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Super shoes: How super are they?

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Abstract. This paper examines the effect of carbon plated "super shoes" on the performance of elite male marathoners. Prototypes of these carbon plated shoes with extraordinary cushioning were used beginning in 2016, and became widely available in 2017. In order to quantify the effect of these shoes on elite athletes, we analyzed data on the number of athletes who ran a marathon in under 2 : 08 : 00 each year from 1985 through 2021. A multiple linear regression model was constructed that controlled for the non-"super shoe" related upward time trend in the number of sub-2 : 08 times, utilizing a Cochrane-Orcutt transformation to correct for autocorrelation. This model shows that this new shoe technology is responsible for an additional roughly 24 additional sub-2 : 08 times per year. Estimated from this, we find a shoe-related time reduction of 1 minute and 31 seconds, or a 1.174% decrease in time.

Keywords: Super shoes, carbon plated shoes, marathons, elite male marathoners

1. Introduction

Although the marathon was popularized with the advent of the Olympic Games in 1896, the term's roots come from ancient Greece. At the "Battle of Marathon," around 490 B.C., the famous courier Pheidippides ran a great distance between cities, from Marathon to Athens, to relay information about the Greek victory in battle. Reportedly, the trip took several days to make, and upon delivering his message Pheidippides collapsed and died. It's estimated that he traveled over 600 km in order to reach his destination (Chung). This is only legend, though: in reality, the distance was 40 km. The modern marathon is nowhere near as extreme as the legend, covering a distance of a mere 42.195 km, or 26.2 miles for us Americans. Because of the Olympic Games' inherent relationship with Greece, the organizers saw it fit to name the long-distance race after Pheidippides' achievement in ancient times.

In modern times, the marathon is not limited to only the Olympic games. There are competitive marathons held in locations such as Boston, Berlin, and London, as well as many more marathon events held throughout the year. The running boom of the 1970 s led to the number of marathons being run in the United States alone to increase dramatically, by a factor of five between 1970 and 1975 (Chung, 2010). Naturally, we expect the athletes running these to get faster and faster, as training and technology improves around them.

In 2016, new carbon-plated shoe technology was released to the public, dubbed as "super shoes" due to the controversy surrounding their high-energy transfer, light weight, and potential to increase the performance of a runner by a large margin. For instance, in the Rio Olympics of 2016, all three medalists had worn a version of these super shoes (Herbert-Losier & Pamment, 2022), although they did not become widely used until 2017. Although the super shoes have had a significant impact on races of all distances, this paper strives to quantify the effect of these supershoes on elite men's marathon race times, as these data were the most readily available over the longest time period.

In the remainder of this paper, we will begin by reviewing the literature relevant to the "supershoe" phenomenon. Next, we will construct a model that will quantify the effect of these shoes in two ways:

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first, by estimating the number of sub-2 : 08 marathon times these shoes are responsible for annually and, second, by estimating the time savings imparted to these sub-2 : 08 marathoners. We conclude by discussing the implications and areas for future research related to these shoes.

2. Literature review

Long distance running is a fairly well researched sport at many levels. An especially relevant area of the long distance running research is related to running economy (RE). This is one of the more important metrics for measuring an athlete's ability. Don Morgan, Philip Martin and Krahenbul define RE to be the steady state VO_2 (volume of oxygen consumed per kg) for a given running velocity (1989). In short, RE is a measure of how an athlete's much oxygen a human requires to maintain a continuous, constant strain. In their same article, Morgan et al. found that the required energy during a steady state RE test is a function of fitness status (1989). In the case of this paper, the discussion focuses on male elite marathon runners; we expect them to have extremely high running economy.

Morgan et al. describe some of the factors that can change an athletes RE, and the effects it had on their research. Age is one such factor; they found that younger children are less economical than older children, and adults are more economical than both; however, after a certain age RE begins to reverse, and the older adults/elderly have worse economy than young children (1989). Elite marathon runners to be on the older side when compared to typical athletes, with an average age of around 28 or 29 years old (Hunter, Stevens, Magennis, Skelton, and Fauth, 2011). Another factor for RE is temperature. Morgan et al. found that changes in temperature can change the performance of a runner; hyperthermic conditions tend to increase performance, while hypothermic conditions decrease performance. However, there is a limit to this factor: go too hot, and there are more adverse effects on the athlete's body (1989). Many of the fast times of elite marathon runners are run in conditions from about 40 degrees Fahrenheit to 50 degrees Fahrenheit. That said, Scheer et. al (2021) found that male marathon world records have been set at a surprisingly high average temperature of roughly 65 degrees Fahrenheit.

There is a defined relationship between RE and running kinetics, also called running mechanics. One such factor in this relationship is ground reaction forces, which is a measure of how hard an athlete's foot is able to hit the ground and leave (Clark, Ryan, and Weyand, 2017). RE is also related to where the foot contacts the ground. This reflects an athlete's mechanical power, and the work the body is able to produce while under the strain of running (Morgan et al., 1989).

This notion of ground reaction forces leads into the paper published by Kim Hébert-Lossier and Milly Pamment in 2022, which discusses the effects modern super shoes have on the RE and performance of a runner. They define super shoes to have a stiff and curved carbon-fiber plate combined with lightweight, high-energy returning foam. This results in a shoe that is significantly more comfortable to run in when compared to other lightweight shoes, as well as easier (due to the energy returned by the shoe's special construction). They found that the Nike Vaporfly returns 87% of the mechanical energy spent while an athlete runs; comparatively, two normal running shoes, the Adidas Adios Boost 2 and Nike Zoom Streak 6 had an energy return of 75.9% and 65.5%. This is due to the stiffness of the carbon plate located in the Vaporfly, and the light weight of the foam, which reduces the loss of mechanical energy near the ankle joints (Hébert-Lossier & Pamment, 2022).

Such energy return should have an effect on the RE of an athlete. Improved running economy is already linked to great performances in long distance races; the Nike Vaporfly shoes are shown to increase an athlete's running economy by about 2%, on average, for elite runners; in recreational runners, the increase in running economy can be as high as 13.3% (Hébert-Lossier & Pamment, 2022). An important note to make is that these effects are not identical in every single athlete. Due to differences in body structures, there will be some variance in whether or not RE and performance will increase from use of the super shoes in a given athlete. Hébert-Lossier and Pamment (2022) make this point in outlining this in their paper, describing how it can give athletes who respond positively to the shoes an unfair advantage.

To date, most of the research on the effects of these "super shoes" on elite athletes has been conducted in a laboratory setting. For example, Joubert and Jones (2022) compared the running economy of several carbon plated shoes by having athletes complete time trials in a laboratory setting. Similarly, Whiting, Hoogkamer, and Kram (2022) examined how these shoes affected the metabolic cost of running at various levels of incline. Hunter et al. (2019) quantified the energetic savings of such shoes by having athletes complete time trials, in carbon plated shoes as well as two standard racing flats. They found that oxygen consumption in the carbon plated shoes was between 1.9% and 2.8% lower than in the two types of traditional shoes.

In the forthcoming section, we take the "super shoe" effect out of the laboratory, and attempt to quantify the effect it has had in real-world elite male marathoning.

3. Methodology and results

In order to assess the effect of these shoes within the realm elite men's marathoning, we will use linear regression analysis. The number of sub-2 : 08 marathon times during a given calendar year is used as the dependent variable.. Naturally, the year the races were run was treated as an independent variable. This is because marathon times have been trending downward over the decades, and we need to control for this inherent trend. The "super shoe effect" was ascertained by using a dummy variable. This is because we hypothesize that the shoes will act like the step in a step function: before 2017, super shoes are yet to exist, so the dummy variable is given a value of 0. During and after 2017, the shoes were released to the public and the dummy variable is given a value of 1. This makes it possible to isolate a "super shoe effect," if one exists. Specifically, we hypothesize that:

$$\mathbf{H_0} : \mathrm{B}_1 = 0$$

$$\mathbf{H_1} : \mathrm{B}_1 \neq 0,$$

Where B_1 is the slope of the super shoe dummy variable in our regression model. Note that we will test this hypothesis at the 0.05 level of significance.

However, a first run of this analysis exhibited the presence of autocorrelated errors, as evidenced by a Durbin-Watson statistic value of 1.159. This is not surprising due to the time series nature of the data. We pause to note that the value of the super shoe dummy variable's slope estimate was 27.776, which is statistically significant. That said, any interpretation of this model would be flawed due to the aforementioned autocorrelation issue.

We then used Cochrane-Orcutt estimation (Cochrane and Orcutt, 1949) to correct for the autocorrelated errors. This technique is an example of a Feasible Generalized Least Squares estimation (FLGS). This technique was used to adjust the values of the year and number of sub-2 : 08 times variables. The values of the super shoe dummy variable (0 or 1), were not adjusted, since this variable is, as noted previously, simply acts to introduce a step function.

A new linear regression was then run on the now transformed data set. This time, there was no evidence of autocorrelated errors (Durbin-Watson statistic = 2.091). We can also seen in the results that multicollinearity is not an issue (all variance inflation factors are well below 2). The results of this regression are presented in Figs. 1 and 2 below.

The most important thing to note in these results is that the super shoe effect is statistically significant (see Fig. 2), as the slope of the super shoe dummy variable B_1 is 23.534. The *p*-value for the test that slope is equal to 0 is 0.002. Therefore, the null hypothesis of no super shoe effect can be rejected. Furthermore, we can see from the R^2 value of 0.746 (see Fig. 1) that this model explains nearly three-fourths of the variability in elite male marathon times.

The coefficient of the super shoe variable, seen in Fig. 2, predicts that there will be an average of roughly 23 new sub 2 : 08 : 00 marathoners per year due to the shoes, and holding any other underlying time trends constant.

R	R^2	$Adjusted\ R^2$	$Coefficients\ Std.Error$	$Durbin-Watson$
.864	.746	.730	10.75853	2.091

Fig. 1. Model summary.

$Model$	$Unstandardized\ B$	$Coefficients\ Std.Error$	t	sig	$Collinearity\ Tolerance$	$Statistics\ VIF$
$(Constant)$	-2398.868	431.254	-5.563	<.001	-	-
$Year$	2.561	.458	5.589	<.001	.684	1.462
$SuperShoe$	23.534	6.911	3.406	.002	.684	1.462

Fig. 2. Coefficient results.

This slope estimate can be used to calculate the average super shoe "time effect." To calculate this effect, we find the slowest sub – 2 : 08 : 00 marathon ran on the world rankings for each year in our data set, and find the 23rd place below that (since the estimated effect is roughly 23 new sub-2 : 08 times per year). We call the average of all these times M_1. We found M_1 to be 2 : 09 : 31. Then, we take the average of all the slowest sub – 2 : 08 : 00 marathon times, and call this M_2. If there are no marathon times below the set standard of 2 : 08 : 00, we then use the fastest time from that year. We found M_2 to be 2 : 08 : 00. The super shoe time effect is then estimated to be the difference: $M_1 - M_2$. This value comes out to be 00 : 01 : 31, or a one minute and thirty-one seconds. Comparing this to the slowest sub – 2 : 08 : 00 marathon shows the super shoe effect as a 1.174% decrease in time for elite men's marathon races.

4. Conclusions

Overall, our results show that there is a statistically significant "super shoe" effect from that occurred upon the release of the shoes in 2017 (p-value = 0.005). Specifically, our model predicts an additional 23.53 new sub 2 : 08 : 00 marathoners per year due to the "super shoe" effect. As noted in the previous section, this corresponds to a time reduction of 1 : 31, or 1.174%. These results clearly have implications for elite distance runners. Even in marathons, a matter of seconds can cost (or earn) an elite runner tens of thousands of dollars. Therefore, the estimated "super shoe effect" of 1 : 31 is highly practically significant. This effect can clearly be the difference between winning and losing in any reasonably close elite marathon.

Comparing these results to the laboratory work done by laboratory researchers such as Hunter, et al. (2019), the effect we found seems to be a bit smaller than expected (1.174% vs 1.9–2.8%). That said, this difference may not be as large as it appears, since Hunter et al. measured the reduction in Oxygen consumption, while we measured the reduction in race times, and these two performance metrics are not identical.

There are, however, some limitations to this research. To start, this research does not explore how the super shoes effect an individual runner's performance. We showed how super shoes can increase the performance on a large scale, across a group of runners, and only in one distance race for one sex. One area for future research would be to see if similar results are seen in the women's marathon, as well as how other distances, such as the 5k or 10k. Related to this, performance improvements in road 5k and 10k races could be compared to track performances at these same distances. This could help to compare the effects of "super shoes" and "super spikes." A final area for future research would be to consider the performance of an individual brands. While this type of comparison has been conducted in laboratory settings (Joubert and Jones, 2022), it would be interesting to extend the approach presented in this paper to compare the different brands in actual elite marathons.

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