PREPRINT

Does advanced footwear technology improve track and road racing performance? An explorative analysis based on the 100 best yearly performances in the world between 2010 and 2022

Running Head:

The effects of advanced footwear technology on world-class track and road racing performances.

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Abstract

High-tech running shoes and spikes ("advanced footwear technology") are currently being debated in sports. There is direct evidence that distance running advanced footwear technology improve running economy; however, it is not well established to which extent world-class performances are affected over the range of track and road running events.

This study examined publicly available performance datasets of annual best track and road performances for evidence of potential systematic performance effects following the introduction of advanced footwear technology. The analysis was based on the 100 best performances per year for men and women in outdoor events from 2010 to 2022, provided by the world governing body of athletics (World Athletics).

We found evidence of progressing improvements in track and road running performances after the introduction of super distance running shoes in 2016 and super spike technology in 2019. This evidence is more pronounced for distances longer than 1500 m in women and longer than 5000 m in men. Women seem to benefit more from advanced footwear technology in distance running events than men.

While the observational study design limits causal inference, this study provides a database on potential systematic performance effects following the introduction of advanced shoes/spikes in track and road running events in world-class athletes. Further research is needed to examine the underlying mechanisms and, in particular, potential sex differences in the performance effects of advanced footwear technology.

Key words:

Adnaced Footwear Technology, Running performance, Spikes, Footwear, Sports Performance, Locomotion

Key Points

- The study provides indirect evidence of the performance-enhancing effects of advanced footwear technology particularly for longer distances and in female athletes.
- However, limitations of the study should be considered, such as the observational nature of the analysis and potential confounding factors such as performance-enhancing drugs.
- The findings have implications for the design and use of advanced footwear technology in competitive distance running, highlighting the need to consider individual differences in anthropometrics and biomechanics and continue monitoring new footwear technologies' effects on athletic training performance.

1. Introduction

High-tech running shoes and spikes have been the subject of intense debate in the sporting world in recent years. Critics see them as techno-doping that artificially enhances athletes' performance. [1]

Thanks to new findings in materials science, athletic shoes have undergone rapid development, especially in recent years. High-tech, in the context of this article, means extremely lightweight shoes that use a compliant "super foam" as the cushioning element in combination with a stiff, curved plate, often made of carbon, running along the sole [2,3]. In the case of spiked shoes, some manufacturers add a spike plate in the forefoot to which the spikes are attached [4].

Potential performance improvements of distance running shoes can be evaluated by assessing their effects on the running economy (RE). Improvements in RE measured in the lab translate directly to race performance, although the magnitude is smaller [5–7]. Overall, there is clear, direct evidence to suggest that distance running advanced footwear technology improve running economy [7–9], even though these improvements might be running speed dependent [10] and differ between individuals [7,11]. While some of these studies included world-class athletes [11], most were performed with high-calibre, predominantly male athletes.

The real-world success of super distance running shoes across a wide range of performance levels was demonstrated in an analysis based on data from the social fitness network Strava. This analysis suggests that super-distance running shoes provide a 3-4% advantage over "traditional" running shoes [12]. Evaluating performance between footwear conditions is more difficult for shorter running and sprinting distances. Here, energy is supplied much more by anaerobic metabolism, so an evaluation of running economy based solely on oxygen uptake is inappropriate [13,14]. Nevertheless, it is still essential to maintain a high speed as efficiently as possible during long sprints and middle-distance races [15,16].

In these situations, the only viable option is to directly test performance while wearing different (spike) shoes via repeated test runs over the competition distance [4]. The performance criterion would then trivially be the time achieved with each shoe. Methodologically, it is difficult to control for the underlying conditions that may influence the time achieved. These include influences such as motivation, fatigue (e.g. due to training on previous days, psychological stress), time of day, training effects, and sleep. Controlling for these conditions is very costly, making it difficult to quantify the effects of footwear on running performance in elite athletes [4]. Integrating world-class athletes in such a testing paradigm seems even more challenging, given their sophisticated training protocols, competition, public relations, and travel schedules.

An alternative approach would be to identify systematic changes in the best performances recorded in competitive events, assuming that super-shoes were increasingly adopted after their introduction. Such an indirect approach has not been taken to date, particularly for sprint and middle-distance events.

Therefore, this study aimed to examine publicly available performance datasets of annual best track and road performances for evidence of potential systematic performance effects following the introduction of advanced shoes/spikes.

We hypothesized that there is identifiable evidence for progressive improvements in track and road running performances after the introduction of super distance running (in 2016) and super spike technology (in 2019).

2. Methods

We based our analysis on a publicly available database of the 100 best track and road running performances provided by the world governing body of athletics (World Athletics). We extracted the data from the World Athletics season top lists (www.worldathletics.org, accessed January 31, 2023). We considered the outdoor events of the top 100 men's and women's performances from 2010 to 2022. Because super distance running shoes were introduced earlier (2016) than super spikes (2019), we used different baseline reference periods for comparison.

We defined the reference period from 2010 to 2015 for long distances (i.e., half-marathon and marathon) and from 2010 to 2018 for events from 100 m to 10,000 m to represent the period before advanced footwear technology or spikes were introduced, respectively. As a result, the observation periods for super-distance running shoes and super-spiked shoes began in 2016 and 2019, respectively. We excluded 2020 from the analysis because of the low number of races and training cancellations due to the Covid-19 pandemic. In order to assess the potential influence of the advanced shoes/spikes on performance, we defined three criteria:

The first criterion was that the arithmetic mean of the medians of the 100 best performances per year during the observation period should be at least 0.5% faster than the reference value. The reference value was calculated as the mean of the medians of the reference period years (Figure 1). The difference threshold (> 0.5%) was chosen to take into account the distributions of the differences obtained between the first places in the track and marathon events during the last four Olympic Games (Figure 1).

The chosen threshold of 0.5% is above the median of the differences between gold and silver medals (0.497%) and well above the median of the differences between bronze medalists and fourth place (0.297%).

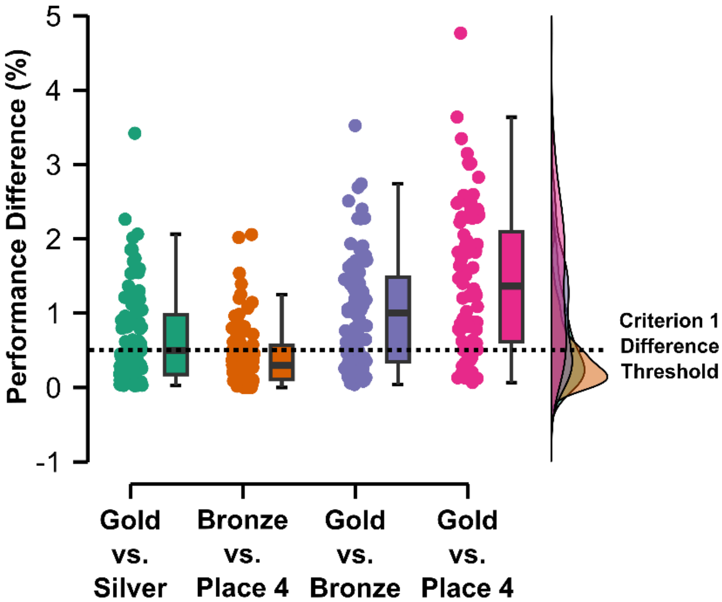

Figure 1: Differences between positions in track and marathon running events in the 2008 to 2021 Olympic Games.

The second criterion was met if at least 75% of the years in the observation period were statistically significantly faster than the reference value. We applied the Bonferroni correction of alpha levels to avoid alpha error accumulation [17]. The resulting alpha level threshold was p<0.000595. The year 2020 was again not considered due to the strong impact of the pandemic, as explained above. Due to the non-parametric and non-symmetric distribution of the sample, we used the one-sample Wilcoxon signed rank test to compare individual years with the reference value.

The final criterion was whether two years within the observation period were overall the fastest years within the entire analysis period.

3. Results

Based on our predefined criteria, we found evidence in several track and road events (Table 1, Figure 2,3). Maximum performance increases within one year compared to the reference level ranged between 0.4% and 1.1% in track events up to 1500 m. (Figure 3). For longer running distances, larger maximum yearly performance increases to the reference of up to 3.5% (half-marathon, female athletes) were observed. However, the evidence for the performance effect of advanced footwear technology was more pronounced in female athletes compared to male athletes (Table 1, Figures 2+3) in distances longer than 1500 m. Maximum performance increases in male runners per year ranged between 1.1% and 1.4% for the distance between 10,000 m and the marathon (Figure 3). Figure 2 shows the evolution of the top 100 track and road running performances yearly since 2010.

For female athletes, all three criteria were met in all events except the 200 m, 400 m hurdles, and 800 m (Table 1). For male athletes, all three criteria were met only for the half marathon. However, all but the third criterion was met for the 10,000 m and marathon distances, and the third criterion was only slightly missed (Table 1).

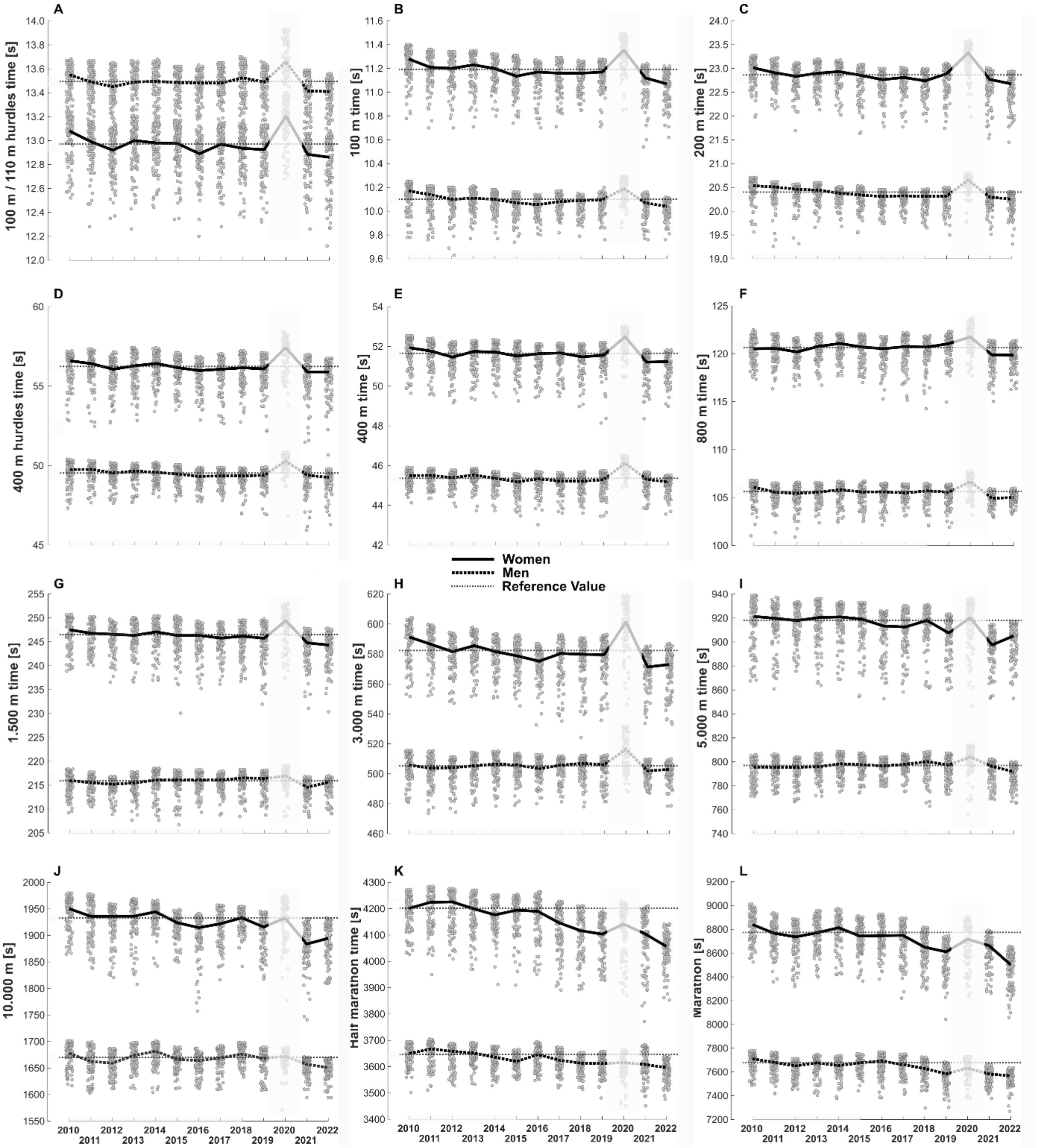

Figure 2: Evolution of the 100 best track and road performances between 2010 and 2022. Thick lines show the evolution of the median of the 100 best performances per year. The dotted horizontal line marks the reference value for each event (separately for men and women). A thicker x-axis for the respective years highlights the observation period per event. The year 2020 was not included in the analysis.

Table 1: Criteria table. A bold style indicates that a criterion has been met.

	first criterion (%)		**second criterion** (i%*)		**third criterion** (best 2 years)	
	Women	**Men**	**Women**	**Men**	**Women**	**Men**
100 m	**0.66**	0.33	**100**	**100**	**2022, 2021**	2022, 2016
100/110 m hurdles	**0.63**	0.41	**100**	67	**2022, 2021**	**2022, 2021**
200 m	0.37	**0.55**	67	**100**	2022, 2018	**2022, 2021**
400 m	**0.63**	0.22	**100**	**100**	**2021, 2022**	2022, 2015
400 m hurdles	0.49	0.38	67	**100**	**2021, 2022**	2022, 2016
800 m	0.31	0.46	67	67	**2022, 2021**	**2021, 2022**
1500 m	**0.66**	0.16	**100**	33	**2022, 2021**	2021, 2012
3000 m steeplechase	**1.33**	0.33	**100**	67	**2021, 2022**	**2021, 2022**
5000 m	**1.63**	0.24	**100**	33	**2021, 2022**	2022, 2012
10000 m	**1.84**	**0.69**	**100**	67	**2021, 2022**	**2022, 2021**
half marathon	**2.05**	**0.84**	**100**	**86**	**2022, 2019**	**2022, 2021**
marathon	**1.45**	**0.73**	**86**	71	**2022, 2019**	**2022, 2021**

*Significance at $p<5.95 \times 10^{-4}$

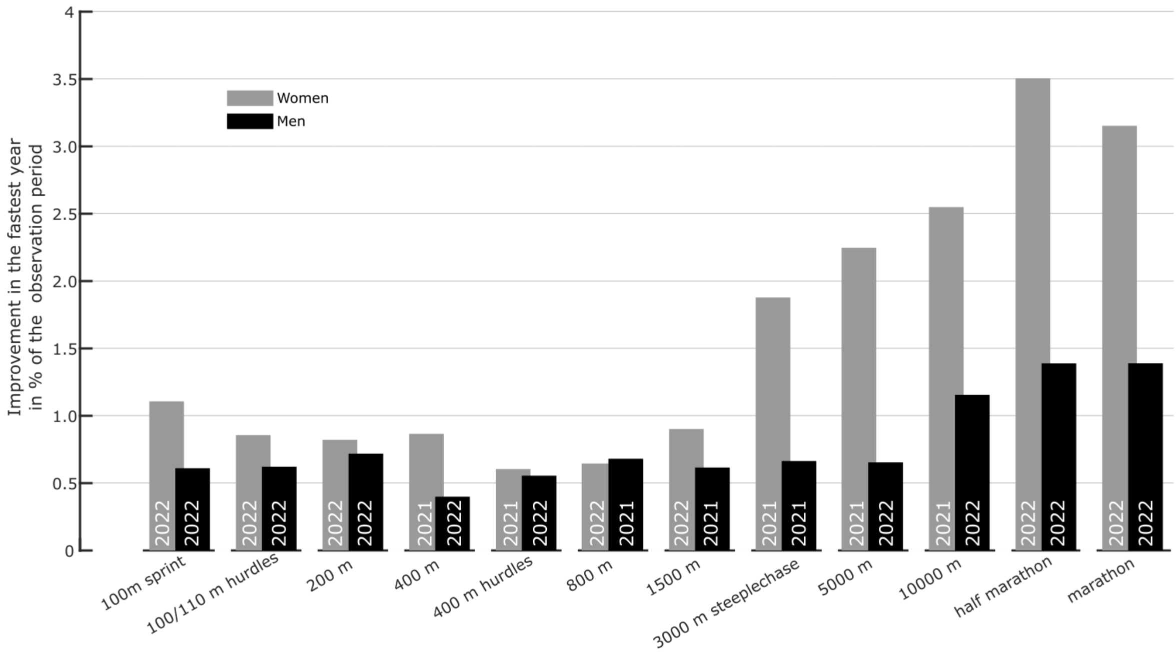

Figure 3: Difference between the performance of the best year in the observation period and the reference value (in %). The best year is highlighted in each bar.

4. Discussion

The present study aimed to explore indirect evidence of potential performance improvements induced by the introduction of super distance running shoes and super spikes from the 100 yearly best race times. The findings suggest evidence of a performance effect of advanced footwear technology in both male and female athletes, but the effect appears to be more pronounced in female athletes. The largest improvements were observed in distances longer than 5000 m for males and longer than 1500 m for females. These findings suggest that our general hypothesis that advanced footwear technology positively affects running performance across the athletic track and road racing events can be accepted. However, this general finding requires a more differentiated analysis.

Our results suggest that the performance effect of advanced footwear technology may be more pronounced in female athletes than in male athletes. The causes of this phenomenon are uncertain, but it may be due to factors such as differences in body weight, competition running speeds, or running biomechanics between men and women. Lower body weight, lower running speed, and increased stride frequency in female runners [18] result in reduced absolute ground reaction force generation, while longer ground contact times, also reported in female runners [18], may increase ground reaction forces. It is currently not well reported whether shoe companies scale the stiffness of the elastic cushioning foams or the bending stiffness of the carbon elements to the mass, speed or sex of runners. However, assuming that this scaling does not occur in most super shoe models, it can be assumed that the specific anthropometrics and biomechanics of female runners appear to benefit more from current super shoe designs. Future studies will need to look more closely at why women might benefit more from advanced footwear technology or if other factors can explain why world-class performances in distance running events have improved more for women than men since the introduction of super running shoes.

Upon analyzing the effects of advanced footwear technology on performance changes, it is evident that the potential improvements are more pronounced for longer track distances compared to sprinting distances (as shown in Figures 2 and 3). Several reasons might explain this observation. Firstly, advanced footwear technology for sprinting have not been available for as long as those for distance running. Consequently, they may have been less widely distributed among the world-class sprinting community. Athletes may not have been as familiar with this new technology as distance runners who have been using advanced footwear technology longer. Secondly, incorporating softer and more elastic materials into the forefoot of sprint shoes may not lead to performance-enhancing effects to the same extent as in distance running shoes. This might be because sprinting requires generating large and well-directed forces to the ground during short ground contact times [19,20]. This force application might be affected by introducing foam materials to the forefoot. There is a lack of systematic investigation into how different forefoot foam properties and geometries interact with (carbon fibre) stiffening elements and how this interaction contributes to performance in sprint events. Finally, the recent introduction of super sprint spikes and the lack of biomechanical studies on their mechanisms of potential performance enhancement suggest that these shoes may still evolve in their functional design, and larger performance improvements enabled by this technology may be possible in the future.

While our study provides indirect evidence for the performance effect of advanced footwear technology, several limitations need to be considered. Firstly, the study is observational and does not account for other factors that may have influenced performance improvements, such as changes in the use of performance-enhancing drugs (PEDs), training methods, or recovery effects due to the Covid-19 pandemic. Secondly, we did not check whether advanced footwear technology was actually worn in the 100 best performances; therefore, it is uncertain whether advanced footwear technology actually affected performance in all races during the observation period. This uncertainty may have led to an underestimation of the observed performance effects. Thirdly, the criteria used to identify potential performance improvements are arbitrary, even though we based them on the distribution of actually relevant performance differences (criterion 1), statistical differences (criterion 2) and overall performance improvement (criterion 3). Future studies should provide a more direct evidence basis for potential performance enhancements due to advanced footwear technology by performing experiments that allow for deriving direct cause-effect relationships.

Regarding PED use, there is evidence that reduced testing during the COVID-19 pandemic may have made it easier for athletes to use PEDs without being detected. This lack of testing could have contributed to performance improvements in 2021 and 2022 [21–23]. In addition, world-class athletes may have generally relied more heavily on using PEDs in the observation compared to the baseline period. This behaviour would undermine our assumption that the performance gains in the observation period were primarily due to improved footwear technology. New developments in PED testing and their potential retrospective application to the periods considered in this study may better address this issue in the future.

In theory, performance improvements could have been achieved through improved training methods, which could have resulted from, e.g., a broader application of scientific knowledge in training practice. Improvements might relate to improving running economy, training intensity, recovery, or load management in general. Whether these factors have influenced our analysis cannot be determined from the information available. One aspect often mentioned anecdotally by runners is that the soft cushioning of super-distance running shoes may affect muscle damage and, therefore, recovery times. To the best of the authors' knowledge, the hypothesis that softer cushioning would affect recovery times and therefore allow for higher training volumes or intensities has not been tested but is an interesting aspect to explore in the future.

In conclusion, our study provides indirect evidence for the performance-enhancing effects of super distance running shoes and super spikes, which appear to be more pronounced in female athletes and at longer running distances. However, several limitations need to be considered, including the study's observational nature, the potential influence of PEDs, and the uncertain impact of other factors such as training methods and recovery effects. Future studies should aim to address these limitations and provide a more direct basis for the potential performance enhancements due to advanced footwear technology. Nevertheless, our findings have important implications for the design and use of advanced footwear technology in competitive distance running, particularly concerning sex differences in footwear design. It seems crucial for manufacturers, coaches, and athletes to consider the specific anthropometrics and biomechanics of runners when designing and selecting advanced footwear technology and to continue to monitor the effects of new footwear technologies on athletic training and performance.

Declarations

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Conflict of interest / Competing interests

Some of the work of the group of Prof. Willwacher is financially supported by Adidas AG, a manufacturer of “Advanced footwear technology”. However, this particular study was not related to those projects.

Availability of data and material

All extracted information can be found in the figures and tables. The raw data of the study is provided as an online digital supplementary.

Authors' contributions

SW and PM devised the study. PM, JR, BU, JH and MH performed the data extraction. JH, PM and SW created figures and tables. JR performed the statistical analyses. All authors contributed to the manuscript, with SW and JR contributing to the largest extent.

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Ethical approval information
Not applicable

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