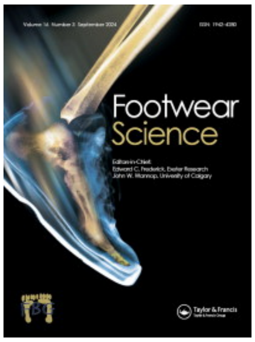

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RESEARCH ARTICLE

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Are super shoes a super placebo? A randomised crossover trial in female recreational runners

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ABSTRACT

We examined the potential placebo effect of advanced footwear technology (AFT) on running economy (RE) and perceptual measures while monitoring biomechanics. Twenty-four female recreational runners completed 4×6-minute RE trials in two pairs of women's Nike ZoomX Vaporfly Next% 2. One pair was described as performance-enhancing super shoes with AFT worn by elite athletes, and the other pair was spray-painted black and described as 'knock-off' AFT shoes. Oxygen consumption (difference: $-0.05 \pm 0.47\,mL\cdot kg^{-1}\cdot min^{-1}$, $d = -0.02$), energy cost (difference: $-0.02 \pm 0.17\,W\cdot kg^{-1}$, $d = -0.03$), and discrete biomechanical variables were not significantly different between conditions. There were no significant differences between shoes in lower-extremity angular and angular velocity curves based on statistical parametric mapping. Overall comfort (100-mm visual analogue scale) was significantly greater (14.6 ± 15.0 mm, $d = 0.94$) in the performance-enhancing than 'knock-off' condition, with most runners (87.5%) preferring the former. Runners perceived running as more enjoyable and less difficult and perceived an improved running performance and lower injury risk in the performance-enhancing shoe ($d = 0.72$–1.16). While no significant physiological or biomechanical differences were observed, a significant placebo effect was apparent for both perceived comfort and perceived performance based on shoe description alone.

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Deception; footwear; perception; physiology; running

Introduction

There is an increasing amount of technology used in the sport, including wearables to monitor training (Toner, 2024), systems to aid with pacing in races (Emig & Adam, 2024), and shoes with advanced footwear technology (AFT) geared at improving performance (Hébert-Losier & Pamment, 2023). Shoes with AFT typically contain a stiff curved plate in the midsole, curved midsole geometry, and high amount of lightweight resilient high-energy returning foam made from materials like polyester block amide (Hébert-Losier & Pamment, 2023). Since their market release in 2016, athletes wearing AFT shoes have broken all World records from the 5 km to the marathon (Muniz-Pardos et al., 2021), with more pronounced progressive improvements in road racing times in females than males and in longer than shorter races (Bermon et al., 2021; Willwacher et al., 2024). It is commonly assumed that shoes play a major role in these records, although several factors cannot be ignored, including constantly improving training techniques and the natural evolution of records.

Running economy (RE) is defined as the oxygen or energy consumption at a given submaximal speed (Barnes & Kilding, 2015) and is a key physiological determinant of running performance. Early laboratory-based research on AFT found RE improved on average by approximately 4% (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019) in both elite and recreational runners. Joubert and Jones (2022) compared seven models of AFT shoes from various brands and found that all of them improved RE on average compared to traditional racing flats in trained male runners; however, only three AFT models improved RE more than 1.5% (Nike Vaporfly 2, Nike AlphaFly, and Asics MetaSpeed). In male and female recreational runners, average RE improvements have been documented at both slower (3.8%) and faster (5.0%) speeds (Paradisis et al., 2023) when wearing a Saucony-branded AFT compared to a more conventional Saucony-branded shoes. These average RE improvements align with those seen in well-trained male amateur runners wearing three different AFT shoe models (3.5–5.0%) (Knopp et al., 2023) compared to racing flats.

Despite the average benefits reported in AFT, inter-individual variability is present with authors reporting detriments in individual RE measures from 0.5 to 13.3% (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Knopp

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et al., 2023) and improvements from 0.08 to 12.6% (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Hunter et al., 2019; Joubert & Jones, 2022; Knopp et al., 2023). Some of this variability may be due to methodological differences (Barrons et al., 2024), but also individual characteristics of runners including their running speed (Hébert-Losier et al., 2022, 2024; Heyde et al., 2022; Joubert et al., 2023; Joubert & Jones, 2022; Knopp et al., 2023; Martinez et al., 2024; Paradisis et al., 2023) and plantarflexion strength (Hoogkamer et al., 2019; Ortega et al., 2021). Runners who increase their step frequencies and decrease their step lengths, vertical pelvis displacement, and lower-extremity joint ranges of motion in stance when wearing AFT shoes appear to respond more favourably in terms of RE metrics (Hébert-Losier et al., 2022). Furthermore, the potential for a placebo effect has been cited as a potential contributor to improved RE in AFT (Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019) and may underpin some of the observed inter-individual variability.

The potential for a placebo effect on RE metrics in runners wearing AFT has not been examined. The placebo effect is a positive outcome deriving from individuals' expectations and/or learned response to a treatment or situation (Beedie et al., 2018). It is linked to the expectancy theory where verbal and social cues are integrated to change a behaviour and/or outcome (Colagiuri et al., 2015). For example, runners' positive beliefs in and expectations of an intervention have been shown to enhance 6-minute time-trial (Valero et al., 2024) and 3-km race (Ross et al., 2015) performances. The placebo effect can also improve the subjective experiences of runners (Ross et al., 2015). Prior research on non-AFT shoes involving deception of runners found significantly greater perceived comfort levels in the same shoes when described as 'the latest shoe model designed to maximise comfort using highly expensive material' than when described as a 'regular running shoe designed for distance running' (Chan et al., 2020). The authors suggested descriptors and price alone can bias shoe comfort ratings.

We aimed to investigate the potential placebo effect of AFT on RE and perceptual measures in female recreational runners while monitoring biomechanics. We hypothesised superior RE and comfort ratings in a shoe described as a 'super shoe' with AFT compared to a 'knock-off' shoe without AFT. A secondary aim was to assess the between-trial reliability of measures.

Materials and methods

Participants

Based on prior work detecting an effect size difference of $d = 0.61$ in RE metrics between the most and least comfortable running shoes (Sinclair et al., 2016), 24 runners were needed to achieve a 5% significance level and 80% power (G*Power 3.1.9.7, difference between two dependent means). To account for 10% of missing data, 26 female recreational runners were recruited after approval from our institutional Human Research Ethics Committee [HREC(HECS)2023#13]. The experimental trial was pre-registered in the Australian New Zealand Trials Registry (ACTRN12623000731695).

We recruited female recreational runners following taxonomy proposed elsewhere (Honert et al., 2020). Eligibility criteria required participants to have been running for more than six months at least once per week, be currently running one to five times a week, and run 5 km in 20 minutes or more. Participants also needed to be comfortable with treadmill running and able to run for 45 minutes. Runners were excluded if they were currently injured or injured within the last month following the consensus definition of running-related injury in recreational runners (Yamato et al., 2015). Runners who did not fit the available experimental shoe sizes (Women US 7.5, 8.5, and 9.5) were also excluded. Participants were recruited through personal contacts, word-of-mouth, running clubs, and social media advertisements.

Experiment

Running economy, biomechanical, and perceptual measures were assessed in two shoe conditions using a randomised and mirrored crossover participant-blinded design that required participants to attend one session at the University of Waikato Adams Centre for High Performance laboratory (Figure 1). Participants were given written and verbal information regarding the study and were made aware of the potential risks associated with participation (those associated with performing physical activities, running, and running in new shoes) before giving informed written consent. Runners were told the study aimed to examine if super shoes improved RE and comfort in the 'everyday' runner compared to a 'knock-off' shoe, and therefore blinded to the fact that both shoes were the same. Baseline measures of height (stadiometer, Seca model 0123), mass (digital scale, Seca model ESE813), and lactate concentrations (Lactate-Pro 2 analyser, Arkray Inc., Kyoto, Japan) were collected to the nearest 0.1 cm, 0.1 kg, and 0.1 $mmol \cdot L^{-1}$, respectively. Runners' own shoes were assessed using the Minimalist Index, which is a valid and reliable rating scale used to determine the degree of 'minimalism' (100%) or 'maximalism' (0%) of running shoes (Esculier et al., 2015).

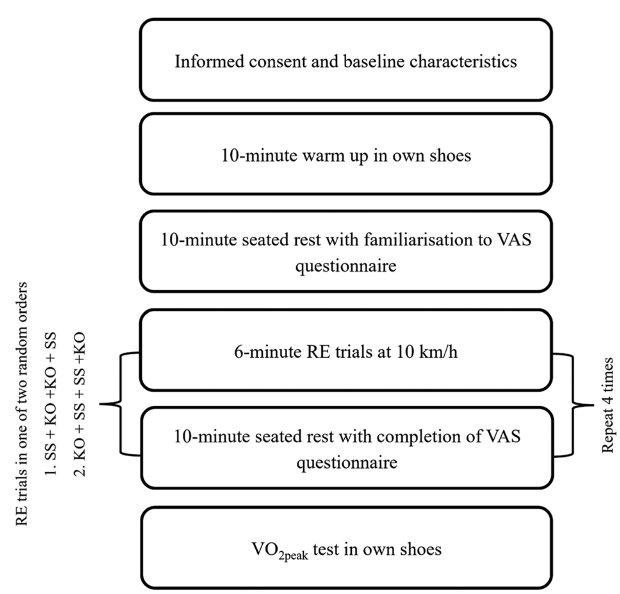

Figure 1. Flow diagram of the experimental protocol. KO: knock-off; RE: running economy; SS: super shoe; VAS: Visual Analogue Scale; VO_{2peak}: peak oxygen uptake.

In the two experimental conditions, the same running shoe model (Women's Nike ZoomX Vaporfly Next% 2) was used (Women US 7.5, mass: 175 g, stack height: 40 mm, heel-to-toe drop: 12 mm, minimalist index: 32%). However, the shoes were described as follows:

- Super shoe (True): This is a super shoe made to maximise performance. The thick cushiony foam is the best on the market at returning energy so running feels easier. There is also a full-length curved carbon-fibre plate that acts like a spring to propel you forward. The shoe is super light and we know from research this is important to save energy when you run. Athletes wearing these super shoes are breaking world records at every distance. The shoe is worth $400 because of all these advanced technologies.
- 'Knock-off' (deception): This is a knock-off of a super shoe. They look almost the same, but they do not have advanced footwear technologies. It is just regular foam and it does not have a carbon fibre plate. Elite athletes would never wear these to race. You can buy a pair of these online for $100. This is our basic control shoe to see how much better the super shoe is.

These descriptions were designed and tested following an iterative process that involved the research team, academics and clinicians outside of the research team, and runners themselves. The more a placebo is appealing to individuals, and individuals believe the intervention is effective, the better (Harris, 2016). Hence, although the descriptions emphasised the shoe features, statements referring to elite athletes and costs were incorporated to better reflect how shoes with AFT are marketed to runners and their perceived value. The same researcher delivered the memorised script verbally to all participants before the first RE trial, emphasising the super shoe features. Before each RE trial, participants were verbally reminded of the shoe condition they were being tested in and the key features (or lack thereof). To ensure participants were unaware the shoes were the same, the 'knock-off' was spray-painted black (Figure 2).

Before the experimental trials, participants completed a 10-minute warm-up at a self-selected speed of up to 10 km·h^{-1} on a motorised treadmill (Steelflex PT10 Fitness, Steelflex Fitness, Taipei, Taiwan) with a 1% incline and a *hard* (350 kN·m^{-1}) treadmill surface (Hardin et al., 2004). After the first five minutes, participants were fitted with the metabolic cart headgear and mouthpiece. Following the warm-up, participants rested for 10-minutes seated on a chair with their shoes removed (Figure 1). During this time, participants were familiarised with the 12-question

Figure 2. Women's Nike ZoomX Vaporfly Next% 2 used for the study. The shoe described as a 'knock-off' was spray-painted black (right photo).

visual analogue scale (VAS) shoe questionnaire that was to be used during experimentation (detailed below).

Thereafter, participants completed four 6-minute RE trials at 10 km·h^{-1} and 1% incline, two in each shoe condition, assigned in a randomised and mirrored sequence (super shoe, 'knock-off', 'knock-off', super shoe for 13 participants or 'knock-off', super shoe, super shoe, 'knock-off' for 11 participants, with 2 participants removed from analysis). This speed was chosen based on the target population of female recreational runners and to ensure participants stayed below their anaerobic threshold. It matches the speed used in previous AFT research involving recreational runners (Joubert et al., 2023). Throughout the 6-minute trials, heart rate (Polar RS800CX, Kempele, Finland) was recorded at 15-second intervals and expired gases were continuously measured via a calibrated metabolic cart (True One 2400, Parvo Medicks, Salt Lake City, UT, USA) to determine oxygen consumption (VO_2) and respiratory exchange ratio (RER). The mean VO_2 (mL·kg^{-1}·min^{-1}) registered in the last two minutes of trials was used as the oxygen consumption measure and to determine energy cost (W·kg^{-1}) using the Péronnet and Massicotte (1991) equation. Data were monitored for RER levels above 1.00, which would indicate a proportion of energy was provided via anaerobic pathways.

Biomechanics data were recorded for 30 seconds from the fifth minute of each RE trial. Lower-body and pelvis kinematics were sampled at 200 Hz using a calibrated 8-camera 3D motion capture system (Oqus 700+ cameras and Qualisys Track Manager Software v.2023.1.7985). Marker positioning was the same as described elsewhere (Hébert-Losier et al., 2022), but included an additional tracking marker placed on the midfoot. The medial femoral epicondyle and malleolus marker positions were marked on participants as these were removed during RE trials. Due to marker repositioning, a 1-second static calibration trial was recorded before each RE trial. Data processing was performed in Visual3D Professional™ (v.2023.08.5, C-Motion Inc., Germantown, Maryland, USA) and MATLAB R2024a (v.24.1.0.2537033, The MathWorks, Inc., Natick, Massachusetts, USA) as described elsewhere (Hébert-Losier et al., 2022). Strides were trimmed to start and end with left foot ground contact. Bilateral hip, knee, and ankle sagittal plane angular displacement (°) and velocity (deg·s^{-1}) curves were extracted for statistical parametric mapping (SPM). The discrete biomechanical measures extracted and averaged across 20 strides (40 steps) from each RE trial were: contact time (ms), flight time (ms), duty factor (%), step frequency (steps·min^{-1}), step length (cm), and vertical pelvis displacement (cm). In addition, inertial measurement units (IMU, Vicon Motion Systems Ltd., Oxford, UK) sampling at 1125 Hz with accelerometer range of ± 16g were secured above the medial malleolus of each leg. A lowpass fourth order Butterworth filter with 100 Hz cut-off frequency was applied to raw signals and resultant tibial accelerations were calculated as $\sqrt{(x^2 + y^2 + z^2)}$ using Visual3D Professional™ (Hébert-Losier et al., 2024). The peak resultant acceleration for each step was extracted and averaged across 20 strides for analysis.

Immediately upon completion of each RE trial, blood lactate concentrations from capillary fingertip samples were collected. Participants then rested seated on a chair for 10 minutes with shoes removed to complete the 12-question VAS questionnaire (Supplemental Material) administered using an Apple iPad (iPad Air 2, MH0W2X/A (15.0)) via the Qualtrics offline survey application (Qualtrics©, Provo, UT (17.1.7)). Participants completed the questionnaire without comments or inputs from the researcher to limit biasing their scores. The same researcher placed and removed the experimental shoes from the feet of participants to limit their interactions with the shoes, but let participants tie their own shoelaces.

The 12-question VAS questionnaire examined subjective perceptions of overall comfort, shoe properties, and overall running experience using 0 to 100 mm scales (Hébert-Losier et al., 2024). Overall comfort VAS endpoints were 'Not comfortable at all' and 'Most comfortable imaginable'. Goldilocks scales were used for shoe properties where the VAS midpoint reflected ideal and included heel cushioning, forefoot cushioning, forefoot flexibility, shoe stability, shoe stiffness, technical and supporting features, and shoe weight (Hébert-Losier et al., 2024). The first four properties were used to derive the Running Shoe Comfort Assessment Tool (RUN-CAT) score, where 100 represents the most ideal and 0 the least ideal shoe (Bishop et al., 2020). Overall running experience included VAS ratings for pleasure/displeasure, easier/harder, performance, and injury risk. Traditional anchor points were used, where higher scores indicate greater pleasure, running feeling easier, greater performance, and lower perceived injury risk.

After the final RE trial, participants ranked their preferred shoe (super shoe or 'knock-off') based on comfort, performance, and injury risk reduction, and an exit interview was conducted (Supplemental Material). The answers were voice recorded and aimed to assess the quality of blinding of participants. Ten minutes after the final RE trial, participants completed a peak oxygen uptake (VO_{2peak}) test in their own shoes following a speed ramp protocol. The starting speed was individually set (6–8 km·h^{-1}) based on lactate and RER values during the RE trials. The speed of the 1% inclined treadmill was increased by 1 km·h^{-1} every minute until volitional cessation. Once the study was complete, all participants were contacted and informed of the deception involved.

Statistical analysis

Descriptive statistics are reported as mean and standard deviation (mean ± SD) unless stated otherwise. Between-trial reliability was examined using a customisable statistical spreadsheet (Hopkins, 2017) and the data from the first and second RE trials completed in each shoe condition. Two-way mixed effects single measurement intraclass correlation coefficient ($ICC_{3,1}$), typical error (TE), and coefficient of variation (CV) with 95% confidence intervals [lower, upper] were calculated to quantify the relative (ICC) and absolute (TE and CV) reliability of physiological, discrete biomechanical, and perceptual measures. Relative reliability was interpreted using the following thresholds: ICC <0.40 *poor*, 0.40 ≤ ICC <0.75 *fair*, 0.75 ≤ ICC <0.90 *good*, and ICC ≥0.90 *excellent* (Rosner, 2006). Absolute reliability was deemed acceptable (CV <10%) or suboptimal (CV ≥10%) based on CV values (Atkinson & Nevill, 1998). Paired *t*-tests were conducted to identify significant systematic between-trial bias.

To statistically compare RE, discrete biomechanical, and perceptual measures between shoe conditions, data from the two RE trials from the separate shoe conditions were averaged. These data were analysed using two-tailed paired *t*-tests. Magnitudes of Cohens *d* for paired samples using an average variance with 95% confidence intervals [lower, upper] were extracted and the effect size (ES) difference interpreted using the following thresholds: <0.20 *trivial*, 0.20 *small*, 0.50 *moderate*, and 0.80 *large* (Lakens, 2013). The SPM time-continuous paired 6D Hotelling's T^2 test was used to compare the ankle, knee, and hip sagittal plane angular displacement and velocity curves between shoe conditions (Pataky et al., 2013). *Post-hoc* Bonferroni corrected SPM *t*-tests were conducted on each curve if the T^2 curve exceeded the critical value at any point in the stride. Analyses were performed using Microsoft® Excel® for Microsoft 365 MSO (v.2407 build 16.0.17830.20056, Redmond, WA, USA) and MATLAB R2024a. Ranking data were analysed using exact binomial probability calculations for hypothesis testing through VassarStats (Lowry, 2023). Statistical significance was set at $p < 0.05$.

Results

Participants

Twenty-six participants were recruited and completed the protocol. However, two participant datasets were above the aforementioned RER threshold and were removed from subsequent analyses. Therefore, data from 24 participants (age: 33.3 ± 8.9 years, height: 166.1 ± 6.1 cm, mass: 63.0 ± 5.4 kg, VO_{2peak}: 45.58 ± 4.17 mL·kg^{-1}·min^{-1}, speed at VO_{2peak}: 15.8 ± 1.3 km·h^{-1}, own shoe minimalist index: 23 ± 7.9%, running frequency: 3.9 ± 1.1 sessions·week^{-1}, running volume: 33.4 ± 17.4 km·week^{-1}) were analysed. The RE speed of 10 km·h^{-1} reflected 64 ± 5% (range: 56–77%) of their VO_{2peak} speed. In the exit interview, two of the 24 participants (8.3%) indicated they believed the shoes were the same. No participant had run in super shoes prior to this study or was involved in shoe testing programmes.

Reliability

There were no significant differences between the two trials run in each shoe across physiological and biomechanical measures, except for RER and lactate where the means were greater for RER and lower for lactate during the second trial (Table 1). Relative reliability was *excellent* for heart rate, oxygen consumption, energetic cost, and all biomechanical measures; *good* for lactate; and *fair* for RER. Absolute reliability was acceptable for all these measures (CV ≤4.6%), except for lactate (CV = 20.8%, Table 1).

There were no significant differences between the two trials run in each shoe across perceptual measures, except for RUN-CAT and technical and supporting features scores where the means were greater during the second trial (Table 2). Relative reliability was *good* for overall comfort, pleasure/displeasure, easier/harder, and performance (ICC ≥0.75), and *fair* for the remaining measures (ICC ≥0.44). Absolute reliability was suboptimal for all measures (CV = 10.1–19.8%), except for RUN-CAT (CV = 9.1%, Table 2). The TE ranged from 5.1 to 10.7 mm.

Table 1. Reliability statistics of physiological and biomechanical measures from the running economy trials of 24 female recreational runners.

	Trials		Statistics			
Measures	1 (raw units)	2 (raw units)	TE (raw units)	CV (%) [95% CI]	ICC [95% CI]	*p*-value
Physiological						
Oxygen consumption (mL·kg^{-1}·min^{-1})	31.11 ± 1.96	31.11 ± 2.2	0.54 [0.45, 0.68]	1.7 [1.4, 2.2]	0.94 [0.89, 0.96]	0.973
Energy cost (W·kg^{-1})	10.98 ± 0.67	11.02 ± 0.72	0.19 [0.16, 0.23]	1.7 [1.4, 2.1]	0.93 [0.88, 0.42]	0.419
RER	0.89 ± 0.04	0.90 ± 0.05	0.03 [0.02, 0.03]	3.0 [2.5, 3.7]	0.64 [0.44, 0.07]	**0.014***
Lactate (mmol·L^{-1})	1.6 ± 1.0	1.3 ± 0.7	0.31 [0.26, 0.39]	20.8 [17.4, 26.1]	0.87 [0.77, 0.71]	**<0.001***
Heart rate (bpm)	148 ± 13	149 ± 13	3.3 [2.7, 4.1]	2.2 [1.8, 2.8]	0.94 [0.9, 11.42]	0.132
Biomechanical						
Contact time (ms)	224 ± 20	225 ± 21	4 [3, 5]	1.8 [1.5, 2.2]	0.96 [0.93, 0.98]	0.936
Flight time (ms)	131 ± 14	132 ± 15	4 [3, 4]	2.7 [2.2, 3.4]	0.95 [0.9, 0.97]	0.666
Duty factor (%)	36.9 ± 4	37.1 ± 4.3	1 [0.8, 1.2]	2.7 [2.2, 3.3]	0.95 [0.91, 0.97]	0.817
Step frequency (step·m^{-1})	169 ± 9	169 ± 9	1 [1, 2]	0.7 [0.6, 0.9]	0.98 [0.97, 0.99]	0.678
Step length (cm)	99 ± 5	100 ± 5	1 [1, 1]	1.2 [1, 1.5]	0.94 [0.9, 0.97]	0.854
Pelvis vertical displacement (cm)	8.7 ± 1.3	8.8 ± 1.3	0.2 [0.2, 0.3]	2.8 [2.3, 3.5]	0.97 [0.94, 0.98]	0.746
IMU tibial resultant acceleration (g)	12.6 ± 2.4	12.7 ± 2.4	0.6 [0.5, 0.7]	4.6 [3.8, 5.7]	0.94 [0.9, 0.97]	0.953

Data are from the first and second trials ran in each shoe ($n = 48$ trials).
Abbreviations: CI: confidence interval; CV: coefficient of variation; ICC: intra-class correlation coefficient; IMU: inertial measurement unit; RER: respiratory exchange ratio; TE: typical error.
*Significant difference ($p < 0.05$) are in bold and between trials based on paired *t*-tests.

Table 2. Reliability statistics of VAS scores from the running economy trials of 24 female recreational runners.

	Trials		Statistics			
VAS measures	1 (Raw units)	2 (Raw units)	TE (Raw units)	CV (%) [95% CI]	ICC [95% CI]	*P*-Value
Overall comfort	60.2 ± 18.4	61.4 ± 18.1	8.7 [7.2, 10.9]	14.3 [11.9, 17.9]	0.78 [0.64, 0.87]	0.527
RUN-CAT	79.2 ± 14.9	84.0 ± 12.9	7.4 [6.2, 9.3]	9.1 [7.6, 11.1]	0.72 [0.56, 0.84]	**0.003***
Heel cushioning[†ʃ]	53.4 ± 16.4	54.5 ± 14.4	8.3 [6.9, 10.3]	15.3 [12.7, 19.2]	0.72 [0.55, 0.83]	0.507
Forefoot cushioning[†ʃ]	49.9 ± 15.3	50.2 ± 12.9	8.4 [7.0, 10.5]	16.8 [14.0, 21.0]	0.65 [0.46, 0.79]	0.888
Forefoot flexibility[†ʃ]	49.1 ± 11.5	48.2 ± 9.6	6.4 [5.3, 8.0]	13.1 [10.9, 16.4]	0.65 [0.45, 0.79]	0.462
Shoe stability[†ʃ]	41.6 ± 13.6	43.3 ± 8.3	7.9 [6.6, 9.9]	18.7 [15.6, 23.4]	0.51 [0.27, 0.69]	0.294
Shoe stiffness[†]	47.2 ± 14.9	49.8 ± 12.2	9.6 [8.0, 12.0]	19.8 [16.5, 24.8]	0.51 [0.27, 0.69]	0.215
Technical and supporting features[†]	50.0 ± 13.2	53.2 ± 12.8	7.6 [6.3, 9.5]	14.7 [12.2, 18.4]	0.67 [0.47, 0.80]	**0.041***
Shoe weight[†]	50.0 ± 7.1	50.8 ± 12.8	5.1 [4.2, 6.4]	10.1 [8.4, 12.7]	0.44 [0.18, 0.64]	0.406
Pleasure/displeasure	58.7 ± 20.7	62.2 ± 21.7	10.7 [8.9, 13.4]	17.7 [14.7, 22.2]	0.75 [0.60, 0.85]	0.123
Easier/harder	58.3 ± 21.1	61.9 ± 21.5	8.7 [7.3, 10.9]	14.5 [12.1, 18.2]	0.84 [0.73, 0.91]	0.051
Performance	61.4 ± 18.8	61.4 ± 19.3	7.6 [6.3, 9.6]	12.4 [10.3, 15.6]	0.85 [0.74, 0.91]	1.000
Injury risk	44.3 ± 15.8	46.4 ± 14.3	8.8 [7.3, 11.1]	19.5 [16.1, 24.5]	0.66 [0.47, 0.80]	0.252

Data are from the first and second trials ran in each shoe.
Note: Unless stated, values were measured on a scale from 0 to 100 mm, where 100 indicates the most ideal.
[†]Values were measured on a scale from 0 to 100, where 50 indicates ideal.
[ʃ]RUN-CAT properties.
*Significant difference ($p < 0.05$) are in bold and for between trials based on paired *t*-tests.
Abbreviations: CI: confidence interval; CV: coefficient of variation; ICC: intra-class correlation; RUN-CAT: running shoe comfort assessment tool; TE: typical error; VAS: Visual Analogue Scale.

Between shoe comparison

Across all physiological and biomechanical measures (Table 3), differences were *trivial* and not significant between super and 'knock-off' shoes (ES range: ±0.11, $p \geq 0.077$). The difference between conditions in oxygen consumption ranged from −1.1 to 1.1%, and in energetic cost from −0.4 to 0.4%. SPM analysis revealed no significant differences in ankle, knee, and hip sagittal plane angular displacement and velocity curves between conditions (Figure 3).

Runners perceived the super shoe as more comfortable overall (*large* ES = 0.94) and felt this shoe increased their running pleasure (*large* ES = 0.87), made running easier (*large* ES = 1.06), increased their running performance (*large* ES = 1.16), and had a lower injury risk than the 'knock-off' shoe (*moderate* ES = 0.72, all $p \leq 0.009$, Table 4). Runners also perceived the super shoe as having too much heel cushioning (*moderate* ES = 0.65), too much forefoot cushioning (*moderate* ES = 0.58), and too many technical and supporting features (*moderate* ES = 0.70) compared to the 'knock-off', which was perceived as having not enough (all $p \leq 0.033$). There were no other significant differences in perceived shoe characteristics between conditions, including the RUN-CAT (Table 4). Most runners ranked the super shoe as their preferred shoe in terms of overall comfort (87.5%), performance (87.5%), and decreased injury risk (79.2%, $p \leq 0.003$, Table 4).

Discussion

To our knowledge, this is the first study to specifically examine the presence of a potential placebo effect of running in AFT shoes on RE and perceptual measures while monitoring biomechanics. Contrary to our hypothesis, there were no significant differences in RE measures between the super shoe

Table 3. Running economy trial physiological and biomechanical measures from 24 female recreational runners.

	SS	KO	Difference (SS − KO)		
Measures	Mean ± SD	Mean ± SD	Mean ± SD	Effect size [95% CI]	*p*-value
Physiological					
Oxygen consumption (mL·kg⁻¹·min⁻¹)	31.09 ± 2.03	31.13 ± 2.11	−0.05 ± 0.47	−0.02 [−0.11, 0.07]	0.642
Energy cost (W·kg⁻¹)	10.99 ± 0.68	11.01 ± 0.70	−0.02 ± 0.17	−0.03 [−0.13, 0.07]	0.540
Lactate (mmol·L⁻¹)	1.5 ± 0.8	1.5 ± 0.9	−0.1 ± 0.3	−0.06 [−0.19, 0.07]	0.335
Heart rate (bpm)	148 ± 13	148 ± 13	0.3 ± 1.5	0.03 [−0.02, 0.07]	0.273
Biomechanical					
Contact time (ms)	226 ± 20	224 ± 21	2 ± 6	0.11 [−0.01, 0.22]	0.077
Flight time (ms)	131 ± 15	132 ± 14	−1 ± 6	−0.09 [−0.25, 0.08]	0.306
Duty factor (%)	36.7 ± 4.2	37.2 ± 4.2	−0.5 ± 1.7	−0.11 [−0.27, 0.06]	0.193
Step frequency (step·m⁻¹)	169 ± 9	169 ± 9	0 ± 1	−0.04 [−0.09, 0.01]	0.078
Step length (cm)	100 ± 5	99 ± 5	0 ± 1	0.06 [−0.01, 0.13]	0.082
Pelvis vertical displacement (cm)	8.8 ± 1.3	8.8 ± 1.3	0 ± 0.2	0.01 [−0.06, 0.08]	0.817
IMU tibial resultant acceleration (g)	12.6 ± 2.4	12.7 ± 2.4	0.0 ± 0.6	0.00 [−0.01, 0.01]	0.718

Data are an average of two trials per shoe condition per participant.
Abbreviations: CI: confidence interval; KO: 'knock-off'; IMU: inertial measurement unit; RER: respiratory exchange ratio; SD: standard deviation; SS: super shoes.
p-Values are for between trial comparisons between conditions based on paired *t*-tests.

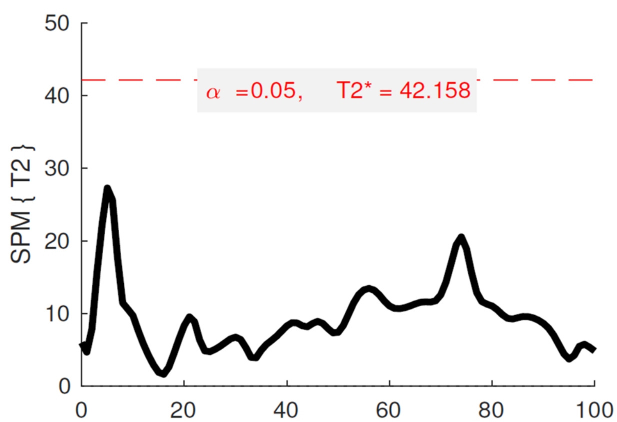

Figure 3. The statistical parametric mapping (SPM) time-continuous paired 6D Hotelling's T^2 test comparing ankle, knee, and hip sagittal plane angular displacement and velocity curves between super shoe and 'knock off' conditions. Horizontal red dashed line is the critical threshold for the SPM 6D paired Hotelling's T2 test.

and 'knock-off' conditions despite significantly greater comfort and performance ratings in super shoes and runners overall preferring this shoe. Furthermore, most runners felt the super shoe made running easier. However, these more positive perceptions did not translate into improved RE or biomechanical differences, challenging the notion that superior shoe comfort leads to improved RE measures (Fuller et al., 2015; Luo et al., 2009; Sinclair et al., 2016; 2016) or differences in running biomechanics (Lindorfer et al., 2020; Nigg et al., 2015). Noteworthy is that all significant differences in perceptual measures between conditions (mean difference: 7.2 to 19.2 mm) were above the between-trial difference for a given shoe extracted from our dataset, except for ratings on technical and supporting features.

Researchers have suggested the placebo effect may contribute to the positive RE responses seen in AFT (Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019; Knopp et al., 2023), but our findings indicate otherwise. While our results suggest no significant placebo effect on submaximal RE measures, researchers have identified a potential placebo effect leading to positive gains in maximal and anaerobic running performances, including 200-m sprint (de la Vega et al., 2017), 3-km race (Ross et al., 2015), and 6-minute time-trial (Valero et al., 2024) performances. Economy is but one of the key physiological determinants of endurance exercise performance (Jones, 2024), and our study was not designed to assess running performance outcomes directly. As such, a potential placebo effect from running in AFT for time-trial, maximal, or racing efforts cannot be ruled out based on our submaximal running trial observations.

Given the apparent absence of a potential placebo effect on RE metrics, the RE improvements reported in the literature (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Hunter et al., 2019; Joubert & Jones, 2022; Knopp et al., 2023) appear to have a greater mechanical than psychological basis. The mechanical properties of the shoes themselves – such as their lightweight properties (Hébert-Losier & Pamment, 2023), highly compliant and resilient midsole foams (Hoogkamer et al., 2018), and increased longitudinal bending stiffness via their rigid plates (McLeod et al., 2020) – and how runners interact with these properties appear to underpin the RE improvements (Hébert-Losier & Pamment, 2023). The corollary then is that the inter-individual variations reported in the literature most likely derive from how individuals interact with the shoes and their properties rather than from a placebo effect, although this individualised response requires further investigation (Barrons et al., 2024).

In contrast to the RE findings, the shoe descriptions significantly influenced the perceptual measures and shoe preferences of runners, agreeing with prior findings (Chan et al., 2020; Hennig & Schulz, 2011). When participants are blinded to shoe brand, quality ratings have been shown to improve for lower-cost discount brands and worsen for well-known brands (Hennig & Schulz, 2011). In another study, Chan et al. (2020) described one pair of shoes to runners as the latest model worth USD 150 yet to be released, designed to maximise comfort, and made from highly expensive material. The same shoes were described as a regular running shoe available on the market designed for distance running worth USD 50. Participants favoured the former, with an average difference in overall comfort of 9.8 mm (*moderate* ES = 0.70) (Chan et al., 2020). While our difference in overall comfort of 14.6 mm between shoes was larger (*large* ES = 0.94); together, these results indicate that shoe descriptions, branding, and marketing can significantly

Table 4. VAS scores and shoe preference rankings from 24 female recreational runners.

	SS	KO	Difference (SS − KO)		
	Mean ± SD	Mean ± SD	Mean ± SD	Effect size [95% CI]	p-Value
VAS measures (mm)					
Overall comfort	68.1 ± 15.4	53.5 ± 15.8	14.6 ± 15.0	0.94 [0.46, 1.40]	**<0.001***
RUN-CAT	82.1 ± 14.2	81.2 ± 11.9	0.9 ± 12.3	0.07 [-0.31, 0.45]	0.712
Heel cushioning[†ʃ]	58.3 ± 12.4	49.3 ± 14.9	9.0 ± 19.3	0.65 [0.05, 1.24]	**0.033***
Forefoot cushioning[†ʃ]	53.7 ± 14.0	46.5 ± 10.4	7.2 ± 14.0	0.58 [0.10, 1.06]	**0.019***
Forefoot flexibility[†ʃ]	49.5 ± 9.8	47.8 ± 9.5	1.7 ± 8.8	0.17 [-0.20, 0.54]	0.366
Shoe stability[†ʃ]	43.5 ± 9.0	41.6 ± 10.6	1.9 ± 9.6	0.19 [-0.21, 0.58]	0.355
Shoe stiffness[†]	48.4 ± 11.8	48.6 ± 11.6	−0.2 ± 14.7	−0.02 [-0.52, 0.49]	0.951
Technical and supporting features[†]	55.6 ± 8.4	47.7 ± 13.6	7.9 ± 14.5	0.70 [0.14, 1.25]	**0.013***
Shoe weight[†]	49.2 ± 5.7	51.6 ± 5.7	−2.4 ± 5.8	−0.43 [-0.85, 0.00]	0.050
Pleasure/displeasure	68.3 ± 18.6	52.5 ± 17.9	15.8 ± 21.6	0.87 [0.32, 1.39]	**0.002***
Easier/harder	69.7 ± 17.5	50.5 ± 18.6	19.2 ± 21.0	1.06 [0.50, 1.61]	**<0.001***
Performance	70.7 ± 14.9	52.1 ± 16.9	18.5 ± 16.5	1.16 [0.62, 1.69]	**<0.001***
Injury risk	50.1 ± 13.6	40.6 ± 12.4	9.4 ± 16.3	0.72 [0.18, 1.26]	**0.009***
Rankings					
Shoe preference overall comfort (*n*, %)[a]	21 (87.5%)	3 (12.5%)	18 (75%)		**<0.001***
Shoe preference performance (*n*, %)[b]	21 (87.5%)	3 (12.5%)	18 (75%)		**<0.001***
Shoe preference injury risk (*n*, %)[c]	19 (79.2%)	5 (20.8%)	14 (58.3%)		**0.003***

Data are an average of two trials per shoe condition per participant, except for rankings.
Note. Unless stated, VAS values were measured on a scale from 0 to 100 mm, where 100 indicates the most ideal.
[†]Values were measured on a scale from 0 to 100 mm, where 50 indicates ideal.
[ʃ]RUN-CAT properties.
[a]Response to 'Overall, which shoe was the most comfortable?'
[b]Response to 'Overall, which shoe do you think you would perform the best in under a race or time-trial situation?'
[c]Response to 'Overall, which shoe do you think your injury risk would be lowest?'
*Significant difference ($p < 0.05$) are in bold and for between conditions based on paired *t*-tests.
Abbreviations: CI: confidence interval; KO: 'knock-off'; RUN-CAT: running shoe comfort assessment tool; SD: standard deviation; SS: super shoe; VAS: Visual Analogue Scale.

influence the subjective perceptions of shoes, including comfort. The Hawthorne effect (Wickström & Bendix, 2000) may also be at play whereby participants modify their perceptual ratings based on what they believe we (the researchers or salespeople) want to hear, noting the researcher did not interact with the participants during the VAS ratings and we saw no overt Hawthorne effect on RE and biomechanics. Noteworthy is that the largest difference in perceptual measures between shoes was for performance (18.5 mm, *large* ES = 1.16), which aligns with the performance focus we placed on the super shoe description.

There are many psychological factors, such as enthusiasm, self-confidence, and motivation, that can aid or hinder performance (Sarkar & Fletcher, 2014) and numerous contextual factors that can mediate the placebo effect (Beedie et al., 2018), which were not assessed or controlled herein. The psychobiological model of motivation intensity theory suggests perception of effort and potential motivation underpin task engagement (Brehm & Self, 1989; Gendolla & Richter, 2010). Based on this theory, individuals consciously decide on the level of effort needed to succeed at a given task. Therefore, while we did not observe an improved RE in shoes described as performance enhancing, runners perceived the shoe increased their performance. These runners might be more confident and motivated to run at a higher intensity, thereby leading to improved running performance despite similar RE measures, under the caveat that the intensity is physiologically sustainable and would not lead to early onset of fatigue.

Strengths and limitations

A strength of this study is the examination of the between-trial reliability of measures within our cohort. All significant differences in perceptual measures between shoe conditions (except ratings on technical and supporting features) exceeded the between-trial TE, strengthening the validity of the findings. Other researchers can use the physiological, biomechanical, and perceptual reliability outcomes to inform the meaningfulness of subsequent between-shoe comparisons. The blinding of the shoe conditions was mostly effective with only two of the 24 runners (8.3%) expressing their belief that the conditions were the same. The data from these participants were maintained for ecological validity of findings and our intention to attempt to influence perceptions. Also, the use of a randomised mirrored crossover design meant multiple trials were collected to examine the responses of the intervention in a randomised sequence (Barrons et al., 2024).

Study limitations exist, including that the testing was completed at only one speed. The use of set speeds to assess RE measures in AFT research is common (Barnes & Kilding, 2019; Hoogkamer et al., 2018; Hunter et al., 2019; Joubert et al., 2023; Joubert & Jones, 2022) and requires participants to attend a single session only. The set speed of $10\,km\cdot h^{-1}$ was chosen due to targeting female recreational runners to ensure submaximal running and represented on average 64% of their speed at VO_{2peak}. Although this relative intensity approximates the average marathon pace of slower marathon runners (71% of speed at VO_{2peak}) (Sjödin & Svedenhag, 1985), the potential for a placebo effect from running in AFT cannot be ruled out for faster running speeds, time-trial times, and race performances. The colour of shoes are important to road runners (Fife et al., 2023) and might have influenced perceptions. Colour was not randomised between conditions as the vibrant colours are integral to the Vaporfly branding. Although focusing on only female recreational runners is a strength as females are historically underrepresented in sport and exercise science (Cowley et al., 2021;

Martínez-Rosales et al., 2021), this focus limits generalisation to other populations and we cannot conclude that a potential placebo effect on RE measures from wearing AFT does not exist for male or higher-performing runners. Females are reported to value injury prevention and to prefer lighter shoes more than males (Kong & Bagdon, 2010; Xia et al., 2023). While outside of the scope of this work, there are sex differences in the mechanisms underlying placebo responses (Brietzke et al., 2022) and controversy as to whether sex mediates the placebo effect (Enck & Klosterhalfen, 2019). Therefore, it is unclear whether our results in females would be similar in males.

To conclude, there were no significant differences in RE and biomechanics between two pairs of AFT shoes when described as 'super shoes' or 'knock offs'. However, participants perceived the former as more comfortable and making running easier, with potential benefits on their running performance. The benefits of wearing AFT on RE metrics appear to be linked with the shoe properties and how runners interact with them, with limited contributions from a placebo effect. Our study supports existing evidence that product description can significantly influence perceptual measures of footwear, including comfort and expected performance.

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Ethical approval

The HECS Human Research Ethics Committee of the University of Waikato granted ethical approved to conduct this randomised cross-over study with repeated measures study (HREC(HECS)2023#13), which followed the Declaration of Helsinki.

Author contributions

KHL: Conceptualisation, methodology, formal analysis, investigation, resources, data curation, writing – original draft, writing – review & editing, visualisation, supervision, project administration. **AF**: Methodology, formal analysis, investigation, data curation, writing – original draft, writing – review & editing, visualisation, project administration. **SF**: Conceptualisation, methodology, investigation, data curation, writing – review & editing, visualisation. **PL:** Methodology, formal analysis, data curation, writing – review & editing, visualisation. **JFE**: Conceptualization, methodology, writing – review & editing. **CMB**: Conceptualization, methodology, writing – review & editing.

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Data availability statement

The datasets generated during and analysed during the current study are freely available in the OSF repository, at https://doi.org/10.17605/OSF.IO/UQYZD (Hébert-Losier et al., 2024).

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