Quo vadis advanced footwear technology research?

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Abstract

Since the introduction of advanced footwear technology (AFT), distance running performances have improved significantly, as evidenced by a series of world records and general improvements in both elite and recreational running performances. 1 In their recent systematic review and meta-analysis, Stephen et al. 2 synthesize evidence on how AFT as a whole, as well as longitudinal bending stiffness (LBS) and midsole energy return as key constructional features, affect running economy (RE) and ankle mechanics during running. 2 Their systematic review demonstrates that AFT improves RE by 2.7% at an average running speed of 14.5 km/h. In contrast, their synthesis of the currently available literature suggests that neither LBS nor energy return alone significantly improves oxygen consumption or alters ankle mechanics.

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Commentary

Quo vadis advanced footwear technology research?

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Since the introduction of advanced footwear technology (AFT), distance running performances have improved significantly, as evidenced by a series of world records and general improvements in both elite and recreational running performances.[1] In their recent systematic review and meta-analysis, Stephen et al.[2] synthesize evidence on how AFT as a whole, as well as longitudinal bending stiffness (LBS) and midsole energy return as key constructional features, affect running economy (RE) and ankle mechanics during running.[2] Their systematic review demonstrates that AFT improves RE by ~2.7% at an average running speed of 14.5 km/h. In contrast, their synthesis of the currently available literature suggests that neither LBS nor energy return alone significantly improves oxygen consumption or alters ankle mechanics. The authors conclude that, instead, it is the interaction of these constructional features that drives relevant changes.[2]

It is notable that AFT improves running economy while reducing ankle joint demands, given that the ankle's muscle−tendon−ligament complex is typically considered highly efficient for force and work production.[3] Thus, at first sight, it appears counterintuitive that a reduction in mechanical ankle joint contribution would lead to improved RE. The combination of a curved carbon-fiber plate (i.e., a built-in rocker) and light-weight, soft, and highly resilient midsole foam in AFT appears to synergistically offload force and work requirements from active muscle to passive shoe structures, yielding at least 3 potential metabolic advantages:

1. Reduced force requirements: The triceps surae is essential for center of mass propulsion and support,[4] but also demands a high relative proportion of the total contraction-related metabolic cost during running.[5] Reducing torque demands at the ankle lowers the energetic cost of force production by decreasing cross-bridge cycling and activation-related processes.[6] Furthermore, lower force demands may shift muscle recruitment towards more efficient, low-threshold, slow-twitch muscle fibers.[7]
2. Improved muscle fiber contraction conditions: Lower tendon forces lead to reduced tendon strain, which might allow muscle fascicles to work closer to their optimal force-velocity and force-length potentials.[8] Furthermore, triceps surae muscle-tendon-unit shortening velocity is directly related to ankle angular velocity, which AFT can reduce.[9] Improved muscle contraction conditions result in a reduction in active muscle volume and the metabolic cost required to meet force generation demands.
3. Passive energy uptake and return: Some of the force and work of the muscle fibers during stance could be reduced through energy storage and return by elastic materials in the midsole.[10] As this viscoelastic rebound has no direct metabolic cost, the net energy expenditure of running might be further reduced. The findings of this review suggest that higher energy return in isolation does not improve RE. However, studying the effects of energy return in isolation is very challenging, for example, due to the issue of quantifying energy return reliably using material testing[11] or modifying energy return while keeping other construction parameters (e.g., stiffness, mass, LBS) constant.

However, runners differ in their running speeds, anthropometrics, running styles, muscle architectures, and tendon stiffnesses. Therefore, the benefits of bringing ankle mechanical demands closer to optimal and utilizing the spring-like features of elastic midsoles are likely individual, reflecting the variability in responses reported in this review and previous studies.[12] To optimize performance, the target might be identifying the optimal AFT characteristics for a specific individual or altering modifiable runner characteristics (e.g., triceps surae strength and Achilles tendon stiffness) to match AFT characteristics.

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To evaluate the isolated effects of LBS and midsole energy return on RE and ankle kinetics, the authors of this review had to undertake the challenge of synthesizing data from a very heterogeneous database. The heterogeneity is the result of (a) different levels of LBS integrated into footwear in different ways (e.g., as an insole, in the lower or upper part of the midsole), (b) different geometries of the stiffening elements (e.g., flat *vs.* curved), (c) different midsole cushioning materials and geometries, (d) non-standardized testing methods, and (e) insufficient reporting of footwear properties and might have masked the actual isolated effects of these constructional features, which nonetheless may have been present.

Thus, there is a need for academia and industry to develop testing and reporting standards for the midsole properties of running shoes and ATF in general. The Grade of Recommendations Assessment, Development and Evaluation (GRADE) assessment performed in this study revealed low to very low certainty for most outcomes due to heterogeneity, small sample sizes, and risk of bias related to uncontrolled confounders—most notably shoe mass, stack height, and heel-toe drop−which were not consistently reported and controlled across studies, further emphasizing the need for better-controlled studies, which has been emphasized before.[13]

For future research, we recommend well-powered, within-shoes experiments that orthogonally manipulate LBS and energy return characteristics while rigorously controlling for relevant confounding variables. Progress in additive manufacturing or predictive musculoskeletal simulations may alleviate some of the difficulties associated with creating experimental footwear, particularly in laboratories not directly supported by footwear manufacturers.[14]

Furthermore, this review reported that only ∼14% of participants in AFT studies were female, highlighting the need for more diverse cohorts in future footwear research.[2] Greater female integration in AFT studies is necessary, among other reasons, to elucidate why performance increments since the introduction of AFTs are more pronounced in female runners,[1] a finding for which a mechanistic explanation has yet to be found. Future studies should also consider compensatory adjustments at the knee and hip and biomechanical changes with running-induced fatigue, which might influence RE as well as biomechanical risk factors (including cumulative loading characteristics)[15] for overuse injuries.[16−18] Furthermore, the implications of reducing ankle mechanical demand on muscle damage must be better understood to identify potential recovery-related performance-enhancing effects of AFTs.[19,20]

Improving study designs and reporting standards will enable a deeper mechanistic understanding of how AFTs improve performance, informing the development of next-generation footwear design and individualized shoe selection strategies.

Authors' contributions

All authors participated in the conception of the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Declaration of competing interest

Previous and ongoing work of the authors has been funded by footwear manufacturers (e.g., Adidas AG, Brooks Sports Inc.). However, no industry partner was involved at any stage in the preparation of this article. The authors declare that they have no other competing interests.

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