Optimal running occurs around natural bending stiffness of metatarsophalangeal joint

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1 Introduction

Increase of bending stiffness of shoe has been known to improve the running performance and the running economy [1]. However, the underlying mechanism hasn't been clearly known, partially due to separate studies of examining joint kinetics or metabolic cost, and possibly due to a limited range of insole stiffness tested. In this research we examined the joint mechanics and metabolic cost of running with various insole bending stiffness over the natural foot joint stiffness, with a hypothesis that the benefit of added insole stiffness would be maximized by compromising between the reutilization of elastic energy stored in insole and the loss propulsion force caused by resisted metatarsophalangeal (MTP) joint flexion by insole stiffness.

2 Methods

Seven healthy and young man (26.17±4.36 yrs. and 71.87±8.90 kg) participated to running test wearing elastic carbon insoles of various bending stiffness, after signing informed consent approved by KAIST IRB. All experiments were conducted below each anaerobic threshold, which was measured prior to the test [2]. Average running speed was 2.55±0.21 m/s. Bending stiffness coefficient of human metatarsophalangeal (MTP) joint and carbon insole were measured [3] by inverse dynamics (Fig. 1) and universal testing machine (INSTRON, US), respectively. Various bending stiffness of carbon insoles were set to cover the natural bending stiffness of each subject. To examine mechanical and metabolic energy efficiency, foot joint kinematics, ground reaction forces, and metabolic cost were measured by optimal motion capture system (Motion Analysis, US), customized force-plate (Bertec, US) implemented treadmill, and metabolic measurement system (COSMED, Italy), respectively.

3 Results

Elastic energy stored and returned to the propulsion by the elastic carbon increased with stiffness (Fig. 1B), but rather in a restricted manner due to reduced bending angle at stiffer insole, which then increased ankle joint lever arm (not shown) and decreased the propulsion GRF (Fig. 1B). The lowest oxygen consumption rate was obtained at the shoe bending stiffness closed to natural human foot joint stiffness (Fig. 1C).

4 Conclusion

Metabolically optimal running occurs near the natural bending stiffness of foot, where the compromise between the reutilization of the elastic energy stored in insole and the propulsion by the GRF seems to occur.

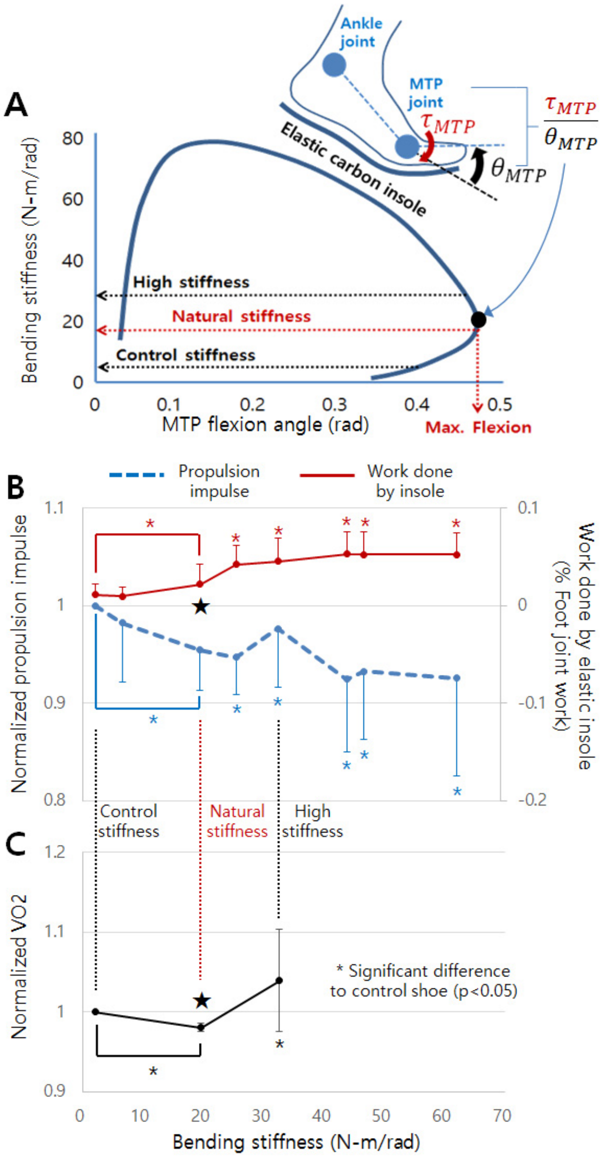

Figure 1: (A) Schematic diagram of bending stiffness of shoe and MTP joint, (C) propulsion impulse and work done, and (C) metabolic cost at various insole stiffnesses

References
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[2] CSEP, "The PFLC Resource Manual", Canadian Society for Exercise Physiology, 1993.
[3] Oleson, et. al., Journal of Biomechanics, 2005.