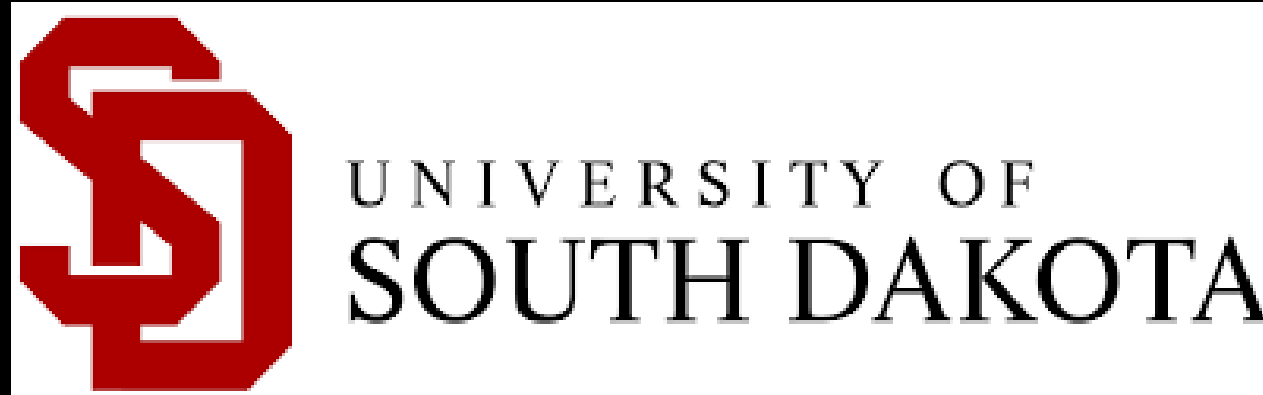


The association of the tibia angle with braking forces during pole vaulting

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Background

- Pole vaulting requires coordinated sprint mechanics with explosive force production during takeoff.
- Ground reaction forces (GRFs)** influence performance and injury risk.
- Tibial angle** describe the orientation of the tibia relative to vertical and is associated with braking force modulation and mechanical efficiency.
- Studies indicate a more vertical tibia angle is associated with less braking GRFs and increased upward force production.
- The relationship between tibial angle and GRFs during pole vault takeoff remains unclear.
- Purpose:** To assess the association between tibia angle and braking ground reaction forces in pole vaulters.

Methods

Design:

- Cross-sectional study.

Participants:

- 7 University of South Dakota pole vaulters during the 2026 track and field season.

Inclusion:

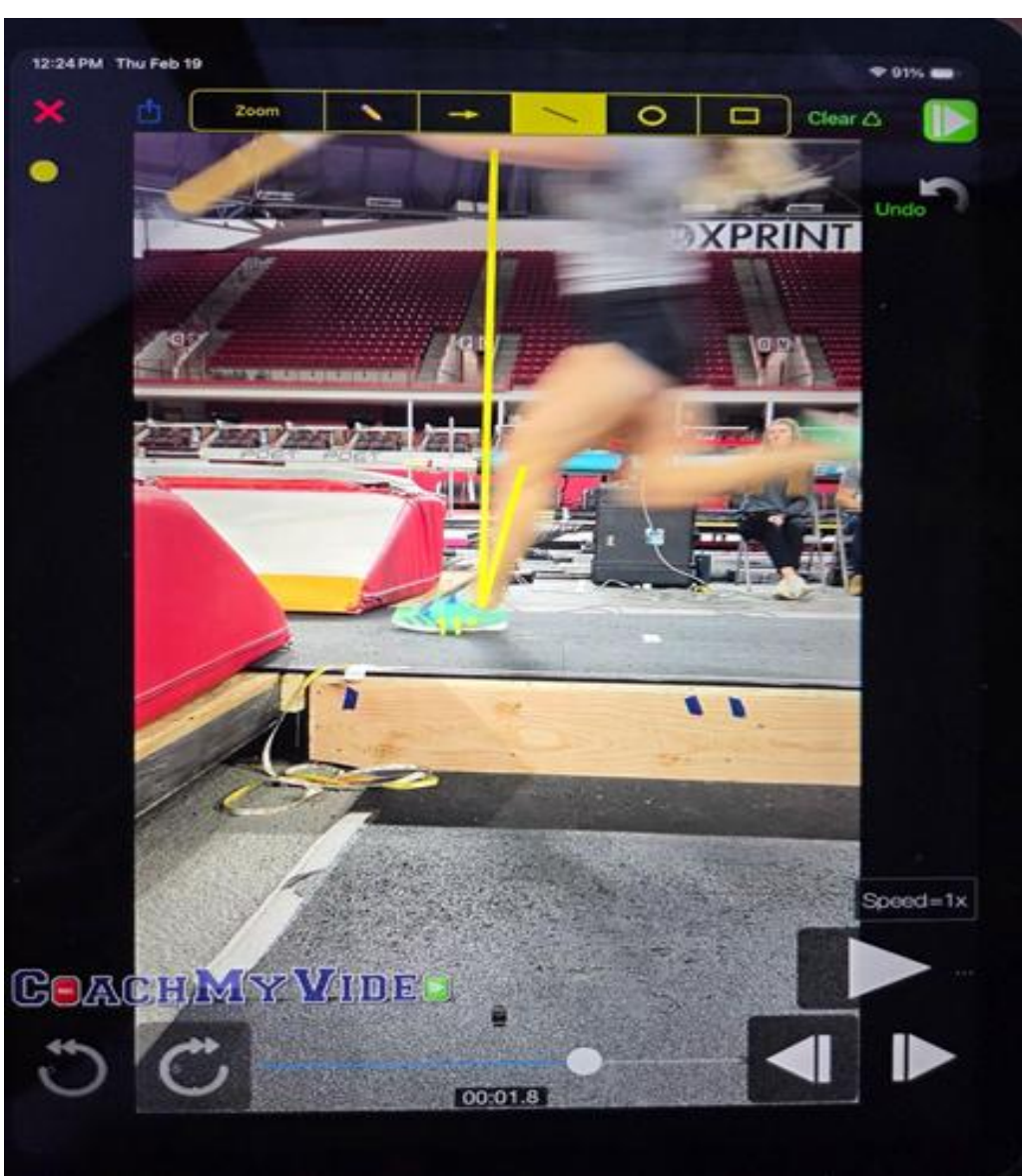
- Actively training and completing unmodified vaults.

Primary outcomes:

- Peak braking ground reaction forces (GRFs)
 - Measurement Tool: Bertec 4060-05 force plate.
- Tibial angle at take-off
 - Measurement Tool: "Coach my Video" application on iPad

Statistical Methods:

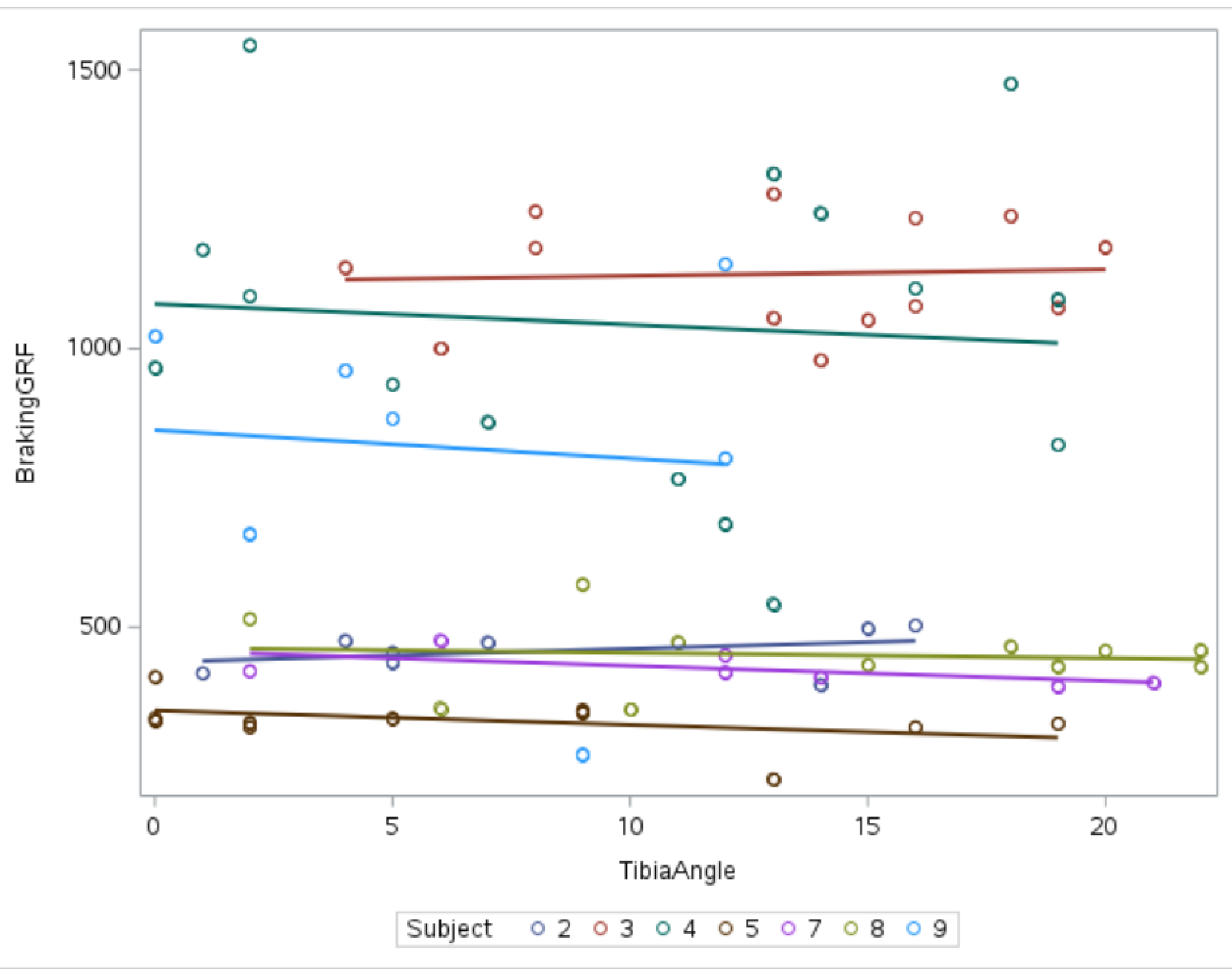
- Linear mixed-effects model with random intercepts for subjects
- 95% confidence intervals were reported



Results

Variable	Mean (95% CI)
Age	19.7 (19.3-20.0)
Height, inches	70.9 (70.0-71.8)
Weight, lbs	161.6 (157.1-166.1)
BMI	22.5 (22.3-22.7)
PR, inches	183.9 (177.9-190.0)
PV Years	7.4 (6.6-8.1)
Tibia Angle, °	10.4 (8.8-11.9)
Braking GRF, N	708.4 (623.9-792.9)

There was no association between tibia angle and braking GRFs. A linear mixed effects model demonstrated a Beta of -1.71 and a p-value of 0.61 . A 95% confidence interval ranged from -8.32 to 6.40 , indicating there was no statistical significance for our results.



This graph shows individual data points (vaults) per participant and demonstrates high residual variance.

Conclusion

Findings:

- No strong biomechanical association between braking GRFs and tibia angle in pole vaulting
- Braking GRFs differed significantly between athletes
 - Suggests kinematics do not fully represent kinetics

Limitations:

- Small sample size
- Equipment and human measurement error
- Removed data points
- 180 fps iPad Frame Rate

Applications:

- Avoid relying solely on tibial angle when evaluating pole vault technique
- Findings don't account for differences in pole vaulters' skill and experience and may not apply equally across populations or experience levels
- Controlled study conditions may not capture variability in weather, runway surfaces, or competition environments

Clinical Relevance

TAKE HOME MESSAGE: There was no association between braking GRFs and tibia angle during pole vaulting.

CLINICAL RELEVANCE: Clinicians should be cautious with only relying on tibia angle to examine injury risk and performance. Tibia angle is not associated with braking GRFs. Additional research is needed to see what variables are associated with it.

References

- Track and field record reporting system (TFRS). Accessed March 26, 2025. <https://www.tfrs.org/>.
- Mackler FO, Cantu RC. Catastrophic injuries and fatalities in high school and college sports, fall 1982-spring 1988. *Med Sci Sports Exerc.* 1990;22(6):737. doi:10.1249/00005768-199012000-00001
- Rebella G. A prospective study of injury patterns in collegiate pole vaulters. *Am J Sports Med.* 2015;43(4):808-815. doi:10.1177/0363546514564542
- Enoki S, Nagao M, Ishimatsu S, Shimizu T, Kuramochi R. Injuries in collegiate track and field jumping: a 2-year prospective surveillance study. *Orthop J Sports Med.* 2021;9(1):2325967120973397. doi:10.1177/2325967120973397
- Enoki S, Kuramochi R, Nakayuku S, Mitsuyama H. The prevalence of spondylosis and intervertebral disc degeneration in male pole vaulters. *J Back Musculoskeletal Rehabil.* 2022;35(1):147-151. doi:10.3233/BMR-200296
- Edouard P, Sanchez H, Bourillon C, Hono S, Frère J, Cassirame J. Biomechanical pole vault patterns were associated with a higher proportion of injuries. *Front Sports Act Living.* 2019;1:20. doi:10.3389/fspor.2019.00020
- Agresta C, Ward CK, Wright NG, Tucker CA. The effect of unilateral arm swing motion on lower extremity running mechanics associated with injury risk. *Sports Biomech.* 2018;17(2):206-215. doi:10.1080/14763141.2016.1269186
- Zheng Y, Fu W, Wei S, Li Q, Liu Y. Joint torque and mechanical power of lower extremity and its relevance to hamstring strain during sprint running. *J Healthc Eng.* 2017;2017:1-7. doi:10.1155/2017/8927415
- Plescia H, Roussange EN, Bouhassira KD. Comparison of the take-off ground reaction force patterns of the pole vault and the long jump. *J Sports Med Phys Fitness.* 2016;50(4):416-421.
- Frère J, L'Hermite M, Slawinski J, Tourry-Chollet C. Mechanics of pole vaulting: a review. *Sports Biomech.* 2010;9(2):123-138. doi:10.1080/14763141.2010.492430
- Mao C, Li M, Li X, et al. The validity of a dual-force plate for assessing counter-movement jump performance. *Sensors.* 2024;24(17):5748. doi:10.3390/s24175748
- Collings TJ, Lima YL, Dufailis B, Bourne MN. Concurrent validity and test-retest reliability of VALD ForceDecks' strength, balance, and movement assessment tests. *J Sci Med Sport.* 2024;27(8):572-580. doi:10.1016/j.jsams.2024.04.014
- Frère J, Sanchez H, Hono S, Rabita G, Morin JB, Cassirame J. Influence of pole carriage on sprint mechanical properties during pole vault run-up. *Comput Methods Biomech Biomed Engin.* 2017;20(sup1):S83-S84. doi:10.1080/10255842.2017.1358272
- Smith C, Deane K, Heilbron B, Leicht A. Reliability of force plate metrics during standard jump, balance, and plank assessments in military personnel. *Mil Med.* 2023;188(7-8):e2058-e2066. doi:10.1093/milmed/usac387
- Valamatos MJ, Abrantes JM, Carmide F, Valamatos MJ, Monteiro CP. Biomechanical performance factors in the track and field sprint start: a systematic review. *Int J Environ Res Public Health.* 2022;19(7):4074. doi:10.3390/ijerph19074074
- Gross M, Bickler Greeley N, Hübner K. Prioritizing Physical Determinants of International Elite Pole Vaulting Performance. *J Strength Cond Res.* 2020;34(1):162-171. doi:10.1519/JSC.0000000000003053
- Linthorne NP, Westman AHG. Effects of run-up velocity on performance, kinematics, and energy exchanges in the pole vault. *J Sports Sci Med.* 2012;11(2):245-254.
- Arampatzis A, Schade F, Brüggemann GP. Effect of the pole-human body interaction on pole vaulting performance. *J Biomech.* 2004;37(9):1353-1360. doi:10.1016/j.jbiomech.2003.12.039
- Li X, Xia Z, Liu F, Gao J, Wu X, Liu Y. Factor analysis of the biomechanical parameters of pole vault run-up and takeoff: exploring sports performance. *Sports Biomech.* 2024;23(12):2974-2994. doi:10.1080/14763141.2022.2080104
- Chen T, Xu D, Zhou Z, Zhou H, Shao S, Gu Y. Prediction of vertical ground reaction forces under different running speeds: integration of wearable IMU with CNN+LSTM. *Sensors.* 2025;25(4):1249. doi:10.3390/s25041249
- Ekevad M, Lundberg B. Simulation of "sprint" pole vaulting. *J Biomech.* 1995;28(9):1079-1090. doi:10.1016/0021-9290(94)90164-4
- Samozino P, Rabita G, Doré S, et al. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scand J Med Sci Sports.* 2016;26(6):648-658. doi:10.1111/sms.12490
- Evans RJ, Moffitt TJ, Mitchell PK, Pamukoff DN. Injury and performance related biomechanical differences between recreational and collegiate runners. *Front Sports Act Living.* 2023;5:1268292. doi:10.3389/fspor.2023.1268292
- Bassemont M, Garnier C, Goss-Sampson M, Watelin E, Lepoutre FX. Using EMGs and kinematics data to study the take-off technique of experts and novices for a pole vaulting short run-up educational exercise. *J Sci Med Sport.* 2010;13(5):545-558. doi:10.1016/j.jsams.2009.07.001
- Tai WH, Wang LL, Peng HT. Biomechanical Comparisons of One-Legged and Two-Legged Running Vertical Jumps. *J Hum Kinet.* 2018;64:71-76. doi:10.1515/hukin-2017-0183
- Mossato SH, Hignett JA, Moen F, et al. Validity and reliability of a smartphone motion analysis app for lower limb kinematics during treadmill running. *Phys Ther Sport.* 2020;43:27-35. doi:10.1016/j.ptsp.2020.02.003