New year, new gear: Does the next version of an advanced footwear model lead to better performance?

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ABSTRACT

In recent years, advanced footwear technology (AFT) has contributed to numerous world records in long-distance running, with new models being developed annually. This study investigated the effects of incremental design changes between two consecutive iterations of AFT on running economy (RE) and subjective perceptions in trained male runners. Participants completed submaximal running trials in the Adidas Adios Pro 3 and Pro 4 models. Results showed a significant 1.31% improvement in RE with the newer Pro 4 model ($p < .001$), with a decrease in oxygen uptake at submaximal speed. The improvement in RE, likely due to reduced shoe mass, modified rocker geometry, and altered cushioning stiffness, could potentially influence elite competition outcomes. However, while in this study, year to year performance improvements due to model updates were found, these findings not neccesarily translate to year to year modifications in other models and manufacturers. However, the findings contribute to our understanding of how subtle design modifications in successive shoe models can impact running performance.

Keywords

Advanced footwear technology, running economy, running performance, locomotion, biomechanics, road racing

Introduction

Over the past few decades, marathon running has become increasingly popular, with the number of annual events and participation increasing [1,2]. As the sport has evolved, so has the scientific understanding of the factors influencing marathon performance. Marathon performance is primarily determined by physiological parameters, including maximal oxygen uptake (VO_{2max}), lactate threshold, and running economy (RE) [3,4]. The metabolic cost is particularly relevant for assessing performance changes, as an altered running economy directly translates to altered distance-running performance [5]. RE has been defined as the rate of oxygen uptake in per time per kilogram body mass required to run at a submaximal speed[6]. Besides traditional physiological parameters, external factors have also been recognized as relevant to marathon performance. These external factors include course profile, environmental conditions, pacing strategy, drafting, nutrition, and footwear [4,7,8]. In particular, footwear has become a field of increased attention in research due to its potential to influence running mechanics and energy expenditure. Running with lighter footwear has been shown to reduce metabolic demands by about 1% per added 100 g [9–11]. Footwear with greater cushioning and greater energy return can affect performance, enabling athletes to run faster and more economically [12–15]. By increasing the longitudinal bending stiffness, performance was shown to be improved, as expressed by improved running economy [16] and reduced muscle shortening velocity [17]. Another factor influencing performance is the (rocker) geometry of the midsole and its stabilizing elements, as the "teeter-totter effect" might contribute at least partially to a more economical running performance [18,19]. Today, AFT combines a lightweight and resilient midsole foam with an embedded rigid carbon fiber plate and a pronounced rocker profile in the sole [20]. AFT combines all of these features, adding up to an average running economy improvement of about 4% [21,22] compared to traditional footwear on average, however, with pronounced between runner variability[23]. The precise mechanisms driving these improvements and the variations between different AFT models and brands remain poorly understood, as studies rarely focus only on one specific constructional aspect, such as bending stiffness or stack height [24,25].

Furthermore, while research has extensively compared different brands of AFT to non-AFT shoes, there is a notable absence of studies examining performance differences between successive models of the same shoe model. This research gap limits our understanding of how incremental changes in shoe design affect running performance. Nonetheless, for runners, it is essential to understand whether year-to-year footwear model modifications improve their users' performance. Understanding the continuous improvements in running shoe technology could provide valuable insights for athletes in selecting optimal footwear for performance enhancement while also guiding manufacturers in refining their design processes and marketing strategies for new shoe models.

Therefore, this study aims to compare the running economy between two consecutive AFT shoe models of the same brand. This research addresses a current gap in the literature by quantifying the effect of incremental shoe design changes on the running economy, potentially informing both elite athletes' equipment choices and manufacturers' product development strategies. This leads to the following research questions: Is there a measurable difference in running economy between two consecutive iterations of an AFT shoe model? Based on year-to-year technological innovations with newer shoe models, including optimized foam composition and constantly adjusted plate geometry, we hypothesize a small but measurable improvement in running economy compared to its predecessor.

Methods

Participants

Nineteen trained male runners (mean ± SD; age: 37.5 ± 12.4 years, height: 1.77 ± 0.05 m, mass: 70.9 ± 5.4 kg) participated in the study. To be included in the study, runners must have been free of lower limb injuries six months prior to testing and fit in the provided shoe size 9 US. The study received ethical approval from the local Research Ethics Committee (approval number: 04/23), and all participants signed informed consent forms before participation.

Footwear condition

Two new highly cushioned, racing AFTs were tested in this study. Adidas Adios Pro 3 and Adidas Adios Pro 4. These shoes were selected as they represent the recently and previously released versions of a top-tier racing shoe model within the same shoe line. Shoe mechanical specifications are provided in **Table 1**. Shoes were not weight-matched, and no other modifications have been made.

Table 1. Mechanical characteristics of both shoe conditions.

Condition	Pro 3	Pro 4
Shoe mass (g)	238	200
Rearfoot thickness (mm)	39.5	39
Forefoot thickness (mm)	33	33

Data collection

Each participant attended a single lab session where they performed two running trials on a force-instrumented treadmill (Bertec Corporation, Columbus, Ohia, USA) set with no gradient. The protocol included an individual warm-up followed by a seven-minute incremental test. The purpose of the incremental test was to determine each subject's anaerobic threshold. Before testing, runners were asked for their 10 km seasonal best, as this running speed matches close to their anaerobic threshold. During the incremental test, the starting speed was 1 m/s slower than the provided 10 km seasonal best speed and was continuously increased by 0.2 m/s every minute, until their anaerobic threshold speed was achieved. A participant's anaerobic threshold was visually identified from the output of a cardiopulmonary exercise testing metabolic cart (Vyntus, Vynair Medical, Mettawa, USA) by looking for a respiratory exchange ratio (RER) value greater than 1 [26]. The submaximal running speed for each subject was determined based on their RER to not exceed 0.9 during the whole measurement relative to each subject's fitness level. This procedure resulted in an average running speed of 13.4 ± 1.1 km/h for the participant sample that was used for subsequent shoe testing.

The participants performed two six-minute runs in each of the two footwear conditions in a randomized order, at the same submaximal running speed. Metabolic data were collected during the whole trial to ensure a submaximal steady-state oxygen consumption and to adjust running speed when an increase in RER was observed. To avoid fatigue effects, participants had a six-minute rest after the incremental test and another six-minute rest period between trials. Subsequently, participants answered a perception questionnaire upon completion in each shoe condition. During the incremental test and each running trial, metabolic data were captured using a breath-by-breath method with a metabolic cart (Vyntus, Vynair Medical, Mettawa, USA). Before each testing session, the metabolic cart was calibrated using room air and a gas mixture of known composition. After each measurement, participants were asked to fill out a questionnaire about their perception of the shoe. They evaluated each shoe condition on a Visual-Analog-Scale (VAS), with higher scores indicating greater energy return, better comfort, greater stability, and easier ride.

Data analysis

Running Economy

Running economy was defined as the average rate of oxygen ($\dot{V}O2$) during a defined window of steady-state running. First, raw breath-by-breath data was visually inspected to confirm that the participants reached steady-state running at the end of the trials. Outlier breaths were identified as all data points that are greater than two standard deviations from the mean. Then, a locally weighted scatterplot smoothing technique (lowess) was applied to smoothen the data. Finally, running economy was defined as the average across the steady-state window between 2:30 min:s and 5:30 min:s of a run.

Perception

Participants evaluated the perception parameters of both shoes (energy return, comfort, stability, and ride) using a 10-point VAS (1 = lowest, 10 = highest). The responses were recorded in a CSV file for each participant and each shoe.

Statistical analysis

Data was subsequently imported into JASP (Version 0.18.3) for statistical analysis. To evaluate whether the running economy data followed a normal distribution, the Shapiro-Wilk test was performed for both shoe conditions, revealing a violation of normality ($p < 0.05$). The running economy data were compared between Pro 3 and Pro 4 using a Wilcoxon Signed Rank Test with an alpha level of 0.05. This test was selected due to the within-subject design, as the same participants were tested in both shoe conditions. To compare the perception of both footwear conditions across four evaluation criteria (energy return, comfort, stability, and ride), participants rated both shoes on a VAS from 1 to 10. Normality of the perception data was evaluated for each variable using the Shapiro-Wilk test. Two variables (stability and ride) exhibited significant results ($p < 0.05$), indicating a deviation from normality. Consequently, the Wilcoxon Signed Rank Test, a non-parametric alternative suitable for paired data, was used for these variables to compare the perception ratings between Pro 3 and Pro 4. For energy return and comfort, a paired t-test was used.

Results

Running Economy

A significant improvement of 1.31% in running economy was found for the Adidas Adios Pro 4 compared to the Adidas Adios Pro 3 shoe condition ($p < .001$, **Figure *1***). The oxygen uptake for running at a submaximal speed of 13.4 ±1.1 (km/h) wearing the Adios Pro 3 was 46.4 ± 4 ($mL \cdot min^{-1} \cdot kg^{-1}$). While wearing the Adidas Adios Pro 4, participants ran at the same speed with an oxygen uptake of 45.8 ± 4.1 ($mL \cdot min^{-1} \cdot kg^{-1}$). The individual responses can be visualized through the change in Running Economy (Δ Running Economy), which illustrates that 84% of the participants (16/19) benefited from the newer model (**Figure *2***).

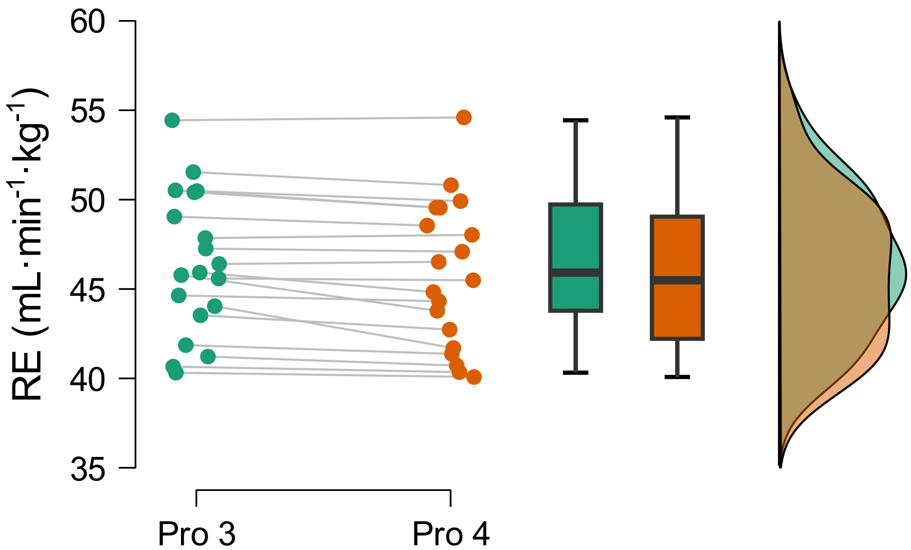

Figure 1. Comparison of running economy (RE) between Pro 3 and Pro 4 conditions.

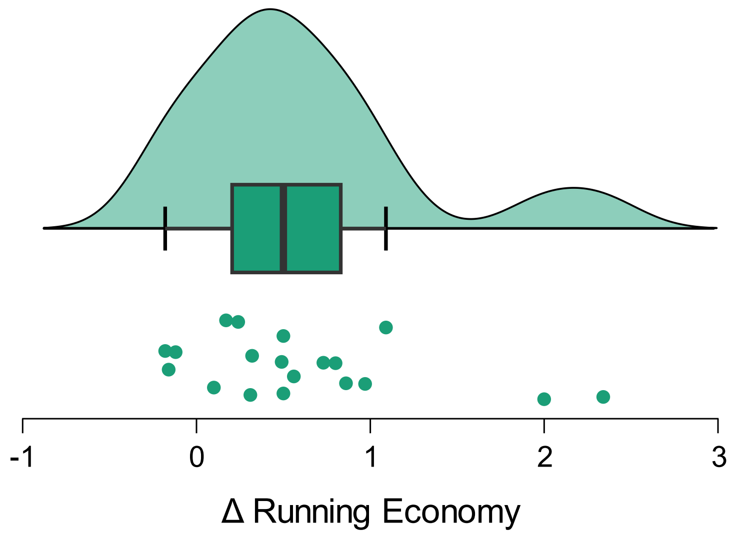

Figure 2. Comparison of running economy between Adidas Adios Pro 3 and Adidas Adios Pro 4. Positive values in deltas represent a better running economy in Adidas Adios Pro 4, negative values represent a better running economy in Adidas Adios Pro 3.

Perception

The perception results indicated no significant differences in energy return (W = 39, p = .135), comfort (W = 52.5, p = 1.000), or ride (p = .143). However, a significant difference was observed for stability, with Pro 3 being rated significantly higher than Pro 4 (p = .005, **Figure *3***).

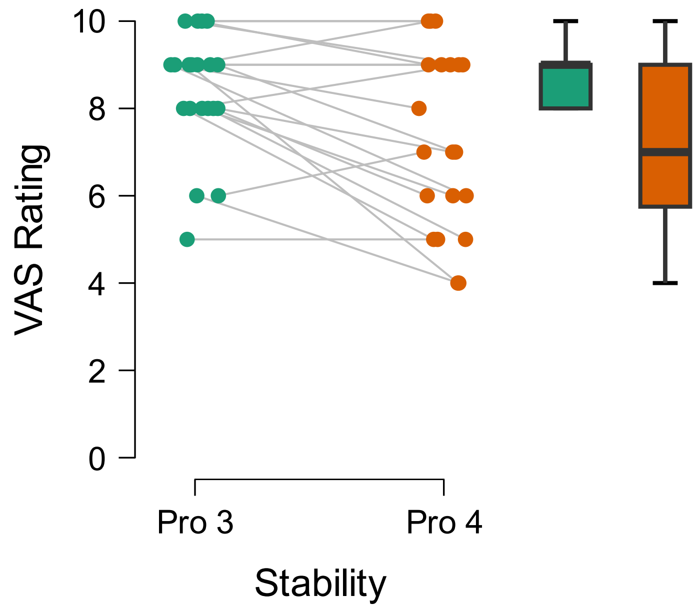

Figure 3. Comparison of stability perception between Adidas Adios Pro 3 and Adidas Adios Pro 4. 0 meaning no stability and 10 meaning extremely stable

Discussion

The aim of this study was to assess the effects of incremental design changes between two consecutive iterations of an AFT model on RE and subjective perceptions in trained runners. The main finding was an improvement in RE of 1.31% ($p < .001$) when wearing the newer Adidas Adios Pro 4 model compared to its predecessor, the Adidas Adios Pro 3, at a submaximal running speed of 13.4 ±1.1 km/h. We observed a decrease in average oxygen consumption from 46.4 ± 4 $mL \cdot min^{-1} \cdot kg^{-1}$ in the Adios Pro 3 to 45.8 ± 4.1 $mL \cdot min^{-1} \cdot kg^{-1}$ in the Adios Pro 4 and therefore our hypothesis of an RE improvement in the Pro 4 can be confirmed.

The average difference between gold and silver medal performances across track and marathon running events in the 2008 to 2021 Olympic Games was 0.497% and 0.297% between bronze and fourth place, respectively[27]. Our observed improvement of 1.31% translates to a 0.87% time improvement[28], suggesting that the incremental changes between consecutive shoe models could potentially influence podium placements in elite competitions. This improvement in running economy can be attributed to several key design changes in the Adidas Adios Pro 4. Primarily, the 30 g reduction in shoe mass likely plays a crucial role, aligning with previous research indicating that a 100 g decrease in shoe weight can enhance running economy by approximately 1%[9–11]. Additionally, the modified rocker geometry in the Pro 4 may contribute to enhanced performance through an optimized teeter-totter effect[18]. However, the synergistic combination of weight reduction, different midsole geometry, and the same foam compliance also leads to an altered bending stiffness, likely overall resulting in the observed 1.31% improvement in running economy, highlighting the complex interplay of shoe design elements in performance enhancement[29].

While our study shows a 1.31% improvement in running economy between consecutive shoe models, it is unlikely that such gains will continue year-over-year. Instead, we can expect to find diminishing returns in performance improvements in future iterations of AFT research. As shoe designs approach their theoretical performance limits, each subsequent improvement is likely to yield smaller gains. This trend is due to the physical limitations of materials, the physiological limits of human adaptation to technological advancements, and the increasing complexity of achieving further improvements. Moreover, regulatory constraints were imposed by World Athletics, controlling shoe properties, including maximum midsole stack height for various race distances. These regulations further limit the potential for continued improvements in running economy through shoe design. Future enhancements may focus more on optimizing within these constraints and on specific aspects of performance rather than achieving substantial improvements in the overall running economy. This pattern of diminishing returns is common in technological advancements and aligns with the general trend observed in sports equipment evolution.

The improvements in running economy observed between the two consecutive Adidas Adios Pro models are specific to the design changes implemented in this particular shoe line. These results cannot be generalized to all newer shoe models or other manufacturers in general. Different brands employ different materials as well as different methods to quantify property characteristics, such as bending stiffness, which may result in varying degrees of performance enhancement and results[30]. Additionally, the baseline performance of previous models differs between brands, affecting the potential for improvement. Individual runners may also respond differently to various shoe designs due to factors such as running style and biomechanical characteristics[23]. Therefore, while our findings suggest the potential for improvement in running economy through incremental design changes, the specific magnitude and nature of these improvements are likely to vary across different shoe models and manufacturers. Further research comparing multiple brands and models is necessary to establish broader trends in the evolution of running shoe performance.

Interestingly, while we observed an improvement in running economy with the Adidas Adios Pro 4, participants reported no significant differences in perceived energy return, comfort, or ride between the two shoe models. This discrepancy between measurable performance improvements and subjective perceptions highlights the difficulty for runners to directly feel small changes in running economy. The short duration of our testing protocol (6-minute runs) may have contributed to this lack of perceived difference, as subtle improvements in efficiency might become more noticeable over longer distances or durations. This finding underscores the importance of objective measurements, such as spirometry, in assessing running shoe performance[5]. Relying solely on subjective feelings of performance may not accurately reflect the actual biomechanical and physiological benefits provided by incremental shoe design changes. Future studies may benefit from incorporating longer test durations or repeated measures over multiple sessions to better align subjective perceptions with objective performance metrics.

Our results revealed a trade-off between perceived stability and measured performance improvement. While the Adidas Adios Pro 4 demonstrated better running economy, participants rated the Adios Pro 3 higher for stability ($p = .005$). This finding highlights the complex relationship between shoe design and performance. Interestingly, Sterzing et al.[31] found that participants didn't perceive differences in stability for different shoe designs, even when biomechanical data showed clear differences. This discrepancy underscores the challenges of relying on subjective stability assessments and the potential limitations of perceived stability as a metric for shoe performance. Stability perception varies among runners, influenced by factors such as experience, anthropometry, and comfort preferences. The apparent trade-off between stability and performance, combined with the inconsistency between perceived and measured stability, emphasizes the need for a more nuanced approach to understanding stability in running shoes and its relationship to measurable performance metrics, such as 3D motion capture.

While our study provides valuable insights into the effects of incremental design changes on the running economy, it's important to acknowledge certain limitations that offer opportunities for future research. Our approach of using a single shoe size allowed for precise control of variables, since bending stiffness may vary between very small and large shoe sizes, isolating the effects of model differences. However, our study design choices also present some limitations. Firstly, we conducted only one measurement per shoe condition for each participant. Recent research has shown that metabolic analyzers can be prone to measurement error, and single-trial assessments may not fully capture individual responses to advanced footwear technology[32]. Therefore, we can only infer interpretations of our data on a group basis and not on an individual basis. Future studies could benefit from conducting a minimum of two trials per condition to obtain more reliable individual responses and to relate these to other variables (e.g., biomechanical or anthropometric) to identify the underlying mechanisms of individual footwear responses in greater detail. Secondly, our study did not capture biomechanical factors or changes in running style. The absence of this data limits our ability to fully understand the mechanisms behind the observed improvements in the running economy. Future research incorporating 3D motion capture or other biomechanical analyses could provide valuable insights into how incremental shoe design changes affect running mechanics and, consequently, running economy. Thirdly, our study sample consisted exclusively of male runners, limiting the generalizability of our findings to female athletes. Given potential differences in biomechanics and physiological responses between male and female runners, future studies should include a diverse sample to ensure broader applicability of results. These limitations provide direction for future research in this field, suggesting the need for more comprehensive, longitudinal studies that incorporate biomechanical analyses and diverse participant samples. Such studies would further enhance our understanding of the complex interplay between shoe design, running mechanics, and performance.

Conclusion

This study provides evidence that incremental design changes between consecutive iterations of an AFT model can lead to measurable improvements in the running economy. Specifically, the newer Adidas Adios Pro 4 model demonstrated a 1.31% improvement in running economy compared to its predecessor, the Adios Pro 3, at submaximal running speeds. This improvement, likely due to a combination of reduced shoe mass, modified rocker geometry, and altered cushioning stiffness, could potentially influence elite competition outcomes. The absence of significant differences observed for most perception variabless underscore the importance of objective measurements in assessing running shoe performance, as subjective perceptions may not accurately reflect physiological benefits. While these results cannot be generalized to all shoe models or manufacturers, they provide valuable insights into the potential for performance enhancement through incremental shoe design changes in AFT.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author contributions statement

Y.D., S.W. and H.K. conceived the experiment(s), H.K. and Y.D. conducted the experiments, Y.D. and S.W. analysed the results. Y.D., L.B. and S.W. contributed to the manuscript. All authors reviewed the manuscript.

Additional information

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