THESIS OF PHD DISSERTATION

Research on musculoskeletal injuries in badminton: Based on a cross-sectional survey and biomechanical analysis

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1. SCIENTIFIC BACKGROUND AND OBJECTIVES

1.1 Scientific Background

Badminton is a highly popular sport enjoyed globally, characterized by players frequently executing a variety of complex movements such as rapid sprints, abrupt stops, multidirectional lunges, and a repertoire of strokes including smashes and clears. These dynamic activities subject the lower limbs to significant biomechanical stress, contributing to the prevalence of injuries, particularly in the ankle and knee joints. This complexity necessitates extensive biomechanical research focused on the kinematic and kinetic variables associated with performance and injuries. Although high-speed cameras and force platforms are instrumental in quantifying movement characteristics and joint loading, their significant financial and human resource costs limit their widespread use. Conversely, retrospective studies in hospitals and clinics often underestimate injury incidences and types because injured amateur players typically do not seek medical attention for minor injuries, such as blisters and ankle sprains. These studies, therefore, rely on personal interviews and structured questionnaires to efficiently gather extensive data.

The comfort of sports shoes, as highlighted by researchers like Llana et al., plays a pivotal role in the design and development process, enhancing shoe quality and functionality. Shoes are the only interface between the human body and the ground, and their design incorporates features that enhance control, support, grip, and agility, which directly impacts sports performance. Poorly fitted shoes can lead to foot problems including blisters, squeezed toes, and soft tissue bruises. Therefore, the design of badminton shoes focuses on minimizing injury risks while maximizing comfort and performance.

Distinct foot morphologies between genders necessitate gender-specific shoe designs. Studies show differences in heel pad stiffness, elasticity, and thickness between males and females, impacting the biomechanical behavior of footwear. Female feet typically have a higher arch and shorter outside ball length, among other features, which require tailored footwear solutions to optimize performance and reduce injury risks in badminton.

Badminton players often exhibit significant asymmetry in their movements, especially between the dominant and non-dominant legs. This sport's non-contact nature involves rapid forward lunges, making it essential to design shoes that cater to the different loads borne by each leg, ensuring both stability and flexibility.

Torsional stiffness is crucial in the design of badminton footwear for injury prevention. Optimal shoe sole stability helps counter excessive pronation and supination, common during dynamic movements. The balance between flexibility and stability in the shoe design supports natural foot posture and controlled motion, which is particularly crucial for a sport requiring rapid directional changes and intricate footwork. Studies such as those by Graf and Stefanyshyn and Luethi et al. have shown that increased torsional stiffness can lead to higher ankle torque and potentially more injuries, whereas shoes with greater flexibility might reduce such risks.

Arch support also plays a significant role in enhancing athletic performance and reducing injuries. More than half of basketball players, for instance, use insoles with medial arch support to lessen lower limb stress. However, the effectiveness of arch support varies, and further research is needed to determine the optimal arch support height for badminton shoes, considering the unique demands of the sport.

Acknowledging the pivotal role of footwear in athletic performance and injury prevention, this study bridges the gap between athletes' personal preferences and the biomechanical impact of shoe design. We focus on two critical features: torsional stiffness and arch support, examining their influence on the biomechanical mechanisms that may predispose badminton players to injuries. The intent of this dissertation is to inform the design of badminton footwear that not only enhances player performance but also reduces the risk of lower limb injuries.

1.2 Scientific Objectives

In my thesis, I would like to draw up three research questions that have been unanswered so far in the relevant field.

1st research question:

Given the predominant focus on biomechanical studies in the evaluation of badminton footwear features, what are the subjective perspectives and requirements of athletes regarding footwear characteristics, and how might these subjective factors differ between genders? Additionally, considering the asymmetric demands of badminton, are there discrepancies in footwear needs and reported lower limb injuries between an athlete's dominant and non-dominant legs?

1st objective:

To conduct a cross-sectional survey to assess the differences in shoe requirements, reported problems/complaints, and pain locations between male and female badminton players, as well as to compare the footwear feature needs of players' dominant and non-dominant legs. The results from this study will aid in understanding the requirements for badminton footwear and the mechanisms of foot pain, providing insights for recommendations on footwear features.

2nd research question:

Building on the identification of gender-related differences in badminton footwear needs, this study extends to assess the influence of torsional stiffness—a critical but less examined feature of badminton shoes—on the biomechanics of the lower limbs. How does torsional stiffness impact the performance and injury risk during badminton-specific footwork, particularly concerning the stability and performance of the foot and lower limb joints?

2nd objective:

To empirically assess the effects of varying torsional stiffness levels, with Shore D hardness values of 50, 60, and 70 (denoted as 50D, 60D, and 70D, respectively), in badminton footwear on the biomechanical functioning of the lower limbs during badminton-specific movements. This entails a detailed analysis of ankle, knee, and MTP joint kinematics, moments, and ground reaction forces to determine how these variables are influenced by footwear torsional stiffness. The study aims to establish an evidence-based understanding of how stiffness variations can affect players' performance and the incidence of injuries, ultimately guiding the design of badminton shoes that optimize the balance between flexibility and stability for enhanced athletic performance and reduced injury risk.

3rd research question:

Building upon the previous study that investigated the biomechanical impact of 50D, 60D, and 70D torsional stiffness levels in badminton shoes, how do more finely graduated torsional stiffness levels (55D, 60D, and 65D), along with varying arch support heights, affect the lower limb joint kinematics, kinetics, and contact forces in badminton athletes? Further, is there a compound effect of these finely differentiated levels of torsional stiffness when combined with different arch support heights on the risk and mechanism of injury, as well as on the optimization of performance in badminton?

3rd objective is:

To determine the combined effects of varying torsional stiffness levels (55D, 60D, and 65D) and arch support heights on lower limb biomechanics using OpenSim musculoskeletal modeling, with a focus on their influence on joint kinematics, kinetics, and contact forces during badminton-specific movements. This objective will explore the potential synergistic or antagonistic interactions between torsional stiffness and arch support height in badminton footwear, assessing their implications for athletic performance optimization and injury prevention in the sport.

2. NEW RESULTS, THESES

1st Thesis point

I experimentally revealed, based on the data of 326 recreational badminton players regarding their shoe properties, complaints, and foot discomforts (Figures 1A), that while both genders prioritize shoe fit and comfort, females place additional importance on aspects such as breathability (by 6.24%), color (by 16.32%), forefoot cushioning (by 5.26%), and upper durability (by 7.50%) compared to males (Figure 1B). These findings indicate clear gender-based disparities in shoe requirements, with noticeable differences in shoe problems/complaints and foot discomfort between genders. Such insights underline the necessity for gender-specific shoe designs in badminton, tailored to address the unique anatomical and biomechanical aspects of male and female players.

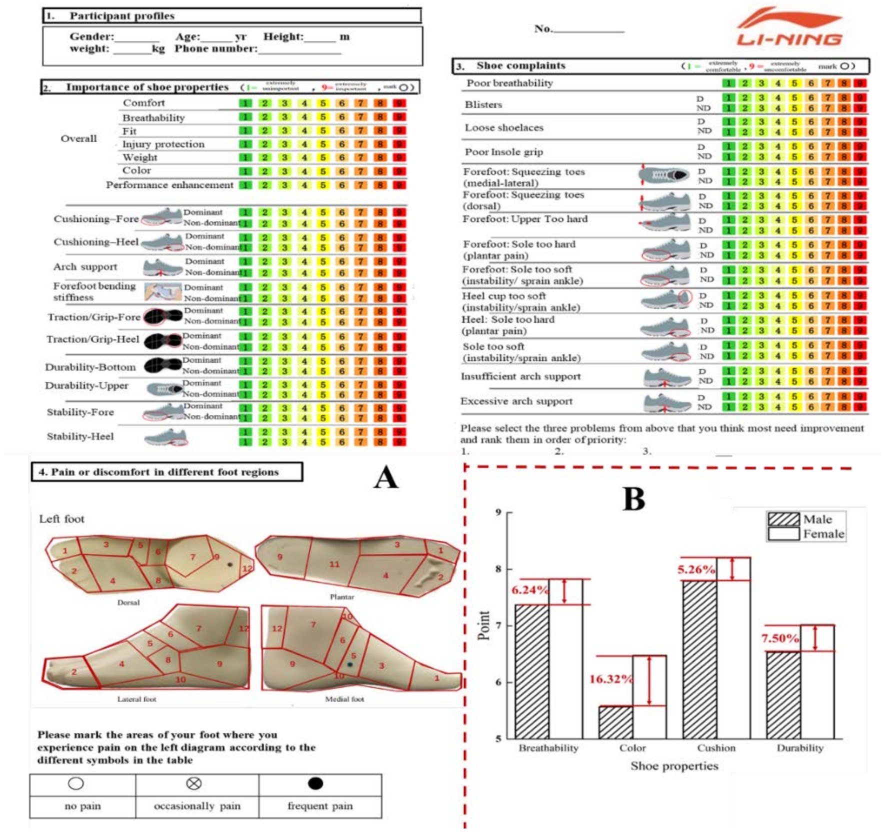

Figure 1. This cross-sectional survey questionnaire (A) and difference of shoe properties between genders (B).

Related articles to the first thesis point:

1. Shen, S., Lam, W.-K., Teng, J., Jia, S.-W., Baker, J. S., Ugbolue, U. C., Fekete, G., & Gu, Y. (2022). Gender and leg-dominance differences in shoe properties and foot injuries in badminton: a cross-sectional survey. *Journal of Foot and Ankle Research*, 15(1), 26. **IF: 2.96, Q2**

2. Xia, Y., **Shen, S.,** Jia, S.-W., Teng, J., Gu, Y., Fekete, G., Korim, T., Zhao, H., Wei, Q., & Yang, F. (2023). Gender differences in footwear characteristics between half and full marathons in China: a cross-sectional survey. *Scientific Reports*, 13(1), 13020. **IF: 4.997, Q1**

2nd Thesis point

I experimentally deduced that shoes with medium stiffness (60D) offer an optimal balance between flexibility and stability, reducing the stance time by 17% compared to 50D (Figure 2B), thereby enhancing performance and reducing injury risk. In contrast, shoes with higher stiffness (70D) show restricted ankle range of motion, however provide increased vertical ground reaction forces (an increase of cca. 8% compared to 50D) (Figure 2C) potentially aiding in quicker movements. Therefore, I can conclude that an intermediate level of torsional stiffness in badminton shoes offer the best balance for sports performance and injury prevention, suggesting the need for further research on the long-term effects of varying shoe stiffness and its relation to different athletic levels and foot morphologies.

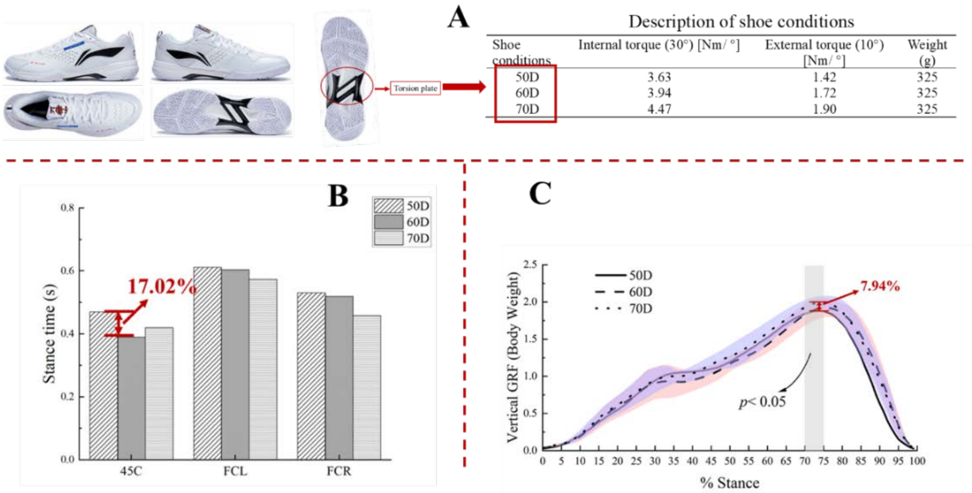

Figure 2. Shoe construction (A) and biomechanical parameters with Impact on Stance Times (B) and vertical ground reaction Forces (C)

Related articles to the second thesis point:

1. Shen, S., Teng, J., Fekete, G., Mei, Q., Zhao, J., Yang, F., & Gu, Y. (2024). Influence of Torsional Stiffness in Badminton Footwear on Lower Limb Biomechanics. *Journal of Sports Science and Medicine,* 23(1), 196-208. **IF: 4.017, Q1**

2. Shen, S. Q., He, Y. Q., Zhang, Y., Fekete, G., & Zhou, Z. X. (2020). Biomechanical analysis of long distance running on different sports surfaces. *Journal of Biomimetics, Biomaterials and Biomedical Engineering*, 45, 31–39. **IF: 0.69, Q4**

3. Zhang, Y. Y., **Shen, S. Q.,** Baker, J. S., & Gu, Y. D. (2018). Effects of different hardness in bionic soles on lower limb biomechanics. *Journal of Biomimetics, Biomaterials and Biomedical Engineering*, 39, 1–12. **IF: 0.69, Q4**

3rd Thesis point

I numerically demonstrated, by means of OpenSim musculoskeletal modeling, that increased arch support significantly reduces hip internal rotation peak angles during specific badminton tasks like 45-degree sidestep cutting (HS vs. NS: -60.25%, HS vs. LS: -69.57%) (Figure 29-a), potentially lowering hip injury risks. In contrast, during other tasks such as forehand clear stroke executed with the right foot, increased arch support may adversely affect performance (LS vs. NS: +135.83%, HS vs. NS: +199.44%) (Figure 3C-b), indicating variable injury risks with different movements. Additionally, enhanced arch support improves ankle dorsiflexion peak angles (45C: LS vs. NS: +17.88%, HS vs. NS: +22.58%; FCR: HS vs. NS: +39.62%) (Figure 3C-c, d), which is beneficial for foot clearance and impact force distribution. However, it is also associated with higher knee abduction angles, suggesting a potential risk for non-contact ACL injuries.

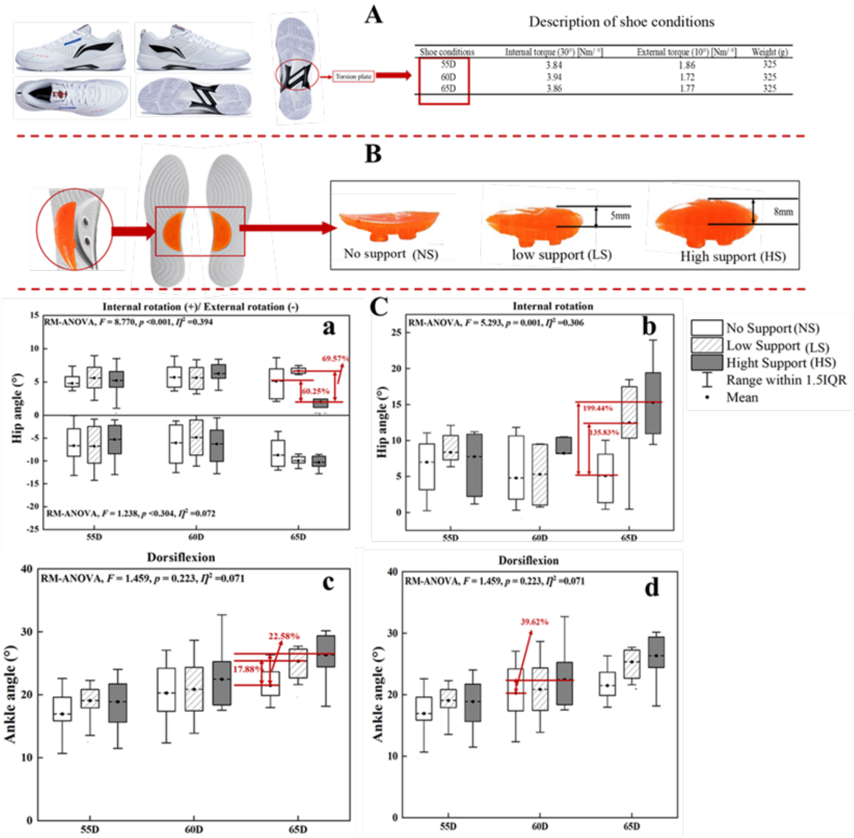

Figure 1. Combination of shoe construction (A), arch support structure (B), and peak hip internal rotation & ankle dorsiflexion angles (C).

Related articles to the third thesis point:

1. Shen, S., Teng, J., Fekete, G., Mei, Q., Zhao, J., Yang, F., & Gu, Y. (2024). Influence of Torsional Stiffness in Badminton Footwear on Lower Limb Biomechanics. *Journal of Sports Science and Medicine*, 23(1), 196-208. **IF: 4.017, Q1**

2. Teng, J., Qu, F., **Shen, S.,** Jia, S.-W., & Lam, W.-K. (2022). Effects of midsole thickness on ground reaction force, ankle stability, and sports performances in four basketball movements. *Sports Biomechanics*, 1–14. **IF: 2.896, Q1**

3. SCIENTIFIC PUBLICATIONS

3.1 Articles related to this thesis:

1. **Shen, S.,** Lam, W.-K., Teng, J., Jia, S.-W., Baker, J. S., Ugbolue, U. C., Fekete, G., & Gu, Y. (2022). Gender and leg-dominance differences in shoe properties and foot injuries in badminton: a cross-sectional survey. *Journal of Foot and Ankle Research*, 15(1), 26. **IF: 2.96, Q2**

2. **Shen, S. Q.**, He, Y. Q., Zhang, Y., Fekete, G., & Zhou, Z. X. (2020). Biomechanical analysis of long distance running on different sports surfaces. *Journal of Biomimetics, Biomaterials and Biomedical Engineering*, 45, 31–39. **IF: 0.69, Q4**

3. **Shen, S.,** Teng, J., Fekete, G., Mei, Q., Zhao, J., Yang, F., & Gu, Y. (2024). Influence of Torsional Stiffness in Badminton Footwear on Lower Limb Biomechanics. *Journal of Sports Science and Medicine*, 23(1), 196-208. **IF: 4.017, Q1**

4. Xia, Y., **Shen, S.,** Jia, S.-W., Teng, J., Gu, Y., Fekete, G., Korim, T., Zhao, H., Wei, Q., & Yang, F. (2023). Gender differences in footwear characteristics between half and full marathons in China: a cross-sectional survey. *Scientific Reports*, 13(1), 13020. **IF: 4.997, Q1**

5. Teng, J., Qu, F., **Shen, S.,** Jia, S.-W., & Lam, W.-K. (2022). Effects of midsole thickness on ground reaction force, ankle stability, and sports performances in four basketball movements. *Sports Biomechanics*, 1–14**. IF: 2.896, Q1**

6. Zhang, Y. Y., **Shen, S. Q.,** Baker, J. S., & Gu, Y. D. (2018). Effects of different hardness in bionic soles on lower limb biomechanics. *Journal of Biomimetics, Biomaterials and Biomedical Engineering*, 39, 1–12. **IF: 0.69, Q4**

3.2 Conference presentations with only abstract:

1. **Shen Siqin**. Kinematic Analysis of the Impact on the Lower Limbs of Long-Distance Runners on Different Running Surfaces. Chinese Society of Sports Science. Compilation of Abstracts of the 11th National Sports Science Congress. At: Nanjing, China.

2. **Shen Siqin**, Gu Yaodong. The Impact of Bionic High Heels on the Biomechanics of the Lower Limbs. Biomechanics Branch of the Chinese Society of Sports Science. Compilation of Abstracts of the 20th National Conference on Sports Biomechanics. At: Lanzhou, China.

3. Teng Jin, **Shen Siqin,** Qu Feng. Research on the Impact of Midsole Thickness in Basketball Shoes on the Biomechanical Characteristics and Athletic Performance of the Lower Limbs. Chinese Society of Sports Science. Compilation of Papers from the 8th China Sports PhD Forum. At: Nanjing, China.

4. Teng jin, **Shen siqin,** Qu feng. Effects of underwater exercise on human health. The 3rd International Academic Forum on Sports Medicine and Health. At: Chengdu, China.

5. Teng jin, **Shen siqin**, Qu feng. Study on the Impact of Midsole Thickness in Basketball Shoes on Sprint Running and Lateral Slide Steps. The 13th National Convention on Sport Science of China. At: Tianjin, China.

3.3 Other publications:

1. Teng, J., **Shen, S.,** & Qu, F. (2023). Study on the Effect of Midsole Thickness of Basketball Shoes on Sprint and Shuffle. *Journal of Beijing Sport University*, (08),123-132. **IF: 2.896.**
2. Zhao, H., Teng, J., Song, G., Fu, X., Pan, X., **Shen, S.,** Yan, Y., & Liu, C. (2023). The optimal exercise parameters of Tai Chi on the effect of glucose and lipid metabolism in patients with type 2 diabetes mellitus: A meta-analysis. *Complementary Therapies in Medicine*, 102995. **IF: 3.335, Q1**
3. Zhao, H., Cheng, R., Song, G., Teng, J., **Shen, S.,** Fu, X., Yan, Y., & Liu, C. (2022). The effect of resistance training on the rehabilitation of elderly patients with sarcopenia: A meta-analysis. *International Journal of Environmental Research and Public Health*, 19(23), 15491. **IF: 4.641, Q2**
4. Zhao, H., Cheng, R., Teng, J., Song, G., Huang, C., Yuan, S., Lu, Y., **Shen, S.,** Liu, J., & Liu, C. (2022). A Meta-Analysis of the Effects of Different Training Modalities on the Inflammatory Response in Adolescents with Obesity. *International Journal of Environmental Research and Public Health*, 19(20), 13224. **IF: 4.641, Q2**
5. Xu, D., Lu, Z., **Shen, S.,** Fekete, G., Ugbolue, U. C., & Gu, Y. (2021). The Differences in lower extremity joints energy dissipation strategy during landing between athletes with symptomatic patellar tendinopathy (PT) and without patellar tendinopathy (UPT). *Molecular & Cellular Biomechanics*, 18(2), 107. **IF: 0.138, Q4**
6. Feng, Y., **Shen, S.,** & Song, Y. (2021). Ultrasound Comparison of the Abductor Hallucis Muscle Between Normal and Hallux Valgus Feet After Long-Distance Running: A Pilot Study. *Journal of Medical Imaging and Health Informatics*, 11(8), 2106–2109. **IF: 0.659, Q4**
7. Li, S. D., **Shen, S. Q.,** Teo, E. C., & Liang, M. J. (2020). Bionic Footwear Effect to Lower Limb Locomotion in Biomechanical Analysis. *Journal of Biomimetics, Biomaterials and Biomedical Engineering*, 47, 105–115. **IF: 0.69, Q4**
8. Wang, M., Baker, J. S., Quan, W., **Shen, S.,** Fekete, G., & Gu, Y. (2020). A preventive role of exercise across the coronavirus 2 (SARS-CoV-2) pandemic. *Frontiers in Physiology,* 11, 572718. **IF: 4.755, Q1**
9. Zhang, Y., Awrejcewicz, J., Szymanowska, O., **Shen, S.,** Zhao, X., Baker, J. S., & Gu, Y. (2018). Effects of severe hallux valgus on metatarsal stress and the metatarsophalangeal loading during balanced standing: A finite element analysis. *Computers in Biology and Medicine,* 97, 1–7. **IF: 6.698, Q1**
10. Zhou, H., **Shen, S.,** & Gu, Y. (2018). Loading Posture Control in Anterior and Posterior Positions Using SEBT. 2017 *International Conference Advanced Engineering and Technology Research* (AETR 2017), 132–137.

3.4 Patents:

1. **Shen Siqin**, Gu Yaodong. A kind of swimming pool [P].CN209686938U,2019-11-26.

Reviewer for international journal articles:

1. BMC Musculoskeletal Disorders
2. BMC Sports Science, Medicine and Rehabilitation
3. Physical Activity and Health
4. PLOS One

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Total independent citations (Scopus): 110

(https://www.scopus.com/authid/detail.uri?authorId=57201659634)

Independent Hirsch index: 4

Total Impact Factor (Web of Science): 44.703