LEG STIFFNESS DURING A LATERAL PLANT-AND-REVERSE MOVEMENT: A MALE-FEMALE COMPARISON

Shane Sauer and Pamela Russell

Bridgewater State University, Bridgewater, MA, USA

This study aimed to apply the spring-mass model to a plant-and-reverse lateral movement. Using the model to calculate leg stiffness (K_{Leg}), research has shown a link to running performance factors, but also to injury indicators. Perhaps similar links could be drawn for lateral movement. A comparison between men and women was also investigated. 3 male and 3 female collegiate tennis players performed a plant-and-reverse movement on a force platform. The change in leg length was measured. K_{Leg} was calculated (M: 49.02 ±12.8 kN/m; W: 23.46 ±5.6 kN/m). A Pearson *r* correlation ensured that the linear spring-mass model was properly applied to the braking phase. No differences were found, but the use of the spring-mass model for lateral movement was supported. Future research may now define how leg stiffness relates to performance and injury indicators for lateral movement.

KEY WORDS: spring-mass, cutting, tennis, performance, injury.

INTRODUCTION: Modern day tennis requires its athletes to move laterally more often than forward and backward. In the past, tennis players would often move forward to try to gain advantage of the net. Since new technology has created more powerful racquets, it is much more challenging for a player to gain control of the net. Therefore, many current players spend the majority of the time on the baseline, running side to side to return the ball to their opponent. If an athlete can change direction more quickly than their opponent, they will have a better chance of getting to the ball to make the next shot. With typically double digit numbers of shots per point, 6 to 8 points per game and 20 to 30 games per match, it becomes clear how critical the ability to laterally change direction is to a player's game.

One way that forward motion has been studied is by modeling the lower extremities as a spring-mass system, where the spring represents the legs. McMahon and Cheng (1990) used this model to calculate leg stiffness as $K_{Leg} = \frac{F_{max}}{\Delta L}$, where F_{max} is the maximum ground reaction force (GRF) and ΔL is the change in leg length during the movement. In running, many investigators (McMahon & Cheng, 1990; Arampatzis, Bruggemann & Metzler, 1999; Heise & Martin, 1998; Farley and Gonzalez, 1996) have related K_{Leg} to performance and injury risk factors such as GRF, velocity, and aerobic demand. However no one has yet looked at how leg stiffness relates to these types of factors in lateral movement.

The purpose of this study was to apply the spring-mass model during a plant and reverse lateral movement to describe the role of lower extremity while changing direction. Leg stiffness (K_{Leg}) was calculated from the model during the braking phase (as motion in one direction was halted) of the movement. A comparison between men and women was then made based on the mean K_{Leg} values with the expectation that men would generate a larger K_{Leg}.

METHODS: Three male (77.5 ±11 kg, 178.3 ±3 cm, 20.0 ±1 years) and three female tennis players (54.5 ±13 kg, 159.4 ±5 cm, 21.0 ±3 years), from Bridgewater State University (BSU) volunteered for the study and signed informed consent documents. All had at least three years of competitive experience. No participants had musculoskeletal injuries of the lower extremities in the last six months or a history of lower extremity injury that may have affected performance during this study.

The experimental layout consisted of a runway, equal to approximately two-thirds the length of a tennis court's baseline (6m), leading to an in-ground force platform. Tape, was placed at the center of the force platform to aid the participant with foot placement. A digital video camcorder mounted on a tripod recorded the entire height of the participant and the entire force platform. Participants wore their own shoes and tight fitting clothing. Warm up consisted of practicing the plant-and-reverse movement until the participant felt comfortable. After warm-up, identification of dominant leg was made via a two-footed jump to one-footed landing. The foot landed on was deemed dominant. Reflective markers were placed on the bilateral posterior superior iliac spines (PSIS), dominant side greater trochanter and lateral malleloi. The participant ran down the runway at their fastest comfortable speed, changed direction by rotating their body 90 degrees as they planted their dominant foot on the taped target and accelerated back down the runway in the opposite direction.
GRF data were collected from the force platform at 600 Hz and marker data were captured at 60 Hz. Leg length was calculated in Dartfish by measuring the distance from the greater trochanter to the lateral malleloi. GRF and leg length data were imported into MS Excel. Leg length measurements were low pass filtered at 6 Hz and GRF data were filtered at 60 Hz. GRF data were time matched leg length data. K_{Leg} was calculated during the braking phase, defined from initial contact with the force platform to the maximum GRF. Calculations of K_{Leg} were made in accordance with McMahon and Cheng's (1990) equation: $K_{Leg} = \frac{F_{max}}{\Delta L}$. A Pearson r was calculated between GRF and ΔL to ensure that the data fit the linear spring-mass model. If r <.80, the trial was eliminated. At least 5 trials for each volunteer met this criteria. Mean K_{Leg} values were determined and a t-test ($p < 0.05$) was used to compare those means between the men and women.

RESULTS: The average K_{Leg} for women was 23.46 ±5.6 kN/m and for men was 49.02 ±12.8 kN/m. This information is displayed in Figure 1.

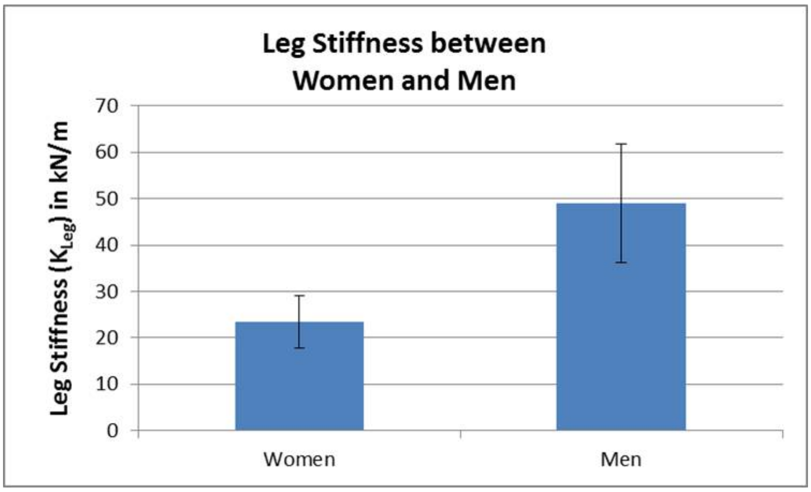

Figure 1: Mean and standard deviation of leg stiffness for women and men.

There was no significant difference ($p = 0.073$) between these means for men and women.

DISCUSSION: The values for K_{Leg} in this study were on the same order of magnitude values demonstrated in the running literature. This gives weight to the spring-mass model's use in the braking phase of lateral movement. Because the spring-mass model is linear, it was also important to see a linear relationship between GRF and ΔL in selected trials. However, requiring a Pearson r correlation greater than .80 demonstrates some trials did not fit this linear model. To explain why, a closer review of the data uncovered an important error in methodology that may have caused these nonlinearities. Because participants were not instructed on how to make the plant-and-reverse movement, a number of times they would leave the trailing foot on the ground. In doing so, the relationship between ΔL and GRF would change because the GRFs in the trailing leg were not being measured. If future studies incorporate a second force platform or some other method to account for the trail leg, it is expected that these nonlinearities would be diminished and data that fits the spring-mass model would be more repeatable.

The fact that no differences were found between men and women is not surprising because of the small sample size used in this study. The lack of a difference may also be explained by the issue with the trailing leg. If the data collection process were improved, it is reasonable to assume that some of the variation in K_{Leg} values could be removed. This would therefore heighten the normal curves allowing for mean differences to be more identifiable. Based on this data future investigation of a possible difference between men and women is certainly warranted.

CONCLUSION: This study showed that the spring-mass model can be applied to the braking phase of a frontal plane motion and K_{Leg} values can be calculated. This creates a similarity between the stiffness literature for sagittal plane movements, such as running, and the frontal plane movement of a plant-and-reverse. Links have been made between K_{Leg} and performance and injury risk factors for sagittal plane movements. Therefore, adapting the spring-mass model to lateral movement may allow for future research to utilize K_{Leg} as way to better understand planting and cutting activities, particularly when it comes to performance and/or injury risk. Although, there was no difference found between men and women, it appears as though these two groups are trending apart. A larger cohort and improved data collection techniques in future studies may allow for a difference to be observed. Identifying differences between men and women and gaining a better understanding of the relationship between K_{Leg} and performance and/or injury indicators will hopefully allow practitioners to optimize the performance and safety of their male or female athletes.

REFERENCES:

Arampatzis, A., Bruggemann, G. P., & Metzler, V. (1999). The effect of speed on leg stiffness and joint kinetics in human running. Journal of Biomechanics, 32(12), 1349-1353.

Farley, C. T., & Gonzalez, O. (1996). Leg stiffness and stride frequency in human running. Journal of Biomechanics, 29(2), 181-186.

Heise, G. D., & Martin, P. E. (1998). "Leg spring" characteristics and the aerobic demand of running. Medicine and Science in Sports and Exercise, 30(5), 750-754.

McMahon, T. A., & Cheng, G. C. (1990). The mechanics of running - How does stiffness couple with speed. Journal of Biomechanics, 23, 65-78.

Acknowledgement: A special thanks goes to Kevin McElwee for his help in the collection of data and recruitment of participants.