extensors; TW-KF: Total Work of Knee Flexors; PT-HE: Peak Hip Extensor Torque; PT-HF: Peak Hip Flexor Torque; PP-HE: Peak Power of Hip Extensors; PP-HF: Peak Power of Hip Flexors; MP-HE: Mean Power of Hip Extensors; MP-HF: Mean Power of Hip Flexors; TW-HE: Total Work of Hip Extensors; TW-HF: Total Work of Hip Flexors; *: indicates a significant correlation at the 5% level; **: indicates a significant correlation at the 1% level.

Figure 1. Heat map showing the correlation analysis between hip joint ROM in two positions and isokinetic muscle strength indicators of the hip and knee joints at 60°/180° angular velocity.

Excessive flexibility of the hip joint during movement results in the muscles being positioned sub optimally for force generation, thereby disrupting the torque balance between the hip and knee and leading to compensatory losses in muscle strength. This phenomenon is more evident under conditions of low speed and high load. Secondly, testing at slow angular velocities predominantly engages slow-twitch muscle fibres, rendering it more appropriate for activities necessitating postural stability, such as when athletes sustain stability during low-speed gliding. Excessive hip joint range of motion (ROM) can lead to muscles being in a state of over-stretching or shortening, which is suboptimal for muscle contraction. Kwon et al. demonstrated that excessive internal rotation reduces the length of gluteus maximus muscle fibres to below 80% of the optimal length for force generation. This reduction diminishes cross-bridge coupling efficiency during slow contractions, leading to a decrease in extension force (Turnbull et al., 2009). This may elevate the load on the medial collateral ligament of the knee during skiing braking movements, as the suboptimal force generation of the hip extensor muscles compels the knee joint to accommodate greater deceleration torque.

Constant speed 180°/S loaded hip external rotation is an indicator of strong explosive power in both the hip and knee joints

An angular velocity of 180°/s indicates muscle explosive power. In alpine skiing, the hip joint is required to execute external rotation, internal rotation, and flexion/extension movements while under load to effectively adjust the direction of the skis and sustain body balance. The employed position measurement method in this study accurately represents the hip joint's range of motion under body weight and dynamic loads. The hip external rotator muscle group and the flexion/extension muscle group must collaborate during measurement to ensure stability and execute the movement, reflecting the dynamic control demands inherent in alpine skiing. The loaded position is more appropriate for evaluating the actual movement demands of alpine skiing than prone or seated positions. This study's results indicate a significant positive correlation between hip external rotation range of motion in the weight-bearing position and the average power and total work of both the knee extensor and hip flexor muscles (Figure 2). This finding demonstrates the substantial impact of hip external rotation range of motion on the efficacy of lower limb muscle group force production during weight-bearing activities. From a biomechanical perspective, in a weight-bearing posture, hip external rotation modifies the angle of the femur, aligning the force lines of the knee extensor muscle group, primarily the quadriceps, more closely with the axis of motion of the knee joint. This facilitates the efficient transmission of force produced by muscle contraction, thereby significantly minimizing force loss (Fu et al., n.d.; Iacobescu et al., 2024). Secondly, hip external rotation enhances the length-contraction range of the knee extensor muscles, which is closely associated with muscle work efficiency. The knee extensor muscle group is capable of achieving greater displacement work within the same time frame, thus significantly enhancing the average power and total work of these muscles (Yubin Lee & Chaegil Lim, 2023).

A significant positive correlation exists between weight-bearing external rotation range of motion and muscle function in hip flexors. The primary reason is the optimization of initial muscle length and improved coordination among muscle fibres and movement. The muscle length-tension relationship indicates that muscle fibres, when moderately stretched, achieve maximal cross-bridge formation between actin and myosin, leading to the highest rapid force production during contraction (Pawar et al., 2021). During hip external rotation, the femur's external rotation results in the outward movement of the lesser trochanter, which passively lengthens the muscle fibres of the hip flexors, particularly the iliopsoas muscle, to their optimal initial length for contraction, thereby significantly improving contraction efficiency. Simultaneously, the rectus femoris muscle, which spans both the hip and knee joints, undergoes decreased inhibition of hip flexion by knee extension as a result of improved knee joint mechanics during hip external rotation. This enables a greater emphasis on hip flexion, thereby enhancing the average power and total work output of the hip flexor muscles (Yan-Tao Ma et al., 2023).

The synergy between the hip and knee is essential in alpine skiing for executing high-quality turns, kick-snow, and other specialized manoeuvres (Shestakov et al., 2021). Hip external rotation enhances the range of motion for the hip flexors, mitigating joint compression. Additionally, the role of the hip flexors contributes to upward momentum for the knee extensors during kick-snow activities. The energy synergy produced by these three components markedly improves movement efficiency (Neumann, 2010). The synergistic effect is more evident under loaded conditions, as the loaded position replicates the body posture encountered during actual skiing. Hip external rotation depends on both the passive flexibility of the joint capsule and ligaments, as well as the active contraction control of the external rotator muscle group. The "*functional range of motion*" is more closely linked to the active force generation of lower limb muscle groups. This may elucidate the stronger correlation observed in the loaded position compared to the prone position.

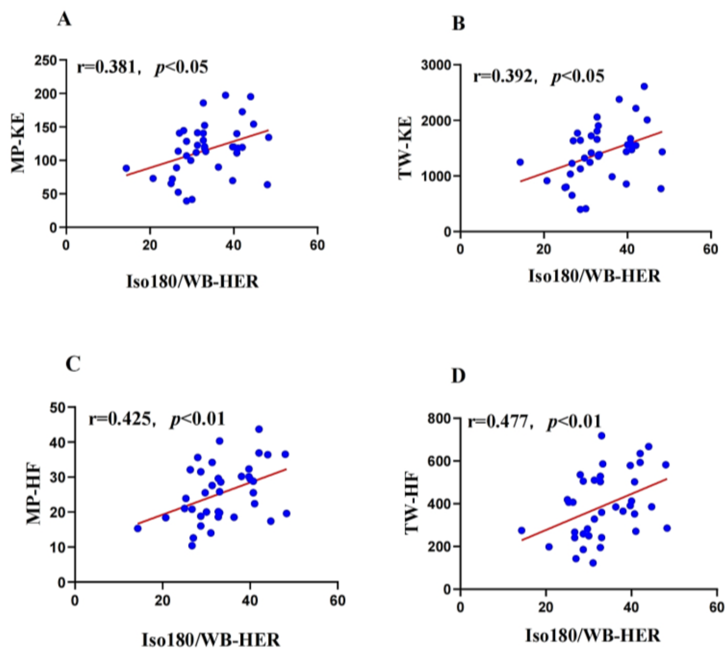


Figure 2. Scatter plot showing the correlation between 180°/S weight-bearing external rotation hip joint range of motion and isokinetic muscle strength indicators of the hip and knee joints.

Prone internal rotation at 180°/S or 60°/S is significantly negatively correlated with total hip extension and flexion work

This research demonstrated a significant negative correlation between prone internal rotation range of motion and indicators of hip extensor and flexor muscle strength as assessed through isokinetic muscle strength testing. A negative correlation was identified in both slow high-load and high-speed explosive conditions, indicating that an excessive range of internal rotation may adversely affect the force generation of the hip muscle group (Figure 3). The incompatibility of the static range of motion measurement method employed in this study with the dynamic functional requirements of alpine skiing-specific movements may account for this discrepancy. The prone hip joint range of motion measurement method evaluates the passive range of motion of the hip joint, primarily indicating the physiological flexibility of the joint capsule, ligaments, and internal rotator muscle groups. All specialized technical movements in alpine skiing occur under joint loading and dynamic conditions, necessitating the hip joint to coordinate rapid flexion, extension, and rotation while under load. Excessive passive internal rotation range of motion can hinder the hip joint's ability to maintain its optimal position for power generation during dynamic flexion and extension. In large-radius turns, the hip joint must sustain a specific external rotation angle to stabilize the centre of gravity. An excessive physiological internal rotation range in an athlete may lead to excessive internal rotation of the femur, which shortens the lever arm between the hip extensor muscle insertion point and the muscle tension line, consequently diminishing torque output efficiency. Sandro Hodel and colleagues discovered that an increase in passive hip internal rotation range of motion correlates with an elevated load pattern of dynamic knee valgus (Hodel et al., 2025). This phenomenon is attributed to the relationship between femoral torsion and knee internal rotation adduction torque, aligning with the findings of this study (Dix et al., 2019; Imhoff et al., 2021). Dynamic eccentric control demands are prevalent in skiing movements; however, static assessment methods fail to address this aspect. During steep slope descent, athletes' hip muscles engage in rapid eccentric contractions to regulate the body's forward lean. Excessive internal rotation range of motion may compel the flexors to perform the dual functions of resisting internal rotation and facilitating hip flexion, resulting in a distribution of energy allocation and a reduction in the overall work accomplished by the flexors. Excessive activity of the internal rotators may disrupt the antagonistic function of the flexors and extensors. The hip flexor and extensor muscle groups exhibit a significant interactive relationship with the internal rotator muscle groups. Hip extension is primarily facilitated by the gluteus maximus, which plays a key role in hip external rotation. In contrast, hip flexion is dependent on the iliopsoas muscle, which is involved in both hip flexion and internal rotation. Excessive static internal rotation range of motion disrupts this balance, as evidenced by imaging and anatomical studies (Lieberman et al., 2006; Suthar et al., 2015). This is evident as an antagonistic effect during hip extension, wherein the gluteus maximus demonstrates a tendency for external rotation. Excessive internal rotation range of motion triggers compensatory contractions in internal rotator muscle groups, including the gluteus minimums, to restrict excessive internal rotation. This process directly hinders the concentric contraction efficiency of the gluteus maximus (Harris et al., 2017; Streeck, 2007). The iliopsoas muscle facilitates hip flexion and internal rotation; however, it necessitates moderate inhibition of external rotation muscle groups, including the piriformis, to prevent excessive movement during effective force generation (Boling et al., 2009). Excessive static internal rotation range of motion leads to increased basal tension in internal rotation muscle groups, which may result in coordination disorders of the iliopsoas muscle during rapid hip flexion.

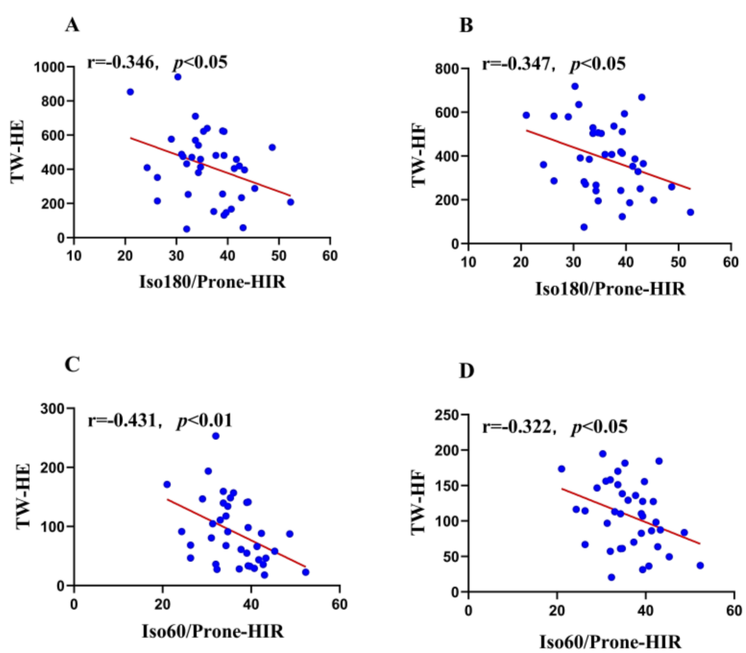


Figure 3. Scatter plot showing the correlation between prone internal rotation at 180°/S and 60°/S and the total work of hip extension and flexion.

Practical significance

This study examined the relationship between hip joint range of motion and the movements of the hip and knee joints at angular velocities of 60°/s and 180°/s in 21 elite male alpine ski athletes, demonstrating the significant impact of hip joint range of motion on the force output of the hip and knee. The findings hold significant practical implications for the training, assessment, and injury prevention of alpine ski athletes. This study's experimental results suggest that the loaded position should be incorporated into the evaluation of hip joint health and lower limb strength in athletes participating in this sport. Historically, clinical assessments of hip joint range of motion in athletes predominantly employed the prone position. However, this static evaluation method inadequately accounts for the athletes' physiological range of motion and may not accurately represent the functional demands imposed by the dynamic loads associated with alpine skiing. The hip external rotation range of motion in a weight-bearing position is the sole indicator in this study that demonstrates a strong correlation with both hip and knee joint explosive power, aligning more closely with the demands of rapid turns and snow-pushing movements in skiing. Incorporating this into the routine assessment system for alpine skiing athletes during training or screening is advisable. In designing lower limb strength exercises for alpine skiing athletes, it is essential for coaches to consider the interplay between hip joint flexibility and stability. In low-speed gliding or posture maintenance tasks, enhancing hip muscle control via anti-rotation or core stability training is advisable to reduce the negative impact of excessive range of motion on stability. Weighted external rotation training can enhance the active contraction capacity of the hip external rotator muscles during high-speed dynamic movements, thus improving the efficiency of explosive power output in the hip and knee joints.

Limitations

This research presents specific limitations. The study involved elite athletes; however, the sample size was limited and exclusively male, potentially leading to inadequate statistical power. Future research should increase the sample size and examine the potential impact of gender differences on these findings. This study primarily examined the univariate correlation between hip joint range of motion and isometric muscle strength of the hip and knee joints, without exploring multi-joint muscle co-activation patterns or intricate biomechanical mechanisms during dynamic movement. Future research should employ various perspectives to thoroughly examine the mechanisms connecting hip internal rotation range of motion with lower limb isometric muscle strength.

AUTHOR CONTRIBUTIONS

Conceptual design: Yupeng Yang (Y.Y.P.), Ying Li (L.Y.), and Mi Zheng (Z.M.); verification: Yupeng Yang (Y.Y.P.), Ying Li (L.Y.), and Mi Zheng (Z.M.); formal analysis: Yupeng Yang (Y.Y.P.), Ying Li (L.Y.); resources: Ying Qin (Q.Y.); data management: Yupeng Yang (Y.Y.P.), Ying Li (L.Y.); draft preparation: Yupeng Yang (Y.Y.P.); review and editing: Yupeng Yang (Y.Y.P.), Ying Li (L.Y.), Mengqi Liu (L.M.Q.); visualization: Mengqi Liu (L.M.Q.), Lisha Tian (T.L.S), and Qinghe Liu (L.Q.H.); supervision: Mi Zheng (Z.M.); project management: Mi Zheng (Z.M.); funding acquisition: Mi Zheng (Z.M.).

SUPPORTING AGENCIES

This research was funded by "*Class A Project of Harbin Sports University*", grant number "*2019KYYWF-FC07*"and "*Harbin Institute of Physical Education's Talent Recruitment Research Start-up Fund*", grant number "*RC20-201903*",The APC was funded by "*Class A Project of Harbin Sports University*".

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

INSTITUTIONAL REVIEW BOARD STATEMENT

This study has been approved by the local ethics committee (approval number: 2025051), and all operations have followed the regulations stipulated in the Helsinki Declaration regarding human experiments.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in this study.

DATA AVAILABILITY STATEMENT

Data generated or analysed during this study are available from the corresponding author upon reasonable request.

ACKNOWLEDGMENTS

The authors would like to express his gratitude to all the participants who took part in the test as well as all the authors of this research.

REFERENCES

Aefsky, B., Fleet, N., Heather Myers, & Butler, R. J. (2016). Reliability and Validity of a Novel Approach to Measure Hip Rotation. Journal of Sport Rehabilitation, 25(4), 330-337. https://doi.org/10.1123/jsr.2015-0013

Baumgart, C., Kurz, E., Freiwald, J., & Hoppe, M. W. (2021). Effects of Hip Flexion on Knee Extension and Flexion Isokinetic Angle-Specific Torques and HQ-Ratios. Sports Medicine - Open, 7(1), 41. https://doi.org/10.1186/s40798-021-00330-w

Boling, M. C., Padua, D. A., & Alexander Creighton, R. (2009). Concentric and Eccentric Torque of the Hip Musculature in Individuals With and Without Patellofemoral Pain. Journal of Athletic Training, 44(1), 7-13. https://doi.org/10.4085/1062-6050-44.1.7

Charlton, P. C., Mentiplay, B. F., Pua, Y.-H., & Clark, R. A. (2015). Reliability and concurrent validity of a Smartphone, bubble inclinometer and motion analysis system for measurement of hip joint range of motion. Journal of Science and Medicine in Sport, 18(3), 262-267. https://doi.org/10.1016/j.jsams.2014.04.008

Dix, J., Marsh, S., Dingenen, B., & Malliaras, P. (2019). The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review. Physical Therapy in Sport, 37, 197-209. https://doi.org/10.1016/j.ptsp.2018.05.015

Donno, L., Francia, C., Motta, F., LoMauro, A., Gorla, C., Scaccabarozzi, D., Tarabini, M., & Galli, M. (2025). Biomechanical insights into ski mountaineering: Kinematics and muscular activation in uphill movements. Applied Sciences, 15(3), 1003. https://doi.org/10.3390/app15031003

Fu, K., Yu, Y., Li, J., Chen, J., Du, Y., Xu, X., & Zhou, D. (n.d.). Emerging strategies in anterior cruciate ligament (ACL) injury prevention: From biomechanics to neuromuscular training. Research in Sports Medicine, 0(0), 1-22. https://doi.org/10.1080/15438627.2025.2521477

Harris, M. D., MacWilliams, B. A., Bo Foreman, K., Peters, C. L., Weiss, J. A., & Anderson, A. E. (2017). Higher medially-directed joint reaction forces are a characteristic of dysplastic hips: A comparative study using subject-specific musculoskeletal models. Journal of Biomechanics, 54, 80-87. https://doi.org/10.1016/j.jbiomech.2017.01.040

Hébert-Losier, K., Supej, M., & Holmberg, H.-C. (2014). Biomechanical factors influencing the performance of elite alpine ski racers. Sports Medicine, 44(4), 519-533. https://doi.org/10.1007/s40279-013-0132-z

Heinrich, D., Van den Bogert, A. J., & Nachbauer, W. (2022). Estimation of joint moments during turning maneuvers in alpine skiing using a three dimensional musculoskeletal skier model and a forward dynamics optimization framework. Frontiers in Bioengineering and Biotechnology, 10. https://doi.org/10.3389/fbioe.2022.894568

Hodel, S., Imhoff, F. B., Strutzenberger, G., Fitze, D., Obrist, S., Vlachopoulos, L., Scherr, J., Fucentese, S. F., Fröhlich, S., & Spörri, J. (2025). Greater hip internal rotation range of motion is associated with increased dynamic knee valgus during jump landing, both before and after fatigue. Knee Surgery, Sports Traumatology, Arthroscopy, 33(5), 1560-1568. https://doi.org/10.1002/ksa.12447

Iacobescu, G.-L., Iacobescu, L., Popa, M. I. G., Covache-Busuioc, R.-A., Corlatescu, A.-D., & Cirstoiu, C. (2024). Genomic determinants of knee joint biomechanics: An exploration into the molecular basis of locomotor function, a narrative review. Current Issues in Molecular Biology, 46(2), Article 2. https://doi.org/10.3390/cimb46020079

Imhoff, F. B., Cotic, M., Dyrna, F. G. E., Cote, M., Diermeier, T., Achtnich, A., Imhoff, A. B., & Beitzel, K. (2021). Dynamic Q-angle is increased in patients with chronic patellofemoral instability and correlates positively with femoral torsion. Knee Surgery, Sports Traumatology, Arthroscopy, 29(4), 1224-1231. https://doi.org/10.1007/s00167-020-06163-6

Lieberman, D. E., Raichlen, D. A., Pontzer, H., Bramble, D. M., & Cutright-Smith, E. (2006). The human gluteus maximus and its role in running. Journal of Experimental Biology, 209(11), 2143-2155. https://doi.org/10.1242/jeb.02255

Malfait, B., Dingenen, B., Smeets, A., Staes, F., Pataky, T., Robinson, M. A., Vanrenterghem, J., & Verschueren, S. (2016). Knee and Hip Joint Kinematics Predict Quadriceps and Hamstrings Neuromuscular Activation Patterns in Drop Jump Landings. PLOS ONE, 11(4), e0153737. https://doi.org/10.1371/journal.pone.0153737

Miley, E., May, J., Albertin, E., Takahashi, E., Goodman, C., & Pettaway, A. (2019). Reliability and validity for measuring active hip rotation with the clinometer smartphone applicationTM. Journal of Rehabilitation Sciences & Research, 6(4), 193-199. https://doi.org/10.30476/jrsr.2019.82397.1031

Miley, E. N., Reeves, A. J., Baker, R. T., Baker, J., & Hanna, S. (2022). Reliability and validity of the clinometerTM smartphone application for measuring knee flexion. https://doi.org/10.1123/ijatt.2021-0019

Neumann, D. A. (2010). Kinesiology of the hip: A focus on muscular actions. Journal of Orthopaedic & Sports Physical Therapy. https://doi.org/10.2519/jospt.2010.3025

Pawar, A., Phansopkar, P., Gachake, A., Mandhane, K., Jain, R., & Vaidya, S. (2021). A Review on Impact of Lower Extremity Muscle Length. Journal of Pharmaceutical Research International, 158-164. https://doi.org/10.9734/jpri/2021/v33i35A31885

Shestakov, M., Zubkova, A., Shestakov, M., & Zubkova, A. (2021). Peculiarities of muscle-tendon mechanics and energetics in elite athletes in various sports. In Contemporary Advances in Sports Science. IntechOpen. https://doi.org/10.5772/intechopen.97000

Streeck, R. (2007). Das Hüftgelenk: Symptomatik und Beschwerdeursachen. Manuelle Medizin, 45(2), 85-90. https://doi.org/10.1007/s00337-007-0510-4

Suthar, P., Patel, C., Gamit, M., Dave, D., Wadhwani, C., & Suthar, B. (2015). Orthopaedic aspect of anatomy and radiology of proximal femur. International Journal of Research in Medical Sciences, 1820-1824. https://doi.org/10.18203/2320-6012.ijrms20150287

Takeda, Y., & Furukawa, K. (2022). Clinical reliability and usability of smartphone goniometers for hip range of motion measurement. Journal of Physical Therapy Science, 34(6), 433-439. https://doi.org/10.1589/jpts.34.433

Turnbull, J. R., Kilding, A. E., & Keogh, J. W. L. (2009). Physiology of alpine skiing. Scandinavian Journal of Medicine & Science in Sports, 19(2), 146-155. https://doi.org/10.1111/j.1600-0838.2009.00901.x

Whyte, E., Ó Doinn, T., Downey, M., & O'Connor, S. (2021). Reliability of a Smartphone Goniometric Application in the Measurement of Hip Range of Motion Among Experienced and Novice Clinicians. Journal of Sport Rehabilitation, 30(6), 969-972. https://doi.org/10.1123/jsr.2020-0165

Yan-Tao Ma, Yu-Lin Dong, Bo Wang, Wen-Pin Xie, Qiang-Min Huang, & Yong-Jun Zheng. (2023). Dry needling on latent and active myofascial trigger points versus oral diclofenac in patients with knee osteoarthritis: A randomized controlled trial. BMC Musculoskeletal Disorders, 24. https://doi.org/10.1186/s12891-022-06116-9

Yubin Lee & Chaegil Lim. (2023). Reference value of knee position sense in weight-bearing and non-weight-bearing conditions. Knee Surgery and Related Research, 35. https://doi.org/10.1186/s43019-023-00199-x