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Patellofemoral Joint Stress During Uphill and Downhill Running in Healthy

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PATELLOFEMORAL JOINT STRESS DURING UPHILL AND DOWNHILL RUNNING IN HEALTHY RUNNERS

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ABSTRACT

Purpose/ Hypothesis: Although patellofemoral pain (PFP) while running downhill is a common complaint in runners, how slope affects patellofemoral joint (PFJ) stress remains unclear. The primary purpose of this study was to compare PFJ stress among level, uphill, and downhill running.

Subjects: Twenty recreational runners participated (mean age of 24.9 years).

Methods: Kinematics and kinetics of the trunk and lower extremity were obtained at 3 conditions: level, 6° uphill, and 6° downhill, at a speed of 2.3 m/s. PFJ stress was determined using a biomechanical model that incorporates knee flexion angle and knee extensor moment as subject-specific input variables. The model output consisted of PFJ reaction force, PFJ stress, and PFJ contact area. One-way ANOVAs with repeated measures and post-hoc t-tests with a Bonferroni adjustment were used to compare outcome variables across the 3 conditions.

Results: Peak PFJ stress during downhill running was significantly higher than the level and uphill conditions ($P < 0.001$). There was not a difference in peak PFJ stress between level and uphill conditions ($P = 1.000$).

Conclusion: The higher stress observed in downhill running was driven by an increase in PFJ reaction force as the result of elevated knee extensor moment and decreased trunk flexion angle. The similar stress level observed in level and uphill running was caused by similarities in PFJ reaction force and minimal differences in PFJ contact area between the 2 conditions.

Clinical Relevance: As downhill running increases peak PFJ stress when compared to level and uphill running, alterations in running slope should be considered when treating runners with PFP.

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INTRODUCTION

Patellofemoral pain (PFP) is the most common running overuse injury (Taunton et al., 2002), and accounts for 25% of all knee injuries treated in orthopedic clinics (Baquie & Brukner, 1997; Devereaux & Lachmann, 1984). In runners, the classic symptom of PFP is retropatellar pain that is aggravated by elevated patellofemoral joint (PFJ) stress, likely due to accumulations of extracellular fluid within the patella as the result of bone stress injuries (Ho, Hu, Colletti, & Powers, 2014). PFJ stress is defined as PFJ reaction force per contact area (Heino Brechter & Powers, 2002). Thus, an increase in PFJ stress is caused by 1) reduced contact areas and/or 2) increases in PFJ reaction forces as the result of increased knee flexion angle and/or elevated knee extensor moment due to an upright trunk posture or a higher ground reaction force (Heino Brechter & Powers, 2002; Ho, Blanchette, & Powers, 2012; Teng & Powers, 2014; Ward & Powers, 2004). For instance, increased ground reaction forces or trunk extension angle during running can result in elevated knee extensor moment given that knee extensor moment is estimated as the product of ground reaction force and knee moment arm (i.e., perpendicular distance from the knee joint axis to the ground reaction force) in the sagittal plane. As such, when one runs with a more upright trunk posture, the posteriorly shifted ground reaction force increases the knee moment arm, thereby elevating the knee extensor moment (Teng & Powers, 2014).

It has been reported that cross country runners experienced a high incidence of PFP (Luedke, Heiderscheit, Williams, & Rauh, 2015), likely due to the fact that their training and competition regime involves running on various gradients (uphill and downhill). It has been observed that runners utilize different biomechanical features during uphill and downhill running. Specifically, a more extended trunk posture (Levine, Colston, Whittle, Pharo, & Marcellin-Little, 2007) and greater peak landing vertical ground reaction forces is found during downhill running (Gottschall

& Kram, 2005). On the contrary, a more flexed trunk posture (Levine et al., 2007) and a smaller peak landing vertical ground reaction force is often adopted in runners during uphill running (Gottschall & Kram, 2005). The effects of altering trunk postures during running on PFJ stress have been studied by Teng and Powers (2014). Their study reveals that a decrease in peak PFJ stress of 6% was associated with an average increase of 6.8° in trunk flexion. They further report that a 3.3° increase in trunk extension was associated with a 7.4% increase in PFJ stress. Additionally, altered PFJ stress profiles in altered trunk positions is driven primarily by a change in PFJ reaction force, given that the changes in PFJ contact area were minimal (Teng & Powers, 2014).

As runners exhibit altered trunk flexion angles and vertical ground reaction forces during downhill/uphill running, the PFJ kinetic profile may be different when they run uphill or downhill. To date, however, the effects of uphill/downhill running on PFJ stress have not been quantified. The primary purpose of this study was to compare peak PFJ stress among level, uphill, and downhill running. The secondary purpose was to determine the contributing factors that lead to altered peak PFJ stress during these three conditions. We hypothesized that peak PFJ stress would be greatest during downhill running due to increased PFJ reaction force resulting from reduced trunk flexion angle and/or increased vertical ground reaction forces. The peak PFJ stress was hypothesized to be smallest during uphill running because of reduced PFJ reaction force resulting from increased trunk flexion angle and/or decreased vertical ground reaction forces.

MATERIALS AND METHODS

Participants

Twenty recreational runners (10 males and 10 females) between the ages of 21 and 40 years were recruited in this study. The data from an existing study were used to estimate the sample size for detecting changes in PFJ stress between running with different trunk postures (Teng & Powers, 2014). With 95% power, and an α level of 0.05, the analysis estimated that 15 individuals would be needed to detect a significant change in PFJ stress between running conditions. However, due to the novelty of this research, a total of 20 participants were recruited. Participants were considered recreational runners if they ran at least 6 miles (approximately 9.7 km) per week for the last 6 months (Ho et al., 2014). Participants were excluded from the study if they had a lower extremity injury or surgery in the past 6 months and if they were pregnant, or thought they were pregnant. Prior to participation, all subjects were informed of the nature of the study and signed a consent form approved by the University of Nevada, Las Vegas, Biomedical Institutional Review Board. The average age, height, weight, and running distance per week of this cohort were 24.9 ± 2.4 years, 1.70 ± 0.07 m, 67.0 ± 9.7 kg, and 13.8 ± 5.6 km, respectively.

Instrumentation

A 12-camera motion analysis system (Vicon, Oxford Metrics Ltd., Oxford, UK) was used to capture kinematic data of lower extremity and trunk at 250 Hz. Ground reaction forces were collected at a rate of 2000 Hz using force plates instrumented in a dual-belt treadmill (Fully Instrumented Treadmill, Bertec Corp., Columbus, OH, USA).

Procedures

Participants were tested in one session under three different treadmill running conditions: level, uphill, and downhill at a standardized speed of 2.3 m/s. Each participant started with 0°

inclination (level condition), followed by 6° incline (uphill condition) or 6° decline (downhill condition). The order of the uphill and downhill conditions was alternated. The speed of 2.3 m/s was chosen as it is considered as a comfortable speed that most runners can achieve (Watkins, 2017). Six degrees of slope resembles a common gradient observed in daily outdoor activities (Abe et al., 2011).

Prior to the running testing, reflective markers were placed on the following anatomical landmarks: the 1st and 5th metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, the joint space between L5–S1 and bilaterally over the greater trochanters, iliac crests, anterior superior iliac spines (ASIS), acromions, and posterior superior iliac spines (PSIS) (Lee, Gillis, Ibarra, Oldroyd, & Zane, 2017). In addition, clusters of rigid reflective tracking markers were placed on the posterior trunk, as well as the lateral surfaces of each participant's thigh, lower leg, and heel counter of the shoe (Lee et al., 2017). After obtaining a static calibration trial, all anatomical markers (with the exception of those attached to the pelvis) were removed.

Each running condition began with a warm-up in which participants ran at a self-selected warm-up speed for 5 minutes. Participants were then asked to run at 2.3 m/s, and three, 20-second trials were then collected for each running condition. The participants rested for at least 5 mins after running each given slope to allow the researchers to adjust the treadmill inclination and calibrate the motion analysis system (i.e., defining the relative position of force platform to the cameras). Extra rest time was allowed at participants' request. The resting duration was deemed reasonable as previous research has determined that significant recovery in neuromuscular function occurs within the first 1-2 minutes of rest after high-intensity dynamic exercise (Froyd, Millet, & Noakes, 2013).

Data analysis

Reflective markers were labeled and digitized using Vicon Nexus software (Oxford Metric Ltd., Oxford, UK). Visual 3D software (C-Motion, Rockville, MD, USA) was used to quantify sagittal plane joint motions of the knee joint. The trunk angle was calculated as the orientation of the trunk segment relative to the global coordinate system (global vertical axis) (Teng & Powers, 2014). Kinematic data were filtered using a 6 Hz Butterworth low pass filter (Ho et al., 2012) and ground reaction force data were filtered using a 30 Hz Butterworth low pass filter (Telhan et al., 2010). An inverse dynamics approach was used to determine the knee joint moment. The middle 5 strides of each 20-second trial were analyzed for all participants. Thus, a total of 15 strides were analyzed for each participant.

The knee extensor moment was then used as an input variable in a previously described PFJ model to quantify the PFJ stress (Heino Brechter & Powers, 2002; Ho et al., 2012; Ward & Powers, 2004). Input variables for the model included knee flexion angle, knee extensor moment, and PFJ contact area obtained from Powers and colleagues (1998). The first step of the algorithm was to compute the quadriceps force (Heino Brechter & Powers, 2002). The quadriceps effective lever arm was determined for each degree of knee flexion by fitting a non-linear curve to the data reported by van Eijden and colleagues (1986). Quadriceps muscle force was then obtained by dividing the knee extensor moment by the effective lever arm. The second step of the algorithm was to obtain the PFJ reaction force during running. Previous work by van Eijden and colleagues (1987) presented a constant between the PFJ reaction force and the quadriceps force as a function of knee flexion angle. This constant was then multiplied by the quadriceps force to obtain the PFJ reaction force. The last step was to obtain PFJ stress. Seven discrete contact areas at each of the seven knee flexion angles (0°, 15°, 30°, 45°, 60°, 75°, and 90°) (Powers et al., 1998) were used to estimate the contact areas from 0° to 90° of knee flexion using a second order polynomial curve fitting algorithm. PFJ stress was then obtained by dividing the PFJ reaction force by the contact area for the knee flexion angle corresponding to the PFJ reaction force value.

Statistical Analyses

The primary variable of interest was the peak PFJ stress. Secondary variables of interest included the following at the time of peak PFJ stress: PFJ reaction force, PFJ contact area, knee extensor moment, knee flexion angle, trunk flexion angle, and vertical ground reaction force. Prior to statistical analyses, all variables were assessed for normality and found to be normally distributed based on results of the Shapiro-Wilk test. The variables were compared across the three running conditions using one-way ANOVA with repeated measures. Post-hoc analyses consisting of paired t-tests with a Bonferroni adjustment were performed when there were significant differences in one-way ANOVA with repeated measures. Thus, the significant threshold for post-hoc testing was reduced to $P < 0.016$. All statistical analyses were performed with use of SPSS 22.0 statistical software (International Business Machines Corp., Armonk, NY, USA).

RESULTS

Peak patellofemoral joint stress

Across the 3 running conditions, the peak PFJ stress occurred at approximately 37% of stance phase (Figure 1). The ANOVA comparing peak PFJ stress between the 3 running conditions was significant ($P = 0.000$). Post-hoc testing revealed that the peak PFJ stress during downhill running was significantly greater than both level running ($P < 0.001$) and uphill running ($P < 0.001$) conditions. There was no significant difference in stress between level and uphill running ($P = 1.000$) (Table 1).

Patellofemoral joint reaction force

The ANOVA comparing PFJ reaction force at the time of peak stress among the 3 running conditions was significant ($P < 0.001$). Post-hoc testing revealed that the PFJ reaction force during downhill running was significantly greater than both the level running ($P < 0.001$) and uphill running ($P < 0.001$) conditions. There was no significant difference in PFJ reaction force between level and uphill running ($P = 1.000$) (Table 1).

Patellofemoral joint contact area

The ANOVA comparing PFJ contact area at the time of peak stress among the 3 running conditions was significant ($P < 0.001$). Post-hoc testing revealed that the PFJ contact area during uphill running was significantly greater than both the downhill running ($P = 0.003$) and level running ($P < 0.001$) conditions. There was no significant difference in PFJ contact area between level and downhill running ($P = 0.115$) (Table 1).

Knee extensor moment

The ANOVA comparing knee extensor moment at the time of peak stress among the 3 running conditions was significant ($P < 0.001$). Post-hoc testing revealed that the knee extensor moment during downhill running was significantly greater than both the level running ($P < 0.001$) and uphill running ($P < 0.001$) conditions. Additionally, knee extensor moment at the time of peak stress during level running was significantly greater when compared to the uphill running condition ($P = 0.015$) (Table 1).

Knee flexion angle

The ANOVA comparing knee flexion angle at the time of peak stress among the 3 running conditions was significant ($P < 0.001$). Post-hoc testing revealed that the knee flexion angle during uphill running was significantly greater than both the downhill running ($P < 0.001$) and level running ($P < 0.001$) conditions. There was no significant difference in knee flexion angle at the time of peak stress between level and downhill running ($P = 0.227$) (Table 1).

Trunk flexion angle

The ANOVA comparing trunk flexion angle at the time of peak stress among the 3 running conditions was significant ($P < 0.001$). Post-hoc testing revealed that the trunk flexion angle during uphill running was significantly greater than both the downhill running ($P < 0.001$) and level running ($P < 0.001$) conditions. Additionally, the trunk flexion angle at the time of peak stress during level running was significantly greater when compared to the downhill running condition ($P < 0.001$) (Table 1).

Vertical ground reaction force

The ANOVA comparing vertical ground reaction force at the time of peak stress among the 3 running conditions was not significant ($P = 0.437$). No further post-hoc analyses were performed (Table 1).

DISCUSSION

This is the first study assessing the effects of slopes on PFJ stress in recreational runners. The primary purpose of this study was to compare peak PFJ stress among level, uphill, and downhill running. In support of our hypothesis, peak PFJ stress is greatest while running downhill. On average, there was a significant increase (36%) in peak PFJ stress during downhill running compared to level running. However, peak PFJ stress during uphill running was not significantly different from level running.

The secondary purpose of the study was to identify the contributing factors that lead to altered peak PFJ stress during uphill and downhill running. In support of our hypothesis, our findings suggested that increased peak PFJ stress observed in downhill running was the result of increased PFJ reaction force with no significant change in PFJ contact area. The increase in PFJ reaction force while running downhill was mainly caused by greater knee extensor moment due to decreased trunk flexion angle. Our data showed that PFJ stress during uphill running was not significantly different from level running. The similar PFJ stress observed in uphill and level running was primarily driven by similarities in PFJ reaction forces. Despite an increase in knee flexion angle, PFJ reaction force remained the same due to a proportional decrease in knee extensor moment resulting from increased trunk flexion angle. Additionally, the change in PFJ contact area between the uphill and level running conditions was minimal (less than 2.3%). Although the increase in PFJ contact area during uphill running was statistically significant when compared to the level condition, the magnitude of the change likely had little effect on PFJ stress.

In agreement with the suggestions by Teng and Powers (2014), we found that altered PFJ stress at different gradients was primarily driven by PFJ reaction force during running, rather than PFJ contact area. During downhill running, the observed increase in PFJ stress with an upright trunk posture was consistent with results reported by Teng and Powers (2014). Our study found increased PFJ stress with a reduced trunk flexion angle of 13° during downhill running when compared to level running. The reduced trunk flexion angle during downhill running elevated PFJ reaction force by 37%. However, unlike the data reported by Teng and Powers (2014), our study did not find a decrease in PFJ stress with a flexed trunk posture. Despite an 8° increase in trunk flexion angle during uphill running, our results did not exhibit a significant difference in PFJ stress between level and uphill running. It is speculated that the potential reduction effect of increased trunk flexion angle on PFJ reaction force was counterbalanced by a higher increase in knee flexion angle during uphill running observed in the current study. Specifically, we found an 10% increase in knee flexion angle with uphill running whereas Teng and Powers reported only a 2% increase in knee flexion angle with flexed-trunk running when compared to the control condition (level running in our study and self-selected trunk posture in Teng and Powers' work (Teng & Powers, 2014)).

Our data showed that the vertical ground reaction force at the time of peak PFJ stress was not significantly different among the uphill, level, and downhill conditions. These findings were not consistent with the data reported by Gottschall and Kram (2005) When compared to level running, they found that the impact vertical ground reaction force was higher during downhill running and was smaller during uphill running. However, these differences can likely be attributed to the focus of investigation. The peak impact vertical ground reaction force occurs much earlier during landing (approximately 25% of stance phase (Gottschall & Kram, 2005)), whereas peak PFJ stress observed in our study occurs at approximately 37% of stance phase. Although the vertical ground reaction force differs at the peak impact, the knee lever arm is small at that time point. As a result, the changes in the impact vertical ground reaction force may not be as relevant for peak PFJ stress.

The present study has several limitations that should be recognized. First, as we aimed to evaluate the effects of slope running on PFJ stress, all participants were instructed to run at a standardized speed across all conditions. This may affect their ability to alter biomechanics in response to changed gradients as it is reported that runners tend to reduce their running speed on uphill gradients and increase their running speed on downhill gradients (Townshend, Worringham, & Stewart, 2010). Such changes may have an effect on ground reaction forces and running mechanics (Nilsson & Thorstensson, 1989). Another limitation is that the order of testing conditions was not completely randomized. As running on a level surface is considered as a more natural condition that most runners are familiar with, we only controlled for the order of uphill and downhill conditions to ensure the sequence effect was minimized. Third, as our study only examined healthy individuals, caution should be used when applying these results to injured running populations. It has been shown that persons with PFP exhibit less contact area compared to pain-free controls (Salsich & Perman, 2007), which may result in greater PFJ stress as compared to our current findings. Additionally, the PFJ model utilized in this study has not been validated against a gold standard (e.g., cadaveric model), thus the absolute PFJ stress values should be viewed with caution. Nevertheless, this work provides basic understanding of the effects of slopes on PFJ mechanics.

CONCLUSION

In conclusion, our study demonstrated that downhill running resulted in an increase in peak PFJ stress as compared to level and uphill running when running at the same speed. The higher PFJ stress observed during downhill running was driven by an increase in PFJ reaction force as the result of elevated knee extensor moment and decreased trunk flexion angle. Compared to level running, uphill running caused no changes in peak PFJ stress due to similar levels of PFJ reaction force and minimal differences in PFJ contact area between the two conditions. As downhill running increases peak PFJ stress when compared to level and uphill running, alterations in running slope should be considered when treating runners with PFP.

APPENDIX

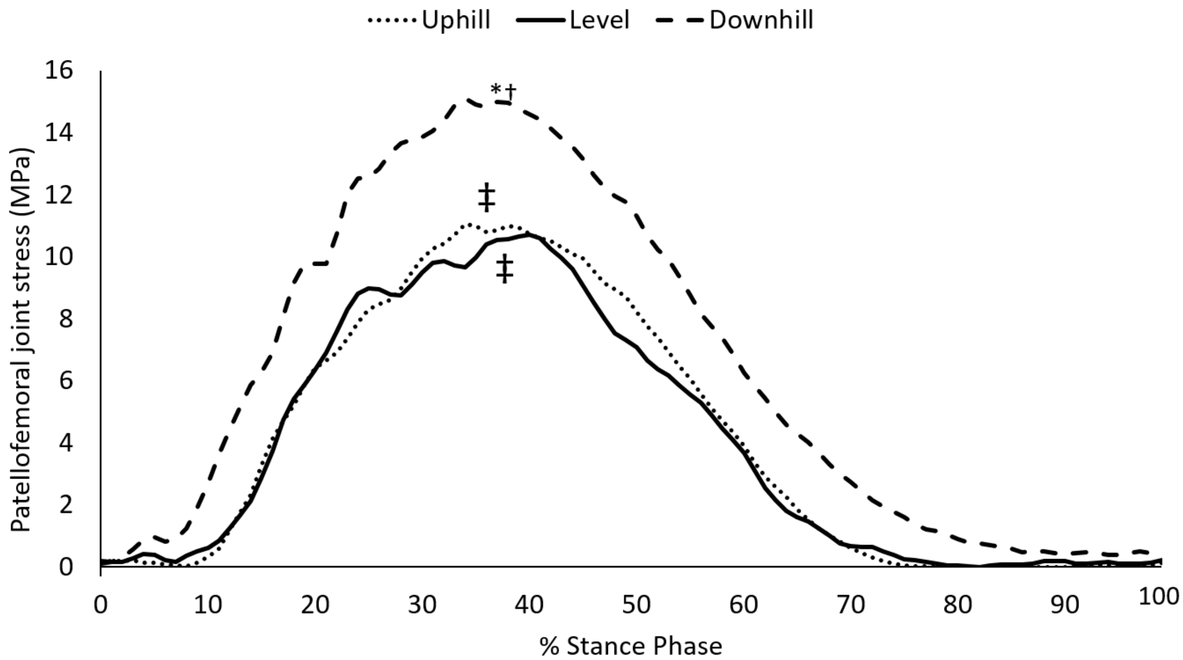
Table 1.
Comparison of variables of interest during uphill, level, and downhill running conditions. Mean ± SD

	Uphill	Level	Downhill	P value of ANOVA
Peak patellofemoral joint stress (MPa)	11.6 ± 3.6‡	11.7 ± 3.4‡	15.9 ± 4.1*†	< 0.001
Patellofemoral joint reaction force at the time of peak stress (N/kg)	40.2 ± 9.7‡	40.0 ± 9.5‡	54.7 ± 11.2*†	< 0.001
Patellofemoral joint contact area at the time of peak stress (mm^2)	234.8 ± 4.8†‡	229.6 ± 7.8*	231.0 ± 6.5*	< 0.001
Knee extensor moment at the time of peak stress (Nm/kg)	1.8 ± 0.3†‡	1.9 ± 0.3*‡	2.6 ± 0.3*†	< 0.001
Knee flexion angle at the time of peak stress (°)	47.1 ± 5.6†‡	42.8 ± 5.8*	43.7 ± 5.4*	< 0.001
Trunk flexion angle at the time of peak stress (°)	21.6 ± 8.0 †‡	13.9 ± 7.7*‡	1.3 ± 7.7*†	< 0.001
Ground reaction force at the time of peak stress (N/kg)	20.3 ± 1.3	20.6 ± 1.7	20.8 ± 1.9	0.437

*Significant difference from uphill condition based on post-hoc analyses with a Bonferroni adjustment (P < 0.016)
†Significant difference from level condition based on post-hoc analyses with a Bonferroni adjustment (P < 0.016)
‡ Significant difference from downhill condition based on post-hoc analyses with a Bonferroni adjustment (P < 0.016)

Figure 1.

Patellofemoral joint stress of the 3 running conditions (uphill, level, and downhill) during the stance phase. *Significant difference from uphill condition (P < 0.016); †Significant difference from level condition (P < 0.016); ‡Significant difference from downhill condition (P < 0.016).



REFERENCES

Abe, D., Fukuoka, Y., Muraki, S., Yasukouchi, A., Sakaguchi, Y., & Niihata, S. (2011). Effects of load and gradient on energy cost of running. Journal of Physiological Anthropology, 30(4), 153-160

Baquie, P., & Brukner, P. (1997). Injuries presenting to an Australian sports medicine centre: a 12-month study. Clinical Journal of Sport Medicine, 7(1), 28-31

Devereaux, M. D., & Lachmann, S. M. (1984). Patello-femoral arthralgia in athletes attending a Sports Injury Clinic. British Journal of Sports Medicine, 18(1), 18-21

Froyd, C., Millet, G. Y., & Noakes, T. D. (2013). The development of peripheral fatigue and short-term recovery during self-paced high-intensity exercise. Journal of Physiology, 591(5), 1339-1346.

Gottschall, J. S., & Kram, R. (2005). Ground reaction forces during downhill and uphill running. Journal of Biomechanics, 38(3), 445-452.

Heino Brechter, J., & Powers, C. M. (2002). Patellofemoral stress during walking in persons with and without patellofemoral pain. Medicine & Science in Sports & Exercise, 34(10), 1582-1593

Ho, K. Y., Blanchette, M. G., & Powers, C. M. (2012). The influence of heel height on patellofemoral joint kinetics during walking. Gait & Posture, 36(2), 271-275.

Ho, K. Y., Hu, H. H., Colletti, P. M., & Powers, C. M. (2014). Running-induced patellofemoral pain fluctuates with changes in patella water content. European Journal of Sport Science, 14(6), 628-634.

Lee, S. P., Gillis, C., Ibarra, J. J., Oldroyd, D., & Zane, R. (2017). Heel-Raised Foot Posture Do Not Affect Trunk And Lower Extremity Biomechanics During A Barbell Back Squat In Recreational Weightlifters. Journal of Strength and Conditioning Research.

Levine, D., Colston, M. A., Whittle, M. W., Pharo, E. C., & Marcellin-Little, D. J. (2007). Sagittal lumbar spine position during standing, walking, and running at various gradients. Journal of Athletic Training, 42(1), 29-34

Luedke, L. E., Heiderscheit, B. C., Williams, D. S., & Rauh, M. J. (2015). Association of Isometric Strength of Hip and Knee Muscles with Injury Risk in High School Cross Country Runners. International Journal of Sports Physical Therapy, 10(6), 868-876

Nilsson, J., & Thorstensson, A. (1989). Ground reaction forces at different speeds of human walking and running. Acta Physiologica Scandinavica, 136(2), 217-227.

Powers, C. M., Lilley, J. C., & Lee, T. Q. (1998). The effects of axial and multi-plane loading of the extensor mechanism on the patellofemoral joint. Clinical Biomechanics, 13(8), 616-624

Salsich, G. B., & Perman, W. H. (2007). Patellofemoral joint contact area is influenced by tibiofemoral rotation alignment in individuals who have patellofemoral pain. Journal of Orthopaedic & Sports Physical Therapy, 37(9), 521-528

Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2002). A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine, 36(2), 95-101

Telhan, G., Franz, J. R., Dicharry, J., Wilder, R. P., Riley, P. O., & Kerrigan, D. C. (2010). Lower limb joint kinetics during moderately sloped running. Journal of Athletic Training, 45(1), 16-21.

Teng, H. L., & Powers, C. M. (2014). Sagittal plane trunk posture influences patellofemoral joint stress during running. Journal of Orthopaedic & Sports Physical Therapy, 44(10), 785-792.

Townshend, A. D., Worringham, C. J., & Stewart, I. B. (2010). Spontaneous pacing during overground hill running. Medicine & Science in Sports & Exercise, 42(1), 160-169.

van Eijden, T. M., Kouwenhoven, E., Verburg, J., & Weijs, W. A. J. A. (1986). A mathematical model of the patellofemoral joint. Journal of Biomechanics, 19(3), 219-229

van Eijden, T. M., Weijs, W. A., Kouwenhoven, E., & Verburg, J. (1987). Forces acting on the patella during maximal voluntary contraction of the quadriceps femoris muscle at different knee flexion/extension angles. Acta Anatomica, 129(4), 310-314

Ward, S. R., & Powers, C. M. (2004). The influence of patella alta on patellofemoral joint stress during normal and fast walking. Clinical Biomechanics, 19(10), 1040-1047

Watkins, J. (2017). Laboratory and Field Exercises in Sport and Exercise Biomechanics: Routledge.

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