

Evidence of variable performance responses to the Nike 4% shoe: Definitely not a game-changer for all recreational runners

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Abstract

Purpose: We compared running economy (RE) and 3-km time-trial (TT) performances of male recreational runners wearing the Nike Vaporfly 4% (NIKE), lightweight racing flats (FLAT), and their habitual footwear (OWN). **Methods:** Eighteen male recreational runners [age: 33.5 (11.9) y, VO_{2peak} : 55.8 (4.4) mL·kg⁻¹·min⁻¹] attended 4 sessions ~7 days apart. The first session consisted of a VO_{2peak} test to inform subsequent RE speeds set at 60, 70, and 80% of the speed eliciting VO_{2peak} . In subsequent sessions, treadmill RE and 3-km TT were assessed in the three footwear in a randomised, counterbalanced crossover design. **Results:** RE was improved in NIKE (3.6 to 4.5%, $p \leq 0.002$) and FLAT (2.4 to 4.0%, $p \leq 0.042$) versus OWN across intensities, with a *trivial* difference between NIKE and FLAT (1.0 to 1.6%, $p \geq 0.325$). NIKE 3-km TT (11:07.6 ± 0:56.6 mm:ss) was superior to OWN by 16.6 s (2.4%, $p = 0.005$) and FLAT by 13.0 s (1.8%, $p = 0.032$), with similar times between OWN and FLAT (0.5%, $p = 0.747$). Only 29% of runners were more economical across intensities *and* faster in NIKE. **Conclusions:** Overall, our findings indicate that NIKE could benefit RE in male recreational runners at relative speeds when compared to OWN, but not when compared to FLAT. More runners exhibited better TT performances in NIKE (61%) versus FLAT (22%) and OWN (17%). The high variability in individual RE (-3.1 to 12.1%) and TT (-3.8 to 8.2%) shoe-responses suggests that individualisation of running footwear prescription is warranted.

Keywords (five)

footwear, individual responses, minimalist, physiology, running.

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1. INTRODUCTION

Running economy (RE) defines the rate of oxygen consumption when running at a given submaximal speed and is a key measure linked with distance running performance [1, 2]. RE varies considerably between individuals [3] and is influenced by multiple variables, including metabolic, cardiorespiratory, biomechanical, and neuromuscular efficiency [1, 2]. Although maximal aerobic power (VO_{2peak}) and fractional utilisation of VO_{2peak} are also considered key factors in distance running performance [3], runners with superior RE at a similar VO_{2peak} and lactate threshold (i.e., estimate of fractional utilisation) generally outperform their peers [3]. Given the direct link between RE and performance [4, 5], acute changes in RE via footwear interventions has become an active area of research [6, 7].

Until recently, shoe mass was one of the few footwear characteristics consistently linked with meaningful improvements in RE and time-trial (TT) performance [8, 9, 4]. The energetic cost of running has been shown to increase ~0.7 to 1% for each 100 g of added mass per shoe [4, 8], explaining why certain elite runners prefer racing in lightweight racing flats. In May 2017, the Breaking2 Nike Inc. sponsored event introduced the Nike Vaporfly Elite. These prototype shoes were lighter than equivalent marathon racing shoes; had a midsole composed of a novel compliant and resilient ZoomX foam from polyether block amide (PEBA) promoted to enhance energy return; and a carbon fibre panel embedded in the midsole stipulated to promote longitudinal bending stiffness [10, 7, 6]. Although Eliud Kipchoge was not successful at running the marathon distance under two hours during Breaking2, he subsequently ran a 2:01:39 World Record marathon time in Berlin wearing Nike footwear. In October 2019, he was successful in running the marathon distance under two hours (i.e., 1:59:40) as part of the INEOS 1:59 Challenge wearing a pair of 'unreleased' Nike shoes. That same weekend, Brigid Kosgei broke Paula Radcliffe's Women World Record marathon time in Chicago in 2:14.04 wearing the next generation of the Vaporfly. Although there are several other factors involved in racing performance to consider, these monumental achievements have sparked debate in the running community regarding the 'fairness' of the Vaporfly [11] and whether their use constitute 'technology doping'.

Nike-sponsored [7] and Nike-independent [6, 10] experiments have confirmed RE improvements under laboratory conditions in high-calibre runners (sub 32:00 men and 35:30 women 10 km) wearing Nike Vaporfly 4% mechanistically driven by the elastic properties and energy return from midsole compression [12]. Using public race reports and big data from Strava, Quealy and Katz [13] have corroborated improvements in runners wearing the now commercially-available Nike Vaporfly in both faster and slower runners. Their analyses indicate that runners wearing Nike Vaporfly 4% or Next% run 4 to 5% faster and have a 73% chance of setting a personal best compared to wearing other popular running shoes (i.e., their habitual footwear) [13]. However, it is debatable whether such a comparison is fair given that most recreational runners wear shoes that are ~100 g heavier, the analysis feeds into the 'fairness' debate of the Vaporfly shoes [11] both at the elite and recreational level. In addition, since previous studies have not blinded participants to footwear, it is unsure whether any 'placebo effect' is contributing to the reported benefits of the Vaporfly [13, 4, 6], or whether the improvements stem solely from their material and lightweight characteristics.

For a given percent improvement in RE; Kipp et al. [5] predict slightly greater percent improvements at running velocities slower than $\sim 3 \text{ m}\cdot\text{s}^{-1}$, and slightly lower percent improvements at faster velocities given the non-linear relationship between oxygen uptake and running velocity. Accordingly, recreational runners might reap greater benefits than elite from wearing Nike Vaporfly, although laboratory-based data from recreational runners are not available. Hence, our aims were to compare running economy (RE) at relative running speeds and 3-km time-trial (TT) performances of male recreational runners wearing the commercially available Nike Vaporfly 4% (NIKE), lightweight racing flats (FLAT), and their habitual footwear (OWN).

2. METHODS

2.1 Participants

Based on published data [10], a sample of 17 runners was required to detect 0.25 effect size improvements in RE between footwear conditions with an 80% power ($\beta = 0.20$) and 5% significance level ($\alpha = 0.05$). According to test-retest reliability data [14] and one-sample comparison of means, a sample of 18 runners was required to detect meaningful improvements in treadmill TT performance with an 80% power and 5% significance level.

Accordingly, 18 male recreational runners [mean (standard deviation) age: 33.5 (11.9) y, height: 1.79 (5.4) m, mass: 76.5 (8.4) kg, $\text{VO}_{2\text{peak}}$: 55.8 (4.4) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, and recent 5-km time 21:18.61 (1:58.22)] completed the experimental protocol as part of this randomised crossover study. Two researchers characterised the footstrike patterns of individuals [15] as rearfoot ($n = 14$) or non-rearfoot (mid/forefoot, $n = 4$) from 2D video recordings (50 Hz) at 70% of the speed found to elicit $\text{VO}_{2\text{peak}}$. Runners were recruited through personal contacts, running clubs, social media, newsletter postings, and word-of-mouth. Inclusion criteria were male runners with a 5-km run time of ~ 20 to 25 minutes within the 3 months prior to testing, and with a men US shoe size of 8.5 to 12. Runners with current or recent (< 3 months) injuries or elite runners were excluded. All participants provided written informed consent prior to participation, and were informed of the potential injury risk of running in novel footwear. The study protocol was approved by our institution's Human Research Ethics Committee [HREC(Health)2018#81] and abided to the ethical standards of the Declaration of Helsinki.

2.1 Experimental protocol

The effect of footwear on RE and TT treadmill performance was assessed using a randomised counterbalanced experimental design that required participants to attend four laboratory sessions (**Fig. 1**). The first session was designed to collect baseline measures, establish $\text{VO}_{2\text{peak}}$, ensure proper shoe fit, and familiarise runners to running in the Nike Vaporfly 4% (NIKE) and the lightweight racing flat (FLAT) Saucony Endorphin Racer 2 road racing shoe. The two experimental shoes were spray-painted black to blind individuals to their make and model (**Fig. 1**) and reduce potential for placebo,[4, 6] adding ~ 2 g to each shoe. In the second, third, and fourth sessions, RE at 60, 70, and 80% of the speed eliciting $\text{VO}_{2\text{peak}}$ ($v\text{VO}_{2\text{peak}}$) and 3-km TT performance were assessed in one of three footwear conditions allocated in a randomised counterbalanced

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manner: NIKE, FLAT, and habitual (OWN). A minimum of four and maximum of seven days separated each session. Participants were asked to replicate their nutrition and training patterns prior to each session, which was monitored using a self-reported log. All tests were performed in a temperature-controlled laboratory, with temperatures ranging from 18 to 20 °C and relative humidity from 55 to 60%.



Fig. 1 Experimental study design (top) and experimental footwear (bottom) pre and post being spray-painted black. ↔, randomised; FLAT, Saucony Endorphin Racer 2 racing flats; NIKE, Nike Vaporfly; OWN, habitual shoes; RE, running economy; TT, time trial; VAS, visual analogue scale; $v\dot{V}O_{2peak}$, speed that elicited $\dot{V}O_{2peak}$

2.1.1 Visit 2

Baseline information, anthropometric characteristics, and the make and model of participants' OWN shoes were recorded in visit 1. Participants then trialed the two experimental shoes to ensure proper fit, walking and jogging around the laboratory. Immediate shoe comfort and experience in the three footwear conditions (NIKE, FLAT, and OWN) were recorded using a visual analogue scale (VAS) based on work by Lindorfer et al. [16] The corresponding anchor points for the two scales were '0 = Not comfortable at all – 10

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= Maximal comfort' and '0 = No experience at all (beginner) – 10 = Extensive experience (expert)'. The degree of minimalism of shoes were assessed using a minimalist index [17]. Shoe-related characteristics are presented in **Table 1**.

Table 1 Shoe characteristics, comfort, and experience. Data are mean (standard deviation)

Characteristics	OWN	NIKE	FLAT
Mass (g)	313 (44) ^{N,F}	211 (12) ^{O,F}	153 (8) ^{O,N}
Stack height (mm)	26.0 (7.9) ^F	31.0 (0) ^F	13 (0) ^{O,N}
Heel-to-toe drop (mm)	9.4 (6.7) ^F	7.0 (0) ^F	1.0 (0) ^{O,N}
Minimalist index (%)	35 (16) ^F	48 (0) ^F	88 (0) ^{O,N}
VAS comfort (0 – 100)	79 (12) ^F	65 (30)	48 (28) ^O
VAS experience (0 – 100)	87 (13) ^{N,F}	29 (34) ^O	25 (28) ^O

Notes. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. VAS, visual analogue scale. Data from right shoes only (size: US 8.5 to 12). ^{F,N,O} Significant difference during post-hoc comparisons ($p < 0.05$) vs FLAT, NIKE, and OWN, respectively

Participants subsequently completed a 4-minute warm-up at 10 km·h⁻¹ running with their own shoes on a motorised treadmill (Steelflex PT10 Fitness, Steelflex Fitness, Taipei, Taiwan) prior to completing a VO_{2peak} ramp test using an incremental speed protocol and 1% incline to assess maximal aerobic power [18]. The test started at 10 km·h⁻¹ and increased 1 km·h⁻¹ per minute until volitional exhaustion. The mean vVO_{2peak} was 18.4 (1.0) km·h⁻¹. After a 10-minute rest, participants ran 2 x 3 minutes at a self-selected speed on the treadmill once in NIKE and once in FLAT for shoe familiarisation.

2.1.2 Visits 2, 3, and 4

RE and 3-km TT performance in NIKE, FLAT, and OWN were assessed in visits 2, 3, and 4 in a randomised order using a 1% incline. Participants ran 2 minute on the treadmill at a self-selected speed as warm-up and completed 3 x 3-minute bouts: one at 60% [11.0 (0.6) km·h⁻¹], 70% [12.9 (0.7) km·h⁻¹], and 80% [14.7 (0.8) km·h⁻¹] of vVO_{2peak}. At the completion of each bout, participants rested 1 minute during which time ratings of perceived exertion (RPE) using a 6 – 20 Borg [19] scale and blood lactate concentration [La] levels from capillary fingertip samples using a Lactate-Pro 2 analyzer (Arkray Inc., Kyoto, Japan) were collected. Throughout the 3-minute bouts, heart rate (HR, Polar RS800CX, Kempele, Finland) was recorded at 15-s intervals and expired gases were continuously measured using a calibrated metabolic cart (True One 2400, Parvo Medics, Salt Lake City, Utah, USA) to determine oxygen uptake (VO₂) and respiratory exchange ratio (RER). The two highest consecutive 15-s VO₂ readings registered in the last minute of each bout were averaged to determine RE (mL·kg⁻¹·min⁻¹). Following the last bout, participants rated their perceived shoe comfort on the comfort VAS and rested 5 minutes before the TT.

The starting speed for the blinded 3-km TT was set at 90% of vVO_{2peak} [16.4 (0.9) km·h⁻¹]. Prior to the start, participants were reminded to run the 3-km TT as fast as they could and provide a maximal effort. Participants were familiarised with the starting speed, speed increases, and speed decreases used during the

TT ($\pm 0.5 \text{ km}\cdot\text{h}^{-1}$) for 1 minute in total. Runners were blinded to their elapsed time and speed during the TT [14]. Participants rested 1 minute following familiarisation and then started the TT.

During the TT, participants verbally communicated 'up' or 'down' when they wanted corresponding $0.5 \text{ km}\cdot\text{h}^{-1}$ increases or decreases in treadmill speed. During the TT, the researcher verbally communicated the covered distance to participants in 400 m increments to 2400 m, and 100 m increments during the last 400 m. The researcher provided no other verbal communication or encouragement. At TT completion, RPE was collected and a perceived shoe performance VAS was obtained to examine whether participants perceived the shoes had aided their performance. The corresponding anchor points were '0 = No help in performance – 10 = Maximal help in performance'.

2.3 Statistics

Descriptive statistics are reported as mean (standard deviation) unless stated otherwise. Data were analysed using repeated measures analyses of variance (RM ANOVA) and covariance (RM ANCOVA). Identity was the between-subjects error term and footwear (NIKE, FLAT, OWN) was the repeated-measures term in all analyses. Shoe mass was added in RE and TT data analyses as a covariate to evaluate any potential effect of shoe mass on outcomes. When not significant, the covariate was removed. Tukey's honest significant difference was used in post-hoc pairwise comparisons to determine which shoe-by-shoe comparisons significantly differed. Statistical significance was set at $p \leq 0.05$ in all analyses.

To interpret practical meaningfulness, magnitudes of the standardized effects were calculated using Cohen's d and standard deviations from the three footwear conditions. Cohen's d magnitudes were interpreted using thresholds of 0.2, 0.5, and 0.8 for *small*, *moderate*, and *large* [20]. An absolute effect size of 0.2 was considered the smallest worthwhile effect, with smaller effects considered *trivial*. The effect was deemed unclear if its 95% confidence interval [lower, upper] overlapped the thresholds for small positive and negative effects (i.e., $d \pm 0.2$). To consider individual responses, percentage differences between conditions were computed for each individual. The data from one RE test in the NIKE condition did not save in the software; hence, RE data from NIKE derive from $n = 17$ individuals.

3. RESULTS

3.1 Running economy

Shoe mass had no significant effect on any of the RE variables ($p \geq 0.108$) and was removed as a covariate. Footwear significantly impacted RE across intensities ($p < 0.002$, **Fig. 2**). The RE improvements of 4.4 [1.3, 7.5], 4.5 [2.2, 6.7], and 3.6 [1.4, 5.8]% in NIKE ($p \leq 0.002$) and of 4.0 [1.6, 6.4], 3.0 [0.9, 5.1], and 2.4 [0.8, 3.9]% in FLAT ($p \leq 0.042$) versus OWN were significant and of *small* magnitude (**Table 2**) at the intensities of 60, 70, and 80% of $v\text{VO}_{2\text{peak}}$. The 1.0 [-1.3, 3.4], 1.6 [-1.0, 4.2], 1.5 [-0.9, 3.9]% RE differences between NIKE and FLAT ($p \geq 0.325$) at these intensities were *trivial*.

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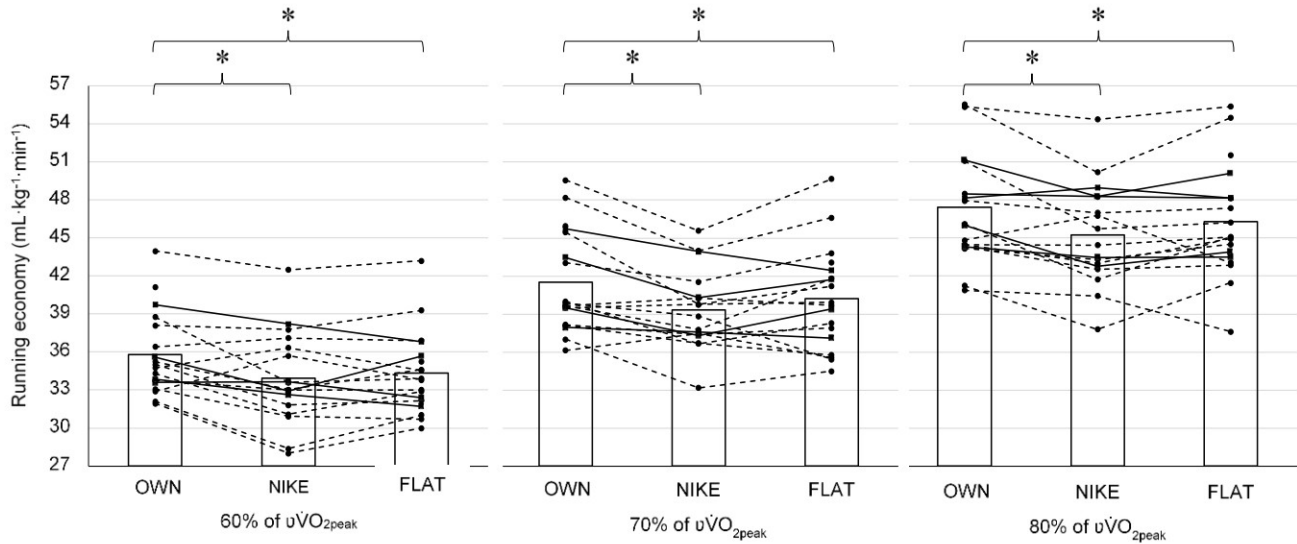


Fig. 2 Running economy ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) at 60%, 70%, and 80% of the speed that elicited $\text{VO}_{2\text{peak}}$ ($v\text{VO}_{2\text{peak}}$). Bar graphs represent mean values, circles joined by dashed lines represent rearfoot runners, and squares joined by black lines represent non-rearfoot runners. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. * $p \leq 0.05$ during post-hoc comparisons when main effect of footwear significant. NB: For NIKE condition, $n = 17$

Table 2 Comparison of all physiological, perceptual, and performance variables from the running economy test (mean [95% CI] and Cohen's d effect size [95% CI]) between footwear conditions from 18 male runners[†]

Variable	Intensity	OWN – NIKE Cohen's d	FLAT – NIKE Cohen's d	OWN – FLAT Cohen's d
Running economy ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	60%	1.6 [0.5, 2.6]* 0.43 [0.13, 0.73], Small	0.4 [-0.4, 1.1] 0.10 [-0.12, 0.31], <i>Trivial</i>	1.5 [0.5, 2.4]* 0.41 [0.15, 0.66], Small
	70%	1.9 [1.0, 2.9]* 0.49 [0.24, 0.74], Small	0.8 [-0.3, 1.8] 0.19 [-0.08, 0.46], <i>Trivial</i>	1.3 [0.4, 2.2]* 0.32 [0.10, 0.55], Small
	80%	1.7 [0.7, 2.8]* 0.38 [0.14, 0.61], Small	0.8 [-0.3, 1.8] 0.16 [-0.07, 0.39], <i>Trivial</i>	1.1 [0.4, 1.9]* 0.25 [0.08, 0.52], Small
Lactate ($\text{mmol}\cdot\text{L}$)	60%	-0.1 [-0.6, 0.5] -0.10 [-0.78, 0.57], <i>Unclear</i>	-0.3 [-0.7, 0.1] -0.38 [-0.91, 0.16], <i>Small</i>	0.2 [-0.2, 0.7] 0.27 [-0.28, 0.83], <i>Unclear</i>
	70%	0.4 [0.1, 0.7]* 0.58 [0.15, 1.01], Moderate	0.2 [-0.1, 0.4] 0.25 [-0.14, 0.65], <i>Small</i>	0.2 [-0.1, 0.5] 0.33 [-0.17, 0.82], <i>Small</i>
	80%	0.7 [0.3, 1.2]* 0.62 [0.22, 1.02], Moderate	0.2 [-0.2, 0.6] 0.16 [-0.15, 0.47], <i>Trivial</i>	0.6 [-0.1, 1.2]* 0.46 [-0.05, 0.98], Small
Heart rate (bpm)	60%	3.8 [-3.3, 10.9] 0.26 [-0.23, 0.75], <i>Unclear</i>	4.6 [-2.2, 11.5] 0.32 [-0.15, 0.79], <i>Small</i>	0.5 [-6.0, 7.0] 0.03 [-0.41, 0.48], <i>Unclear</i>
	70%	4.7 [-0.9, 10.3] 0.34 [-0.06, 0.75], <i>Small</i>	2.0 [-2.2, 6.2] 0.14 [-0.16, 0.45], <i>Trivial</i>	3.3 [-0.4, 7.0] 0.24 [-0.03, 0.51], <i>Small</i>
	80%	1.1 [-2.5, 4.7] 0.08 [-0.18, 0.33], <i>Trivial</i>	-0.1 [-2.5, 2.4] -0.01 [-0.18, 0.17], <i>Trivial</i>	2.2 [-1.9, 6.2] 0.15 [-0.13, 0.44], <i>Trivial</i>
RPE (6 – 20)	60%	0.5 [-0.2, 1.2] 0.32 [-0.11, 0.74], <i>Small</i>	0.3 [-0.4, 1.0] 0.18 [-0.27, 0.62], <i>Unclear</i>	0.2 [-0.3, 0.7] 0.14 [-0.19, 0.47], <i>Trivial</i>
	70%	0.6 [0.04, 1.2] 0.47 [0.03, 0.91], <i>Small</i>	0.3 [-0.2, 0.8] 0.26 [-0.14, 0.65], <i>Small</i>	0.3 [-0.2, 0.8] 0.21 [-0.15, 0.58], <i>Small</i>
	80%	0.8 [0.3, 1.2]* 0.55 [0.22, 0.89], Moderate	1.0 [0.4, 1.6]* 0.71 [0.29, 1.13], Moderate	-0.2 [-0.8, 0.4] -0.16 [-0.59, 0.27], <i>Unclear</i>
VAS comfort (0 – 100)	NA	15.0 [5.9, 24.2]* 0.75 [0.29, 1.22], Moderate	-6.2 [-20.5, 8.2] -0.31 [-1.03, 0.41], <i>Unclear</i>	21.2 [12.3, 30.1]* 1.06 [0.62, 1.51], Large

Notes. [†] For NIKE condition, $n = 17$. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. bpm, beats per minute; CI, confidence interval, NA, not applicable; RPE, rating of perceived exertion. VAS, visual analogue scale. * $p \leq 0.05$ during post-hoc comparisons when main effect of footwear significant. Cohen's d interpreted using thresholds of 0.2, 0.5, and 0.8 for *small*, *moderate*, and *large*, and *trivial* < 0.2.[20] Effect deemed unclear if its 95% CI overlapped the thresholds for small positive (+0.2) and negative (-0.2) effects

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For individual runners, the change in RE across all intensities ranged from -8.6 to 13.3% in NIKE versus OWN; -9.6 to 9.7% in NIKE versus FLAT; and -5.5 to 14.2% in FLAT versus OWN, where a positive percent change indicates improved RE. Of the 17 runners with complete dataset; 8 (47%) were most economical in NIKE, 2 (12%) in FLAT, and 7 (41%) demonstrated inconsistency across intensities. One of the four non-rearfoot strikers (25%) was most economical in NIKE, and the other three (75%) in different footwear across intensities.

Other statistically significant findings from the RE tests (**Table 2 and Table 3**) were lower [LA] in NIKE at 70% $\dot{V}O_{2peak}$, and NIKE and FLAT at 80% $\dot{V}O_{2peak}$ versus OWN of *moderate* and *small* magnitudes; and lower RPE in NIKE versus OWN and FLAT at 80% $\dot{V}O_{2peak}$ of *moderate* magnitudes. Runners perceived their OWN footwear as more comfortable than NIKE and FLAT during the RE test based on VAS ratings.

Table 3 Running economy variables [mean (SD)] from 18 male runners[†]

Variable	Intensity	OWN	NIKE	FLAT	RM ANOVA Footwear (<i>p</i> -value)
Lactate (mmol·L)	60%	2.1 (0.9)	2.2 (0.7)	1.9 (0.6)	0.392
	70%	2.3 (0.8)^N	2.0 (0.5)^O	2.1 (0.6)	0.031
	80%	3.7 (1.3)^{N, F}	2.9 (0.8)^O	3.1 (1.2)^O	0.006
Heart rate (bpm)	60%	132.5 (13.3)	129.4 (14.1)	132.4 (13.8)	0.356
	70%	150.0 (12.4)	145.6 (13.7)	147.1 (12.9)	0.080
	80%	163.8 (12.0)	161.7 (13.9)	161.4 (13.6)	0.312
RPE (6 – 20)	60%	10.3 (1.2)	9.8 (1.6)	10.1 (1.6)	0.264
	70%	12.3 (1.1)	11.7 (1.2)	12.1 (1.4)	0.059
	80%	14.2 (1.0)^N	13.4 (1.3)^{O, F}	14.4 (1.6)^N	0.002
VAS comfort (0 – 100)	NA	75 (15)^{N, F}	60 (22)^O	54 (20)^O	< 0.001

Notes. [†] For NIKE condition, *n* = 17. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. bpm, beats per minute; RM ANOVA, repeated measures analysis of variance; RPE, rating of perceived exertion. VAS, visual analogue scale. ^{F, N, O} Significant difference (*p* ≤ 0.05) vs FLAT, NIKE, and OWN during post-hoc comparisons when main effect of footwear significant, respectively

3.2 Time trial

Shoe mass had no significant effect on any of the TT variables (*p* ≥ 0.190) and was removed as a covariate. Footwear significantly impacted TT performance (*p* = 0.005, **Fig. 3**). Runners ran their 3-km TT with an average speed of 16.3 (1.3) km·h⁻¹ wearing NIKE, 16.0 (1.3) km·h⁻¹ wearing FLAT, and 15.9 (1.3) km·h⁻¹ wearing OWN.

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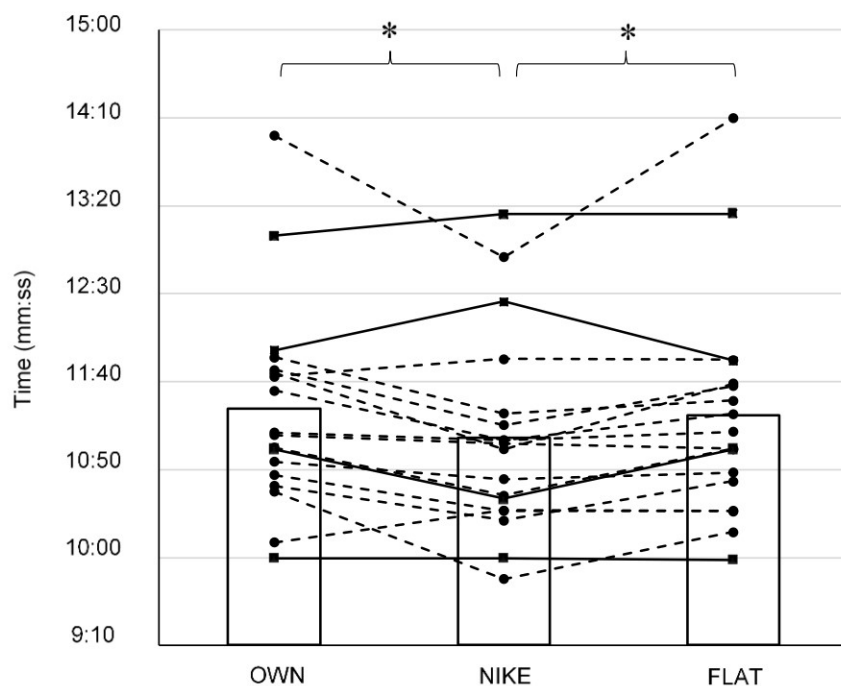


Fig. 3 3-km time-trial time (mm:ss). Bar graphs represent mean values, circles joined by dashed lines represent rearfoot runners, and squares joined by black lines represent non-rearfoot runners. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. *Significant difference ($p \leq 0.05$) during post-hoc comparisons when main effect of footwear significant

The superior TT performance in NIKE of 2.4 [0.6, 4.1]% versus OWN ($p = 0.005$) and of 1.8 [0.3, 3.4]% versus FLAT ($p = 0.032$) were significant and of *small* magnitudes (**Table 4**). Performances were similar between OWN and FLAT (0.5 [-0.3, 1.4]%, $p = 0.747$).

Table 4 Comparison of all physiological, perceptual, and performance variables from the 3-km time trial (mean (SD) and Cohen’s *d* effect size [95% CI]) between footwear conditions from 18 male runners[†]

Variable	OWN – NIKE Cohen’s <i>d</i>	FLAT – NIKE Cohen’s <i>d</i>	OWN – FLAT Cohen’s <i>d</i>
Time (s)	16.6 [4.2, 29.1]* 0.27 [0.07, 0.47], <i>Small</i>	13.0 [1.5, 24.6]* 0.21 [0.02, 0.40], <i>Small</i>	3.6 [-2.3, 9.5] 0.06 [-0.04, 0.15], <i>Trivial</i>
RPE (6 – 20)	0.5 [-0.1, 1.1] 0.36 [-0.05, 0.77], <i>Small</i>	-0.1 [-0.6, 0.5] -0.04 [-.46, 0.38], <i>Unclear</i>	0.6 [0.01, 1.1] 0.40 [0.01, 0.79], <i>Small</i>
VAS performance (0 – 100)	3.8 [-9.2, 16.8] 0.16 [-0.40, 0.72], <i>Unclear</i>	-6.9 [-26.0, 12.1] -0.30 [-1.12, 0.52], <i>Unclear</i>	10.7 [-3.3, 24.8] 0.46 [-0.14, 1.07], <i>Small</i>

Notes. [†] For NIKE condition, $n = 17$. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. CI, confidence interval, RPE, rating of perceived exertion. VAS, visual analogue scale. * $p \leq 0.05$ during post-hoc comparisons when main effect of footwear significant. Cohen’s *d* interpreted using thresholds of 0.2, 0.5, and 0.8 for *small*, *moderate*, and *large*, and *trivial* < 0.2.[20] Effect deemed unclear if its 95% CI overlapped the thresholds for small positive (+0.2) and negative (-0.2) effects

For individual runners, changes in TT performance in NIKE versus OWN ranged from -3.8 to 8.2%, and from -4.7 to 9.3% versus FLAT. Of the 18 runners, 11 (61%) produced their fastest performance in NIKE,

4 (22%) in FLAT, and 3 (17%) in OWN. Two of the four non-rearfoot strikers (50%) performed their best TT in FLAT, with one in NIKE (25%) and one in OWN (25%). There was no significant difference in RPE measures between footwear, and no perceived difference regarding the effect of shoe on performance (**Table 5**).

Table 5 3-km time-trial variables [mean (SD)] from 18 male runners

Variable	OWN	NIKE	FLAT	RM ANOVA Footwear (<i>p</i> -value)
RPE (6 – 20)	18.8 (0.9)	18.3 (1.5)	18.3 (1.5)	0.088
VAS performance (0 – 100)	62 (18)	58 (26)	51 (22)	0.345

Notes. FLAT, Saucony Endorphin Racer 2 road racing flat. NIKE, Nike Vaporfly 4%. OWN, runners own habitual running shoes. RM ANOVA, repeated measures analysis of variance; VAS, visual analogue scale. ^{N, F, O} Significant difference (*p* < 0.05) vs NIKE, FLAT, and OWN when main effect of footwear significant, respectively

Of the 17 runners that presented with complete RE and TT data, 5 exhibited their best RE across intensities *and* TT performance in NIKE (29%). The remaining 12 (71%) performed their best RE across intensities and TT performances in different shoes, which included the four non-rearfoot strikers.

4. DISCUSSION

Our study adds to the body of knowledge on the Nike Vaporfly from an independent laboratory, and is the first to observe that NIKE can benefit RE laboratory-based measures in recreational runners compared to their habitual footwear and at relative (i.e., relative to $v\text{VO}_{2\text{peak}}$) rather than absolute speeds. Despite high individual variability, the commercially available Nike Vaporfly 4% improved RE in recreational runners compared to runners' habitual shoes on average by 4.2%. However, the average 1.4% difference in RE compared to lightweight racing flats was not significant and of *trivial* magnitude. The NIKE benefits extended to the maximal 3-km TT performance compared to the other two footwear, although the TT improvements (2.4%) in NIKE versus OWN were smaller than the corresponding RE ones (4.2%). Only ~60% of runners ran their fastest TT in NIKE, and only ~29% ran more economically *and* faster in NIKE. Responses to footwear did not appear driven by runners' perceptions based on VAS ratings.

Our RE findings mostly agree with previous laboratory-based studies conducted in high-calibre runners showing improved RE in NIKE [10, 7, 6]. Hunter et al. [6] reported 2.8% RE improvements in high-calibre runners wearing NIKE at 16 km·h⁻¹ compared to the Adidas Adios Boost; whereas both Hoogkamer et al. [7] and Barnes and Kilding [10] reported an ~3 to 4% improvement in NIKE at absolute speeds ranging from 14 to 18 km·h⁻¹ after adding lead weights to equalise shoe mass. The variation in the reported percentage RE gains from NIKE between studies are likely of multi-factorial origin, and probably relate to running speed differences [5]; the type of runners and footwear examined [13]; individual responses to footwear; as well as differences in treadmill compliance given that more compliant surfaces can enhance RE [21]. The repeated-measure design of studies somewhat minimise the influence of treadmill compliance however, as individuals act as their own controls. The placebo effect has also been cited as a potential reason for changes in performance with footwear [4, 6], and could contribute to between-study differences in results. Unlike previous

studies, we attempted to minimise the placebo effect by spray-painting our shoes black, and only one runner was able to identify the NIKE shoe at the completion of all experimental trials. Our VAS score analyses relating to perceived shoe experience, immediate shoe comfort, shoe comfort subsequent the RE trials, and perceived impact of shoe on 3-km TT suggest no clear relationship between physiological or performance responses of our participants to footwear conditions, with our runners generally being the most comfortable wearing their OWN shoes, followed by NIKE.

Under mechanical testing with a peak force and contact time similar to running at 18 km·h⁻¹, NIKE has been shown to return 87% of the mechanical energy stored (7.46 J energy return per step) [7]. This greater energy return has been attributed to the greater compliance, rather than resilience, of the NIKE midsole [7]. Although the amount of energy returned from NIKE during running is relatively small compared to that from musculoskeletal structures [22, 23], it is sufficient to diminish the energetic cost of running locomotion. Our data demonstrated that, at the two greatest intensities (70 and 80% of $\dot{V}O_{2peak}$), lactate concentration levels were lower in NIKE than OWN. Accordingly, a shift in lactate accumulation to greater intensities would enable athletes to train or race at a similar speed for a lower metabolic cost, with the potential to improve running endurance performance [24]. Lactate concentrations were also lower in FLAT than OWN at the greatest intensity, indicating a lower metabolic cost in FLAT.

It has been well documented that for every 100 g of added shoe mass, the energetic cost of running increases ~0.7 to 1.0% [4, 25, 8, 26]. In our study, the mean mass of NIKE was 209 g, FLAT was 156 g, and OWN was 313 g. In agreement with the shoe mass – energy cost relationship, there was a 2.0% increase in energy cost for each 100 g of added mass when contrasting FLAT to OWN. On the other hand, considering shoe mass only would mean a 4% increase in energy cost for each 100 g of added mass when comparing NIKE to OWN. Thus, the mass – energy relationship does not fully explain the overall RE advantage observed in the current study, and highlights the positive effects of the NIKE construction on the metabolic cost of running; underpinning the non-significant effect of shoe mass in our analyses.

Frederick et al. [27] were some of the first researchers to address the ‘cost of cushioning’ after noting no change in RE between barefoot and well-cushioned shoes. Subsequent research has confirmed that 10 mm cushioning compared to no cushioning reduced metabolic cost, but that the detrimental effects of shoe mass on energy expenditure counteracted the benefits of cushioning when comparing barefoot to shod treadmill running [26]. When matched for mass and controlling for other footwear features, shoes with a more compliant (i.e., more cushioned) and resilient (i.e., less energy loss) midsole can reduce oxygen cost by ~1% [25]. Similarly, inserting carbon fibre plates to midsoles to increase the longitudinal bending stiffness of running footwear has also been shown to improve RE ~1% [28], although the location of the plate [29], running speed [30], and induced changes in running biomechanics [29, 31] can influence this relationship. The ‘cost of cushioning’ concept and 87% of stored mechanical energy return from the NIKE midsole potentially involve lesser muscular efforts to moderate impacts, which could underpin the 3.6 to 4.5% improvement in RE compared to OWN across running intensities alongside the lighter shoe mass and stiffer midsole, although more mechanistic investigations are required to confirm these assumptions.

Runners from this study also performed better during the 3-km TT in NIKE by 16.6 s (2.4%) and 13.0 s (1.8%) compared to OWN and FLAT. These laboratory-based observations support the reported in-race

improvements observed from Strava marathon and half-marathon data [13]. Hoogkamer et al. [4] found that 3-km TT performance degraded in a predictable fashion based on shoe mass, whereby adding 100 g per shoe negatively impacted performance by 0.78%. Accordingly, TT performance should have been 1.2% and 0.8% better in FLAT and NIKE compared to OWN based on shoe mass alone, which do not reflect the corresponding 3.6 s (0.5%) and 16.6 s (2.4%) changes we observed. The lack of agreement between study findings likely reflects the different calibre of runners (Hoogkamer et al. [4], 10:26.1 (0:55.6) in control footwear; our runners, 11:24.3 (0:58.4) in OWN footwear), the technological benefits of NIKE, [7] differences in the footstrike patterns of cohorts, and the more substantial difference between our runners' OWN and FLAT footwear compared to NIKE (e.g., the observed variability in the minimalist ratings in **Table 1**).

NIKE significantly improved 3-km TT performance compared to FLAT, whereas RE measures were similar between these two footwear conditions. Typically, improvements in RE lead to improved TT performances in a predictable manner [4]. It is possible that the greater difference in shoe characteristics (i.e., shoe drop, stack height, and minimalist index, **Table 1**) between FLAT and OWN compared to NIKE and OWN was more challenging for runners to adapt to at a sustained maximal effort. The lower perceived comfort expressed at baseline in FLAT compared to OWN might have made runners more conservative during the 3-km TT and refrain from requesting speed increments as readily. It is also possible that 3-km TT performance would have improved in FLAT versus OWN had a period of habituation or training in FLAT been provided.

Although our findings overall indicate that NIKE can benefit RE and long distance racing performance in male recreational runners, the non-rearfoot strikers in our study appeared to respond less favourably to NIKE than the rearfoot strikers, as also observed by Hoogkamer et al. [12]. Based on our 3-km TT results, 21 runners per group would be needed to detect a significant difference ($\alpha = 5\%$) in response to footwear between non-rearfoot and rearfoot strikers with 80% power ($\beta = 20\%$). The potential for greater benefits of NIKE in rearfoot strikers might be due to the greater compression of the midsole at the heel region [32] where the amount of ZoomX foam is the greatest, as well as the evidenced – albeit limited – greater vertical loading rates and impact peaks of rearfoot strikers [33]. Research specifically examining responses to NIKE footwear based on footstrike pattern is warranted to elucidate the interaction between footstrike characteristics and the performance enhancing effects of footwear.

Although reliable [14], conducting a TT on a treadmill is one limitation of this study. The TT difference between NIKE and OWN equates to approximately one speed increment difference for the duration of the trial (i.e., 0.5 km·h⁻¹), with non-treadmill TT performances potentially more ecologically valid being not tester-dependent for speed changes. Even though the spray-painting of the shoes minimised the potential for a placebo effect, this method did not completely blind the runner or examiner to footwear worn. Furthermore, running in NIKE compared to other footwear has been shown to influence biomechanics [10, 12, 6], with typical findings of increased stride length, longer flight times, and decreased peak plantar-flexion velocities in NIKE. The RE speeds in this study were slower than those examined previously and in different footwear; hence, investigating the biomechanical adaptation in recreational runners to NIKE could shed light on mechanisms that contribute to improved performance.

5. PRACTICAL APPLICATIONS

Evidence of variable performance responses to the Nike 4% shoe: Definitely not a game-changer for all recreational runners

Our study provides evidence that NIKE can benefit RE and 3-km TT performance and could potentially represent a viable ergogenic aid in recreational running; but only 47% of runners were more economical across intensities in NIKE, only 61% faster in NIKE, and just 29% more economical *and* faster in NIKE. Hence, given the considerable variability between runners and intensities, our data does not support a generalised benefit in recreational runners seeking to improve performance. Certain runners were more economical or performed better in FLAT, whereas no runner was the most economical in their OWN footwear across intensities. Furthermore, one must consider the risks associated with changing biomechanical patterns in uninjured runners [33] and transitioning to novel footwear too quickly [34]. We only recruited male runners because of shoe cost considerations; however, we speculate that recreational female runners would respond similarly given the findings of similar responses to NIKE footwear from elite [10] and Strava [13] cohorts.

6. CONCLUSIONS

We provide evidence that the commercially available Nike Vaporfly can improve RE and effectively enhance performance in *some* male recreational runners using laboratory-based data, particularly when compared to participants' habitual shoes. Lightweight racing flats were also effective in improving RE and enhancing TT performance in some – albeit fewer – runners. When compared with their own footwear, the Nike '4%' benefits may extend to recreational runners, relative submaximal running speeds, and maximal efforts (albeit to a lesser extent).

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Data repository: Data from this study are available at the following link: <https://osf.io/je75y/> [35]

Peer-review note: We have submitted a version of this manuscript to a peer-reviewed journal. We will update this note with the appropriate citation in due course.

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