APPLYING DOSE-RESPONSE ANALYSIS IN SPORT BIOMECHANICS: AN EXAMPLE OF BADMINTON FOOTWORK AND FOOTWEAR

Qichang Mei[1,2], Xiaoyi Yang[1,2], Justin Wade Fernandez[1,2,3], Yaodong Gu[1,2]

[1]Faculty of Sports Science, Ningbo University, China
[2]Auckland Bioengineering Institute, The University of Auckland, Auckland, New Zealand
[3]Department of Engineering Sciences, University of Auckland, Auckland, New Zealand

Efficient footwork and appropriate footwear are important elements in badminton. This study aims to report the application of dose-response analysis in sports biomechanics, presenting the example of analysing the biomechanical response to training intervention with increased wearable resistance (WR) loads and the response of footwork performance to systematically increased wedge hardness in the design of badminton footwear. A further technique of data dimensionality reduction was employed to decipher the dose-response effect via reporting key PC explanation of ~90% with WR intervention, and 61.98%, 21.26%, and 8.1%. The example of badminton biomechanics may provide implications for future research and data analysis, especially understanding dose effect and biomechanical response in sports biomechanics.

KEYWORDS: Dose-Response, Badminton, Footwork, Footwear, Lunge, PCA.

INTRODUCTION: The sport of badminton was characterized by features of turning, cutting, jumping, landing, and lunging in a rapid manner to facilitate on-court athletic performance (W.-K. Lam et al., 2020; Manrique & González-Badillo, 2003; Mei et al., 2017). Considering the specific demand in badminton, the development of training program, such as applying wearable load attached to the trunk or limb to increase resistance (Yu & Mohamad, 2022) and footwear specifications (Chen et al., 2022; W. K. Lam et al., 2017; Yu, Wang, et al., 2023) were proposed to identify the contribution to the potential improvement of badminton footwork performance and prevention of impact or fatigue related badminton injuries.
The dose-response model is a useful tool to analyse the relationship between dose (such as materials or structures in the footwear) to acute and chronic responses in healthcare research, for example, understanding the effect of wedged insoles on foot pronation (Costa et al., 2021) and orthosis on knee osteoarthritis (Khosravi et al., 2023). The influence of specific design, structure, or materials selection in the badminton footwear and attached wearable loads on the motion performance was not reported.
In the current study, we aimed to present the application of the dose-response model in the analysis of sports biomechanics, specifically, an example of the biomechanical response to systematically increased load during the footwork training with the Wearable Resistance (WR) intervention, and a second example of footwork performance while wearing badminton footwear with specifically designed lateral wedge of increased hardness. Further, a dimension reduction technique of principal component analysis (PCA) modelling was employed to analyse and illustrate the dose-response relationship in the joint angles and moments.

METHODS: Two separate datasets were employed in this study. The first part of footwork training with wearable resistance (WR) intervention included 18 badminton athletes of university-level (average age of 28yrs, height of 172cm, mass of 69kg, and badminton playing years of 9.6yrs). Badminton athletes joint the motion capture experiment with increased WR from 0%BM, 3%BM, 6%BM, and 10%BM attached to anterior and posterior aspects of lower extremity, with 2/3 in the thigh and 1/3 in the shank. The second part of footwork analysis with well-designed badminton footwear included 15 male badminton athletes of university-level (average age of 26yrs, height of 176cm, mass of 68kg, and badminton playing years of 7yrs). Badminton athletes participated the lab motion capture experiment while performing typical footwork (specifically left frontcourt backhand lunge, LF, and right frontcourt forehand lunge, RF) with a novel footwear with design of increased lateral wedge hardness from Asker C hardness 55, 60, 65, and 70. The raw marker trajectories and ground reaction forces from biomechanical experiment were further used to calculate joint angles and joint moments following a standardised musculoskeletal pipeline (Mei et al., 2019). A previously established PCA modelling (Yu et al., 2021; Yu, Jiang, et al., 2023) was employed to analyse the dose-response in the joint angles and moments during stance phase of badminton footwork via calculating the scores and PC variations against the mean waveforms, to illustrate the systematic increased dose of WR (0%, 3%, 6%, and 10%BM) and wedge-hardness (Asker C of 55, 60, 65, and 70).

RESULTS: Example (1): Dose-response effect of WR load on lunge towards the left frontcourt backhand lunge (LF) and right frontcourt forehand lunge (RF). As found from the PCA modelling, key variations of knee flexion-extension moment (**Figure 1**) were mainly observed in the PC1 of LF lunge (91.25%) and PC1 of RF lunge (90.26%), during the 8-97% of stance. The PC2 of LF (3.49%) was found during 2-6%, 12-18%, and 45-70%, and RF (5.23%) was found during 2-6%, 11-17%, and 55-79%. Subtle variations were found from the reconstructed PC3 of knee moments during LF (2.51%) and RF (1.92%).

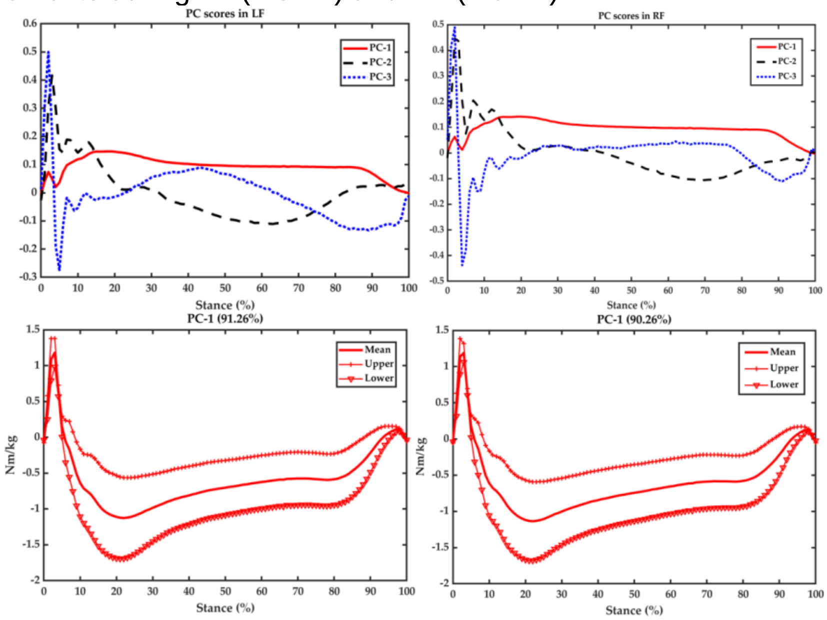

Figure 1. PC scores of the first 3PCs (with accumulative variations of over 95%), and reconstructed variances of PC1 against the mean knee flexion-extension moment

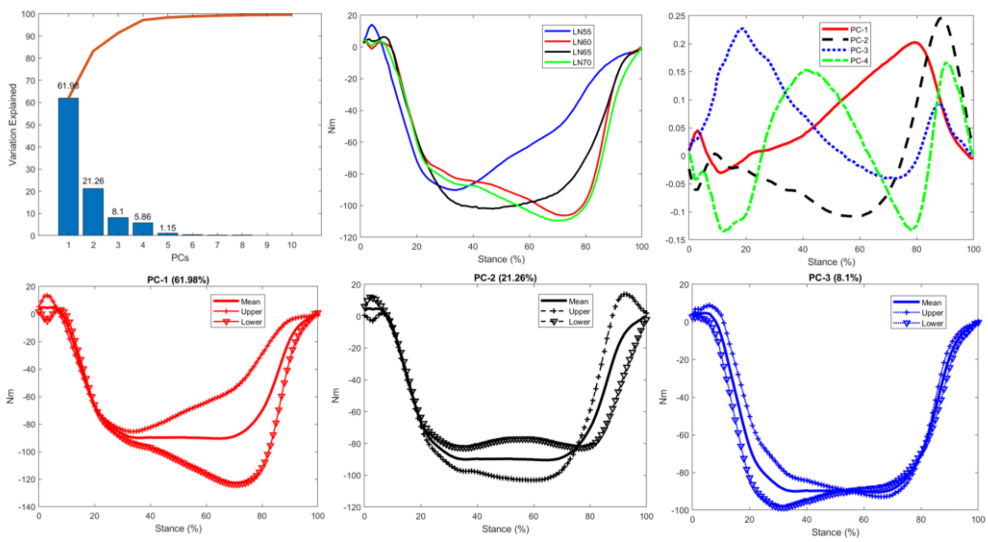

Figure 2. Illustration of variations (and accumulated variances), scores, and key PC3 of main variances during the right frontcourt forehand lunge (RF) with wedge hardness of Asker 55 (LN55), 60 (LN60), 65 (LN65), and 70 (LN70).

Example (2): Dose-response relationship between increased wedge hardness and lunge performance was mainly reported during the right frontcourt forehand lunge (RF), as presented in the **Figure 2**. The main modes of variances during RF footwork showed variances of 61.98% (PC1), 21.26% (PC2), and 8.1% (PC3). Specifically, the RF had key variances during 30-100% of lunging stance.

DISCUSSION: The knee joint, as the inter-link between the proximal hip joint and distal ankle joint played a key role in the lunges to avoid over flexion, which would impose decreased footwork performance (Fu et al., 2017; W.-K. Lam et al., 2020; Lee & Loh, 2019; Valldecabres et al., 2018). The LF backhand and RF forehand lunges showed no significance in the maximal extension and flexion moments, which differed from previous studies (Huang et al., 2014; Lin et al., 2015; Valldecabres et al., 2018). Further, the maximal knee extension moment showed consecutive reduction as incremental WR loads, which may be an adjustment to avoid over-loadings of the anterior knee (Yu et al., 2021). The PCA modelling revealed the key variances of knee flexion and extension moments in the PC1 of the LF (91.26%) backhand and RF (90.26%) forehand lunges during the weight acceptance, midstance and push-off phase of stance. This may indicate biomechanical response to the increased WR dose during badminton lunging footwork.

As for another example, PCA modelling typically reduced the high dimensionality data, extracted and reconstructed the key variances (Brandon et al., 2013), especially the ankle moments during stance. As observed, a systematic increase of the wedge hardness altered the magnitude (upper against lower limits) of ankle dorsi and plantar flexion moments in the RF driving-off during stance. Variances of ankle plantar flexion moments suggested that the increased wedge hardness may assist the output of ankle plantar-flexors moment to facilitate drive-off, thus reducing the stance time for subsequent execution and improving the footwork agility.

CONCLUSION: The current study illustrated the application of the dose-response effect in sports biomechanics, taking badminton footwork training and footwear intervention as an example. Further PCA modelling reported the variations and key variances as a response to the systematically increased dose of WR load (~10%BM) and footwear wedge hardness. The two examples may provide practical implications for footwork training and footwear selection while applying the dose-response analysis to understanding specific biomechanical influences.

REFERENCES

Brandon, S. C. E., Graham, R. B., Almosnino, S., Sadler, E. M., Stevenson, J. M., & Deluzio, K. J. (2013). Interpreting principal components in biomechanics: Representative extremes and single component reconstruction. Journal of Electromyography and Kinesiology, 23(6), 1304–1310. https://doi.org/10.1016/j.jelekin.2013.09.010

Chen, C.H., Condello, G., Chen, W.H., Liu, T.H., Tessitore, A., Shiang, T.Y., & Liu, C. (2022). Effects of a novel inclined-adaptive footwear on change-of-direction performance in male athletes. Gait & Posture, 94, 189–194. https://doi.org/10.1016/j.gaitpost.2022.03.010

Costa, B.L., Magalhães, F. A., Araújo, V. L., Richards, J., Vieira, F. M., Souza, T. R., & Trede, R. (2021). Is there a dose-response of medial wedge insoles on lower limb biomechanics in people with pronated feet during walking and running? Gait & Posture, 90, 190–196. https://doi.org/10.1016/j.gaitpost.2021.09.163

Fu, L., Ren, F., & Baker, J. S. (2017). Comparison of Joint Loading in Badminton Lunging between Professional and Amateur Badminton Players. Applied Bionics and Biomechanics, 2017, 5397656. https://doi.org/10.1155/2017/5397656

Huang, M.T., Lee, H.H., Lin, C.F., Tsai, Y.J., & Liao, J.C. (2014). How does knee pain affect trunk and knee motion during badminton forehand lunges? Journal of Sports Sciences, 32(7), 690–700. https://doi.org/10.1080/02640414.2013.848998

Khosravi, M., Jalali, M., Babaee, T., Ali Sanjari, M., & Rahimi, A. (2023). Evaluating the effective pressure applied by a valgus knee orthosis in individuals with medial knee osteoarthritis based on the dose–response relationship. The Knee, 40, 174–182. https://doi.org/10.1016/j.knee.2022.11.002
Lam, W. K., Ryue, J., Lee, K. K., Park, S. K., Cheung, J. T. M., & Ryu, J. (2017). Does shoe heel design influence ground reaction forces and knee moments during maximum lunges in elite and intermediate badminton players? PLoS ONE, 12(3), e0174604. https://doi.org/10.1371/journal.pone.0174604
Lam, W.-K., Wong, D. W.-C., & Lee, W. C.-C. (2020). Biomechanics of lower limb in badminton lunge: a systematic scoping review. PeerJ, 8, e10300. https://doi.org/10.7717/peerj.10300
Lee, J. J. J., & Loh, W. P. (2019). A state-of-the-art review on badminton lunge attributes. Computers in Biology and Medicine, 108, 213–222. https://doi.org/10.1016/j.compbiomed.2019.04.003
Lin, C.F., Hua, S.H., Huang, M.T., Lee, H.H., & Liao, J.C. (2015). Biomechanical analysis of knee and trunk in badminton players with and without knee pain during backhand diagonal lunges. Journal of Sports Sciences, 33(14), 1429–1439. https://doi.org/10.1080/02640414.2014.990492
Manrique, D. C., & González-Badillo, J. J. (2003). Analysis of the characteristics of competitive badminton. British Journal of Sports Medicine, 37(1), 62–66. https://doi.org/10.1136/bjsm.37.1.62
Mei, Q., Gu, Y., Fu, F., & Fernandez, J. (2017). A biomechanical investigation of right-forward lunging step among badminton players. Journal of Sports Sciences, 35(5), 457–462. https://doi.org/10.1080/02640414.2016.1172723
Mei, Q., Gu, Y., Xiang, L., Baker, J. S., & Fernandez, J. (2019). Foot Pronation Contributes to Altered Lower Extremity Loading After Long Distance Running. Frontiers in Physiology, 10(May), 573. https://doi.org/10.3389/fphys.2019.00573
Valldecabres, R., De Benito, A. M., Littler, G., & Richards, J. (2018). An exploration of the effect of proprioceptive knee bracing on biomechanics during a badminton lunge to the net, and the implications to injury mechanisms. PeerJ, 6, e6033. https://doi.org/10.7717/peerj.6033
Yu, L., Jiang, H., Mei, Q., Mohamad, N. I., Fernandez, J., & Gu, Y. (2023). Intelligent prediction of lower extremity loadings during badminton lunge footwork in a lab-simulated court. Frontiers in Bioengineering and Biotechnology, 11(1229574). https://doi.org/10.3389/fbioe.2023.1229574
Yu, L., Mei, Q., Xiang, L., Liu, W., Mohamad, N. I., István, B., Fernandez, J., & Gu, Y. (2021). Principal Component Analysis of the Running Ground Reaction Forces With Different Speeds. Frontiers in Bioengineering and Biotechnology, 9, 629809. https://doi.org/10.3389/fbioe.2021.629809
Yu, L., & Mohamad, N. I. (2022). Development of Badminton-specific Footwork Training from Traditional Physical Exercise to Novel Intervention Approaches. Physical Activity and Health, 6(1), 219–225. https://doi.org/10.5334/paah.207
Yu, L., Wang, Y., Fernandez, J., Mei, Q., Zhao, J., Yang, F., & Gu, Y. (2023). Dose–response effect of incremental lateral-wedge hardness on the lower limb Biomechanics during typical badminton footwork. Journal of Sports Sciences, 41(10), 972–989. https://doi.org/10.1080/02640414.2023.2257513

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