



Ten questions in sports engineering: supershoe use in distance running

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Abstract

Footwear used in competitive distance running has remained relatively unchanged in nature for decades. However, such technology has recently generated controversy with the introduction of so-called ‘supershoes’. Such footwear appear both aesthetically and functionally different to those used prior to their introduction and their arrival coincided with a spate of distance running world records being broken. The ten questions presented in this paper address a series of issues that relate to supershoes. These include their definition, what level of performance enhancement they provide and what impact they have had in competitive sport. Furthermore, it is explored how such technology is regulated and whether it should be considered fair. Via these questions, we hope to inform readers towards a greater understanding of this form of sports technology and highlight research and engineering gaps for future work.

Keywords Running · Supershoes · Marathon

1 Introduction

The design of footwear used for competitive distance running has remained relatively unchanged for decades yet has recently seen substantial levels of innovation. Much of this has been attributed to extensive changes in sole design. This progression is often credited to Nike circa 2016 but similar concepts were also allegedly undertaken by Fila two decades earlier [1]. Either way, many of the recent performances in competitive distance running have been partly attributed to footwear utilising novel approaches to sports engineering [2, 3].

In 2016, several medallists of the Olympic Games Marathon were reportedly wearing a prototype shoe that utilised a curved carbon fibre plate within a high-energy return sole [4, 5]. It was then reported in 2018 that a prototype running shoe potentially possessed the performance capabilities to assist a runner to achieve the first sub 2 h marathon [6]. This proposal was then realised in 2019 when Kenyan Eliud Kipchoge wore such shoes and became the first person to complete the marathon running distance in under 2 h as

part of the Ineos 1:59 Challenge project [7]. In 2018 alone, runners wearing supershoes broke world records in the 100-km, marathon, half marathon and 15-km running distances [8]. This rapid spate of records then resulted in controversy regarding the running shoes that were worn for them. Today, many running brands now offer a supershoe design and their widespread use has generated much debate over their form, function and purpose.

The ten questions presented in this paper define these shoes (Question 1), explores how such technology is regulated (Question 2) as well as addressing specific questions on the level of their performance enhancement, the factors behind this, their impact on the sport and whether they are fundamentally fair (Questions 3–9). Finally the limitations of our current understanding of the technology and where their future lies is explored (Question 10). For the purposes of this paper, the colloquial term ‘supershoe’ [9] is used as a blanket term to cover the advanced running shoe designs discussed in this paper.

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2 Question 1: what are supershoes and how do they differ from traditional distance running footwear?

Answer: Supershoes comprise a unique aesthetic and sole design that differs from traditional running footwear. The sole of supershoes does not typically rely on a single material alone and utilise a range of composite, foam, and rubber components working together symbiotically. The shoes key differences could be summarised as a sole comprising a stiffness moderator [9], a compliant midsole material capable of returning a high magnitude of energy [10], a rocker shaped midsole of substantial thickness [9], and the subsequent shoe being low in mass [11].

The thickness of the sole or its heel in particular is typically both larger and unusually shaped compared to more traditional shoe designs and this region is synonymously referred to as ‘stack height’ [12]. They can also possess an exaggerated rocker-like shape of their sole. Internally the soles possessed a combination of composite plates and rubber or foam sections. This often utilises midsole materials, such as polyamide block elastomer (known by its tradename as ‘Pebax’) [10]. Pebax is typically lighter and more efficient in its energy storage and return than traditional sole foam materials, such as ethylene vinyl acetate (EVA) or thermoplastic polyurethane [8]. The level of energy return with a Pebax sole has been reported to be as high as 87%, whereas traditional distance running shoes were only cited in the range of 65–75% [3].

Other brands have sought alternative design solutions to generate performance enhancement or possibly to avoid any intellectual property rights that may exist. For example, Adidas have differed themselves from other brands like Nike by utilising composite infused rods in the soles within one of their supershoe designs [9]. Either way, given the relative infancy of these running shoes, they will likely continue to evolve in terms of both their form and function.

3 Question 2: are there rules and regulations for distance running shoes?

Answer: It should be noted that prior to introduction of supershoes, few rules were in place to regulate athletic footwear design. However, after several distance running records were broken and the subsequent controversy emerged, World Athletics created a set of rules for running footwear design in 2020 [3] and revised them in 2022 [13]. These are designated the Athletic Shoe Regulations,

C2.1A [13]. These new rules regulate shoe design by limiting by sole stack height to 40 mm as well as requiring the shoes to be available on the open market before they could be used in competition [3]. The former rule would limit the space available to maximise the aspects such as energy return or effective leg length. The latter rule would subsequently prevent the use of prototypes or one-off custom designs. The rules state that shoes must be available for purchase by any athlete. However, this is arguably contradicted whereby the rules also allow the use of ‘development shoes’ for a 12 month period or customised footwear provided they are approved by the governing body in advance. Whilst the current legislation will maintain the shoes dimensional envelope, the current full lack of understanding into how such shoes function means that it is not known at this time how effective the existing legislature will be at limiting performance enhancement in the future.

4 Question 3: how do supershoes work?

Answer: There are limited studies to date that have attempted to explain specifically how supershoes function in a mechanical sense. Instead, many recent studies have mainly focused on the resulting ergogenic effects they provide. Other difficulties in explaining the supershoes function are that their cited improvements in an athletes *running economy* cannot currently be explained from a biomechanical standpoint [14]. Running economy in these cases is generally defined as a measure of steady-state oxygen consumption per unit body mass at various submaximal running speeds [12] and has been used as a key performance metric of supershoes [3].

Of the evidence that does exist regarding supershoe function, their distinctly thick midsole was cited as the most important aspect that contributed to the improved performance of running footwear [8]. However, this has been either disputed [15], likely had a beneficial maximum limit [16] or was stated as being complicated to reliably measure due to uncontrollable variables [17]. As an aside, it should also be noted that the increased shoe stack height caused by the midsole thickness increases the runners’ effective leg length [3] which may also provide biomechanical benefits to the athlete. Furthermore, there has been some speculation towards what has been termed the “teeter-totter” effect [18]. This effect is proposed to passively enhance the propulsive stance of the runner [19]. This has been described as being when the ground reaction force travels forwards during the end of the runners stance phase, the rocker axis acts as a fulcrum and a heel upwards direction force is created during the push-off phase, thereby reducing the muscle force required at the ankle plantar flexors [19].

An alternative approach to ascertaining a supershoes function has been to evaluate their individual features or components. First, the use of a carbon fibre footplate had been speculated to create a positive performance enhancing spring-like effect [20]. Furthermore, supershoe longitudinal bending stiffness has also been cited as a major contributor to their functionality. However, when this characteristic was experimentally investigated, through medially cutting the carbon fibre plate within a supershoe, it was found to have minimal impact on the runners' performance [21]. However this might be partially explained that whilst the longitudinal bending stiffness of footwear can improve running economy, it can only do so when matched to an individual's running characteristics such as speed, body mass and strike pattern [22]. Caution has been advised when considering any of the shoes individual component benefits when assessing them in isolation from each other [20]. This is because it is claimed that a symbiotic interaction exists between all of the shoes components that then form the basis of the shoes performance enhancing effects [22].

5 Question 4: what level of performance enhancement has been proposed with the use of such shoes?

Answer: There have been multiple studies that have attempted to quantify the magnitude of supershoe performance enhancement when under scientific conditions. A review of the existing literature unequivocally summarised that supershoes are performance enhancing [3] with several studies typically focusing on significant improvements in running economy and/or lower time trial completion times as the basis for this argument. However the specific values of these have differed from study to study, vary based on the test protocol utilised or the targeted running velocity [23] and whether the shoes are normalised for their mass or not [24]. The seminal studies and their proposed investigation of supershoe performance enhancement are summarised in Table 1.

A fuller review of supershoe performance enhancement was also summarised in a systematic review performed in 2022 [24]. Whilst all of these studies have been performed under controlled conditions, they should not be viewed as directly comparable due to different participants and test conditions. However, these studies broadly complement other methods of analysis that propose that supershoe use has shown an increase in running velocity of circa 3.4% when running at marathon world record pace [37].

6 Question 5: does everyone obtain the same effect or improvement?

Answer: Whilst the key performance indicators of long distance running are well reported, each athlete will possess their own unique anatomical, musculoskeletal and biomechanical differences. Coupled with this, the selected footwear construction and running style can influence the timing and magnitude of footwear-based energy storage and return during running [38]. As a result, due to the unique different mass, step frequency, velocity and any prior familiarisation of the footwear by a runner, it is unlikely that supershoes would provide the same level of performance to all types of users. This hypothesis has been borne out in testing [29] with some runners experiencing no improvements in running economy yet others showing an increase of up to 6.4% [32].

This apparent lack of agreement between studies regarding the level of performance enhancement may reflect the different abilities of participants used within them [29]. What does seem to be evident is a large emphasis in studies to date placed upon well-trained male runners. There has been scant attention to date regarding recreational runners, females or a broad spectrum of age groups who could all arguably make up a large proportion of the commercial market of such shoes.

7 Question 6: could the gains in race performance be due to a placebo effect?

Answer: The placebo effect is a constant concern for the scientific community when evaluating one form of sports technology against another. Indeed, the placebo effect has been demonstrated to be a concern with sports footwear and is challenging to remove entirely [39]. It could be assumed that part of the difficulty in this case is that the extra stack height or aesthetic differences of supershoes are quite obvious when compared to traditional designs.

Whilst the use of supershoes has demonstrated an unequivocal performance enhancement to date, it has been acknowledged in multiple studies that some level of a placebo effect is likely to exist [40] and could not be ruled out [32]. However, many studies that compare supershoes cannot easily utilise safeguards such as double blinding to prevent placebo when the shape, colour or response could signal a shoes identity. Safeguards such as blinding in this context have been stated as being impossible to implement [38] although attempted to be overcome by using methods such as spraying all test shoes black [29, 30]. As a result, this effect could also be contributing to some of

Table 1 Summary of performance enhancement

Paper	Supershoe utilised	Comparison shoe #1	Comparison shoe #2	Participant demographic	Methods	Notable Performance enhancement
Barnes and Kilding 2019 [25]	Nike Vaporfly	Adidas Adizero Adios 3	Nike Zoom Matumbo 3	12 male, 12 female runners	Fixed duration treadmill tests	Supershoe obtained 4.2% improvement in running economy compared to Adidas shoe and 2.6% to track spike
Castellanos-Salamanca et al. 2023 [26]	Nike ZoomX Vaporfly Next % 2	'Traditional running shoe'	n/a	12 male well-trained runners	Jump tests and track-based time trials	Supershoe took 2.4% less time to complete 1 km time trials
Dinato et al. 2021 [27]	Adidas Energy Boost	Nike Free Run 2	n/a	11 male recreational runners	Fixed distance/duration treadmill and track tests	Supershoe obtained 2.4% improvement in running economy
Healey and Hoogkamer 2022 [21]	Nike Vaporfly 4%	Nike Vaporfly 4% (modified)	n/a	15 male well-trained runners	Steady state, fixed velocity treadmill-based tests. Runway use	Medial cuts made to carbon plate but no significant differences found in running economy between same supershoe design
Hébert-Losier et al. 2020 [28]	Nike Vaporfly 4%	Saucony Endorphin racing flats	Participants own shoes	18 male recreational runners	Time trial-based treadmill tests	1–1.6% lower oxygen consumption of supershoe to racing flats. Supershoe took 1.8% less time to complete 3 km time trials vs racing flats
Hébert-Losier et al. 2022 [29]	Nike Vaporfly 4%	Saucony Endorphin racing flats	Participants own shoes	18 male recreational runners	Time trial-based treadmill tests	Appears to be same dataset and results as their 2020 study
Hébert-Losier et al. 2022 [30]	Nike Vaporfly 4%	Saucony Endorphin racing flats	Participants own shoes	16 male well-trained runners	Time trial-based treadmill tests	Biomechanical/kinematic differences exhibited between footwear
Hoogkamer et al. 2018 [6]	Nike Zoom Vaporfly prototype	Adidas Adizero Adios Boost 2	Nike Zoom Streak 6	18 male well-trained runners	Mechanical testing and treadmill tests	Vaporfly exhibited 4% lower metabolic costs
Hoogkamer et al. 2019 [31],	Nike Zoom Vaporfly prototype	Adidas Adizero Adios Boost 2	Nike Zoom Streak 6	10 male well-trained runners	Treadmill-based tests	The metabolic savings of the Vaporfly shoes were superior and attributed to its sole design
Hunter et al. 2019 [32]	Nike Vaporfly 4%	Adidas Adios Boost	Nike Zoom Streak	19 male runners	Steady state, fixed velocity treadmill-based tests	Vaporfly running economy improvement by 2.8% over Adidas shoe and 1.9% to Zoom Streaks

Table 1 (continued)

Paper	Supershoe utilised	Comparison shoe #1	Comparison shoe #2	Participant demographic	Methods	Notable Performance enhancement
Joubert and Jones 2022 [33]	7 different types of carbon plate-based supershoes			12 male well-trained runners	Time trial-based treadmill tests	Significant differences in oxygen uptake between supershoe models
Joubert et al. 2023 [23]	Nike ZoomX Vaporfly Next % 2	Asics Hyperspeed racing flat	n/a	8 male and 8 female well-trained runners	Steady state, fixed velocity treadmill-based tests	Supershoe possessed 0.9–1.4% improvement in running economy
Martinez et al. 2024 [34]	Nike Vaporfly Next % 2	Nike Pegasus 38	n/a	18 female competitive runners	Steady state, fixed velocity treadmill-based tests	Supershoe possessed 3.9% improvement in running economy and 4.2% less metabolic power
Paradisis et al. 2023 [35]	Saucony Endorphin Speed 2	Saucony Cohesion 13	n/a	5 male and 5 female students	Steady state, fixed velocity treadmill-based tests	Supershoe saw a 3.9–5% reduction in oxygen consumption
Ruiz-Alias et al. 2023 [11]	Nike ZoomX Vaporfly Next % 2	Nike ZoomX Dragonfly track spikes	n/a	14 'highly trained' runners	Two short duration time trials	Supershoe was only significantly faster (by 0.97%) in 3 min time trial but had positive impact on biomechanics
Rodrigo-Carranza et al. 2023 [36]	Four different types of supershoe prototypes	unknown brand		22 male well trained runners	Mechanical tests and treadmill-based tests	Highlighted the varying rate of degradation of supershoe soles

the aforementioned reported variability of the supershoes ergogenic effects.

8 Question 7: is there any evidence that supershoes have impacted on competitive distance running?

Answer: There are a small number of studies to date that have investigated how supershoes have societally impacted on the sport of distance running. In an observational study, it was calculated that any use of supershoes from 2015 to 2019 yielded a gain of 2–3.9 min and a time improvement of 1.4–2.8% in the men’s marathon or a 0.8–3.5 min gain and a time improvement of 0.6–2.2% in the women’s events [42]. The introduction of this technology was also detected to be mainly from 2017 onwards. However, the magnitude of this change was higher in female than in male elite athletes and was most pronounced in the marathon rather than the shorter racing distances [43]. Furthermore, a male world record holder was anecdotally described to have improved his personal best by 2.7% over the marathon distance in 4 years since transitioning to supershoe use [3]. However, all such data should be viewed with some caution due to any emergence of exceptional athletes, the impact of the global COVID-19 pandemic and any societal changes in training practise that may have also occurred during this time.

9 Question 8: what issues are caused in competitive sport by allowing the use of advanced technology such as these shoes?

Answer: Whilst there are proposed marked performance advantages to an individual runner, some case studies of controversial sports technologies in the past have negatively affected the integrity of a sport [44]. It was then suggested that fewer people could participate in sport due to not being able to access or afford some forms of sports technology or could be coerced to use them solely on the basis to remain competitive [44]. This situation has already occurred with supershoes when an elite athlete broke their sponsorship contract with one brand to then race in another brands supershoe instead [3]. The inclusion of such technology can also cause other unknown indirect or secondary ‘revenge effects’. This effect is described as consequences or events that are not always known when a new technology is initially introduced but can become evident over time [45]. This could be aspects such as declining participation, increased injury rates or increasing costs to competitors.

There is also the issue of the supershoes effective life in service. It has been anecdotally speculated in online media

that the effective lifespan of a supershoe may only be circa 160 km of running. If true this would be considerably less than the reported use of traditional sole materials like EVA that have been shown to diminish in performance significantly after circa 500 km of running mileage [46]. More specifically, it was recently proposed that supershoes that utilised Pebax soles saw a faster degradation in running economy than those that were EVA based. After 450 km of use, the Pebax and EVA shoes in this study actually both possessed similar running economy [36]. This demonstrates that the effective lifespan of supershoes is noticeably less than that of traditional distance running footwear. This would mean athletes would dispose and replace their footwear with an increased frequency. This would not only create concerns surrounding increasing costs in the sport but would also create increasing environmental waste issues which could be seen as causing harm to the sports integrity. Such a situation was recently highlighted when Adidas were publicly criticised with the introduction of the Adios Pro Evo 1 supershoe for its single use intent [47].

10 Question 9: are such shoe designs fundamentally fair?

Answer: Whilst the broad scope of sports technology fairness has been reviewed and summarised [44], most supershoe studies to date have generally focused any discussion of their fairness with the concept of *universality*. In this case, this has meant the ability for any participant to access the same technology as their competitors [8, 47]. This ethos of requiring equal access is accounted for within the aforementioned World Athletics rules and is therefore mitigated for to some degree. However, the concept of universality and access were not the only reported concerns regarding the fairness of supershoes [37]. In this case, such concerns also included those surrounding *high product cost* and *technological coercion* as well. However, whilst it was deemed that supershoes could be seen as fundamentally unfair, this was judged on balance to be a short term concern but would require ongoing vigilance by the sports stakeholders.

Either way, the concept of ‘fairness’ is complicated due to the nature of it being relative to the individual considering it and/or the context of the technology that is being evaluated [44]. In other words, what one person considers fair or appropriate may not be the same as another and both could be considered right and wrong or ethically appropriate or inappropriate depending on how such viewpoints are obtained or measured [44]. Either way, the number of studies that have attempted to address whether such footwear is fundamentally fair are scant in number at this time and are subjective or interpretative in their conclusions.

11 Question 10: which areas in supershoe design have been identified as areas for improvement or investigation in the future?

Answer: Whilst supershoe research has seen increasing attention since 2019, the peer reviewed research to date has maintained that there remains a lack of understanding of both the biomechanical advantages [14] and the functional mechanisms of supershoes [41]. Furthermore, it is conceded that our understanding of how the shoes should be tailored to the body mass, step frequency and running technique of an individual runner is also at a point of relative infancy. Such interests have already been investigated in other products such as composite lower-limb running prosthesis [48] so it is feasible that this could also occur with supershoe footwear too.

Most of the studies to date have also only focused on well-trained male distance runners. As a result, there is seemingly a need to better understand the performance and running behaviour in a wider range of user groups. A more thorough understanding of this would potentially affect the design and prescription of commercially available products and see further optimisation in supershoe design.

Finally, there is possibly a need to develop more complex tools, sensors and simulation technologies for the purposes of investigating supershoes. Not only would these provide further insight into this field of study but it may also begin to address the current lack of full understanding of the shoes likely biomechanical advantages, their function and to minimise the impact of placebo effects when evaluating said technology. Such tools may well prove useful when it has been indicated that some studies that have evaluated supershoes to date have relied upon a single trial evaluation of running economy which has generated concerns over the lack of statistical power created [49].

12 Discussion

Our understanding of supershoe technology and the engineering required to optimise them is still in a state of relative infancy so it is conceded that the answers offered in this paper are far from conclusive. We still don't fully understand the underlying mechanisms of supershoes [41]. Furthermore, there is limited evidence that other brands have struggled to achieve the same level of performance that Nike's shoes in particular were credited with until at least 2022 [33]. Both of these points infer the lack of knowledge that currently exists. Most of the scientific literature to date has also mainly centred on Nike brand

supershoes which could provide a certain degree of bias due to any limitations based upon their own design ethos or commercial decisions. However, the type and level of performance enhancement in the future may well be different as other brands continue to develop their own innovations. Ultimately, distance running shoe engineering is in a rapid state of change and the sport now sees a metaphorical 'arms race' that has been witnessed in several other sports before [44]. The impact of this technology has also started to inform other applications too. For example, the use of a carbon fibre plate has recently been replicated in military boots and this too improved the propulsive force and subsequent velocity of the wearer [50].

Many of the studies to date have been focussed on results from single trials. Given the inherent variability of working with human participants, a degree of uncertainty regarding their familiarisation of supershoe technology and the unknown repeatability of the measurement techniques being employed, there are legitimate questions as to the exact magnitude of the performance claims being made. This all said, future work should now progress beyond investigating whether such shoes are generally advantageous or not and instead move to understand specifically on optimising such technology for the broadest range of end users in terms of their ability, age and gender. This would have three potential benefits. The first would be to maximise performance of the shoe technology to the widest possible range of users. The second is that this may help address the reported variability of performance enhancement that such shoes provide [28]. The third is that there could be indirect benefits when using such technology such as improved safety or injury reduction. For example it was proposed that the advantages of this shoe technology may also be that they could reduce post-exercise muscle fatigue [26]. As a result, supershoes could not only be a tool to run faster but could also be a means to safely increase the total training volume. This could then enhance the athletes training adaptations without increasing their risk of injury with the net result then being further improvements in their athletic performances.

Ultimately, supershoes may well be a controversial form of sports technology but one that has been legislated for and will therefore seemingly remain part of an effective distance runners' performance in the future.

13 Conclusion

The footwear utilised for competitive distance running continues to develop and have an impact in its competitive performances. The engineering required for their optimisation is far from investigated nor understood. However, it is hoped that this paper has provided readers some insight into the understanding of them so far and has highlighted areas

of exploration for them in the future. There are a range of paths of inquiry that can be addressed as well as the ongoing assessment of new running footwear innovations. Our interest in this matter will not only maximise what is possible by athletes but alternatively will provide knowledge and guidance as to what should be considered fair and appropriate to its stakeholders.

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