The Potential Placebo Effect of Advanced Footwear Technology on Running Economy and Comfort in Female Recreational Runners

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Abstract

Since the release of advanced footwear technology (AFT) in 2017, the running landscape has changed forever. However, researchers are unable to decisively conclude what part of AFT contributes the most to running economy (RE) improvements, with some eluding to a potential placebo effect of AFT shoes. Therefore, this study aimed to investigate the presence of a potential placebo effect of AFT on RE and perceptual measures in female recreational runners.

Chapter One provides a brief overview of the origins of AFT, the properties of AFT proposed to contribute to RE improvements, shoe comfort, and placebo effects in sports and footwear research. Features of AFT shoes typically are a curved geometry, a rigid plate embedded in the midsole, and a resilient and compliant energy-returning foam midsole. AFT shoes are also typically lightweight, linked with improved RE. Research generally reports an average improvement in RE of runners when wearing AFT; however, responses are variable and there are responders and non-responders to AFT.

In Chapter Two, 26 female recreational runners (age: 34.7 ± 10.1 y, VO_{2peak}: 45.19 ± 4.65 mL/kg/min) completed one session at the University of Waikato Adams Centre for High Performance Laboratory to assess RE and perceptual measures in two pairs of women's Nike Vaporfly NEXT% 2. Participants completed 4 x 6-minute RE trials in these two pairs of shoes. One pair was described as a performance-enhancing super shoe (SS) with AFT worn by elite athletes, and the other pair was spray-painted black and described as a "knock-off" (KO) of the performance-enhancing shoe without AFT. Data from 24 participants were analysed (age: 33.3 ± 8.9 y, VO_{2peak}: 45.58 ± 4.17 mL/kg/min) as physiological data from two

participants suggested running above their aerobic threshold. Oxygen consumption was not significantly different between SS and KO (mean difference: 0.24 ± 0.64 mL/kg/min, p = 0.077, d = 0.11 [-0.01, 0.23]). Overall comfort on a 100 mm visual analogue scale (VAS) was significantly greater in SS than KO (mean difference: 14.6 ± 15.0 mm, $p < 0.001$, d = 0.94 [0.46, 1.40]), with 87.5% of runners preferring the SS over the KO. Runners perceived running as more enjoyable and less difficult, and perceived an improved running performance and lower injury risk in SS when compared to KO based on visual analogue scale scores ($p \leq$ 0.009, d = 0.72 to 1.16). While no significant physiological difference was observed between shoes, a significant difference in perceived comfort and performance was observed favouring the performance-enhancing SS, suggesting a perceptual placebo effect based on shoe description alone.

Chapter Three summarises the findings and provides avenues for future research. Overall, this thesis provides evidence that product descriptions can influence the perception of shoe comfort, performance, and injury risk. The improvements in RE reported for AFT shoes appear underpinned by how runners interact with the shoe properties, rather than by a placebo effect – at least in female recreational runners. Investigating a potential placebo effect in AFT during maximal running performances may provide further insight into the performance enhancements associated with shoes containing AFT.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AFT – advanced footwear technology

BC – before Christ

bpm – beats per minute

CI – confidence interval

CV – coefficient of variation

d – Cohens *d*

ES – effect size

EVA – ethylene-vinyl acetate

ICC – intraclass correlation coefficient

kg – kilogram

km – kilometre

km/h – kilometres per hour

kN/m – kilonewtons per metre

KO – knock-off

J/kg/min – Joules per kilogram per minute

m – metres

mL/kg/min – millilitre per kilogram per minute

mm – millimetre

mmol/L – millimole per litre

p – *p*-value

PEBA – polyester block amide

RE – running economy

RER – respiratory exchange ratio

RPE – rating of perceived exertion

RUN-CAT – running shoe comfort assessment tool

SD – standard deviation

SS – super shoe

TE – typical error

TPU – thermoplastic polyurethane

US – United States

USD – United States dollar

VAS – visual analogue scale

VO_2 – oxygen consumption

VO_{2max} – maximal aerobic capacity

VO_{2peak} – peak oxygen uptake

W/kg – watts per kilogram

y – years

Thesis Overview

The main aim of this thesis was to explore the potential placebo effect of advanced footwear technology (AFT) on the running economy (RE) and perceptual measures in female recreational runners. Female runners ran in two pairs of women's Nike Vaporfly NEXT% 2 to achieve this aim. One pair was described as a performance-enhancing super shoe, and the other was described as being a “knock-off” of a super shoe. The thesis is comprised of three chapters, as depicted in Figure 1.

Chapter One – Literature Review summarises literature on RE, AFT, perceptions of footwear comfort, and placebo effect in sports. Chapter Two – Experimental Study presents a randomised crossover study investigating the RE and perceptual measures of female recreational runners in two pairs of the same AFT shoes described to participants as being different. The chapter is presented in an article format suitable for peer-reviewed publication. Chapter Three – Final Chapter summarises the key findings from this body of work, highlighting strengths and limitations, and providing suggestions for future research.

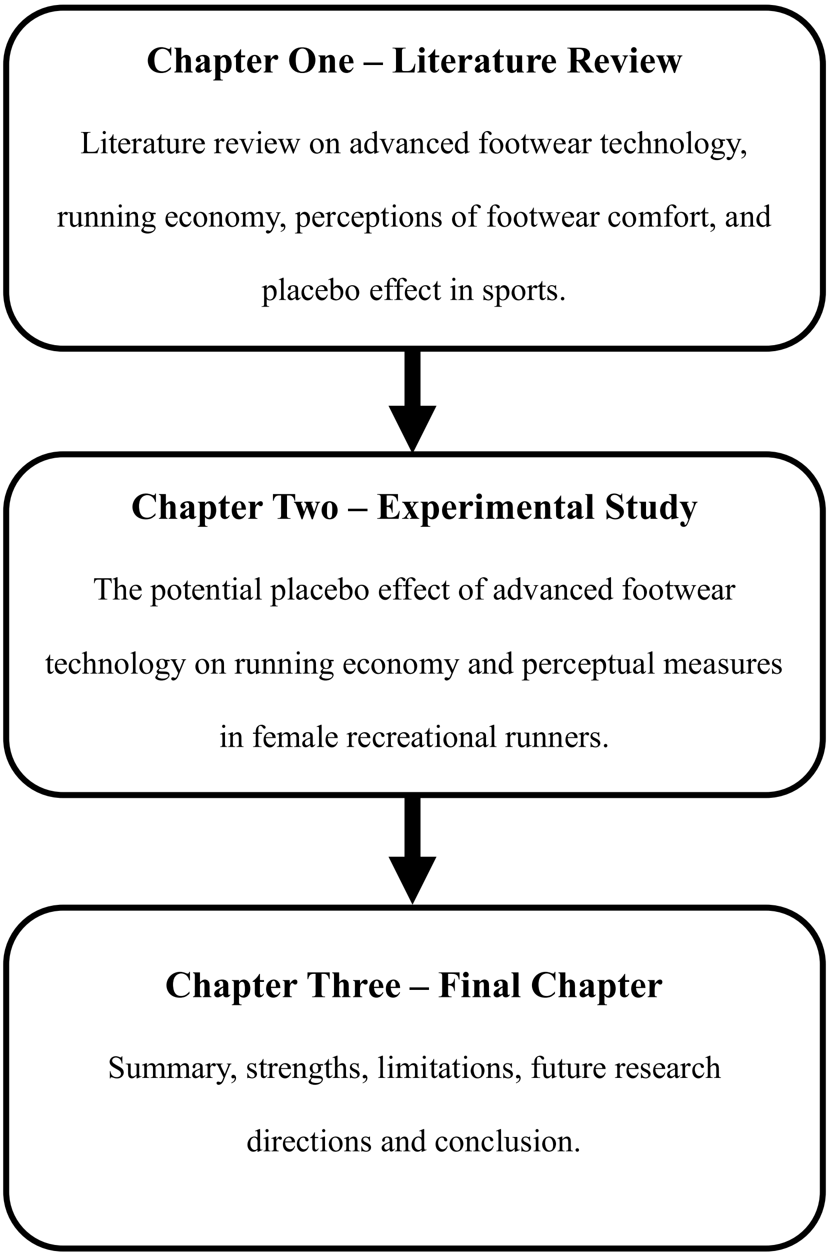

Figure 1. Flow diagram of the structure of this thesis.

Chapter One – Literature Review

Literature review of advanced footwear technology, running economy, perceptions of footwear comfort, and placebo effect in sports.

Shoes with advanced footwear technology (AFT) have revolutionised the running landscape since their release to the market in 2017. AFT, or commonly known as "super shoes", have been shown to improve running economy (RE) in both elite and recreational runners compared to lightweight and other racing shoes (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019; Joubert et al., 2023). The emergence of AFT has speculatively contributed to improved running performances and the establishment of new World Records from 5 km to marathon race distances (Muniz-Pardos et al., 2021). Although shoes with AFT have no consensus definition, the typical features of AFT shoes are a curved rigid plate embedded in the midsole, their general curved geometry, and a lightweight, compliant, and resilient energy-returning midsole foam.

Sporting products from well-known brands such as Nike Inc. have been shown to objectively enhance the performance of its users due to the brands' strong performance associations even when compared to unbranded products that are materially identical (Germann & Garvey, 2022). Research suggests the existence of a potential placebo effect that can contribute to positive gains in maximal running performances (de la Vega et al., 2017; Ross et al., 2015; Valero et al., 2024). Together, these studies indicate that positive beliefs in and expectations of interventions, as well as branding in sporting contexts, are important factors to consider for the overall performance of athletes.

AFT background

Shoes containing AFT made their first appearance in competitive road running when a Nike prototype shoe was allegedly given to three marathoners during the 2016 Rio de Janeiro Olympics (Burfoot, 2020). All three runners went on to place first, second, and third in the race. This prototype shoe was later released to the market in 2017 as the Nike Vaporfly 4%.

The shoe was given this coveted title as it was reported from early laboratory testing data to improve the RE of highly-trained runners by an average of 4% (Hoogkamer et al., 2018). Other than all women's and men's World Records from 5 km to the marathon being broken since the release of AFT shoes (Muniz-Pardos et al., 2021); a feat thought impossible (Hill, 1925; Liu & Schutz, 1998), running a sub-two-hour marathon, is now believed feasible and likely to occur in the next few years (Sousa et al., 2018).

The first attempt at a sub-two-hour marathon under contrived circumstances was held in 2017 during the Nike Breaking2 event. Wearing a prototype of the Nike Vaporfly Elite, Eliud Kipchoge ran the 42.2 km marathon distance in 2:00:25 (hr:min:sec) (Oppermann, 2017). In his second attempt at a sub-two-hour marathon held during the INEOS 1:59 challenge in 2019, Eliud Kipchoge succeeded with a time of 1:59:42 (hr:min:sec) wearing a prototype of what was later released as the Nike Air Zoom AlphaFly NEXT% (INEOS, 2019). While neither of these two attempts can be considered World Record times as they were unofficial races and involved sports science and other support (e.g., rotational pacers, pacing car, etc.), it nonetheless suggests that technological advancement in footwear can contribute to enhancing running performances. Furthermore, recent running World Records have been achieved in AFT-containing shoes. The late Kelvin Kiptum is the current men's World Record holder for the marathon (2:00:35 [hr:min:sec]) and achieved this during the Chicago Marathon in October 2023 wearing an early release of the Nike Alphafly 3 (Ball, 2023), an AFT shoe. The current women's World Record holder for the marathon is Tigist Assefa (2:11:53 [hr:min:sec]) who wore the Adizero Adios Evo Pro 1 during the Berlin Marathon in 2023 (Kahler, 2023), an AFT shoe valued at USD 500 and guaranteed to last one marathon.

Although Nike Inc. were the first to the shoe market with AFT, most other popular sports brands now manufacture their own version of shoes containing a rigid plate embedded in a highly resilient and compliant energy-returning foam midsole. Joubert and Jones (2022) compared seven models of shoes containing AFT from various well-known sports brands and found all AFT shoes examined improved RE on average compared to traditional racing flats; however, only three AFT models improved RE by more than 2.5% on average (Nike Vaporfly 2, Nike AlphaFly, Asics MetaSpeed) compared to the traditional racing flats (Asics Hyperspeed). This research highlights that variability in RE response exists across footwear brands and individuals, with certain runners benefiting more from one AFT shoe than another upon inspection of the individual data presented Joubert and Jones (2022).

Why are AFT effective?

While it has been shown that shoes containing AFT generally improve RE (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019; Joubert et al., 2023), which translates into improved running performances (Hoogkamer et al., 2016), it is difficult to quantify the relative contributions of the various shoe features to these improvements. Some of the key features proposed to contribute to improvements in AFT are their relatively low mass, the resilient and compliant energy-returning foam midsole, the potential teeter-totter effect from the curved shoe geometry, and the increased longitudinal bending stiffness from the stiff plate embedded in the midsole. Furthermore, the subjective perceptions of shoe comfort and performance of runners could contribute to the enhanced RE and performance (Lam et al., 2022; Lindorfer et al., 2020) observed in AFT. These aspects will be discussed further below.

Within distance running, it has long been established that there are four key physiological determinants for performance (Scrimgeour et al., 1986). These determinants are RE, lactate threshold, maximal aerobic capacity (VO_{2max}), and fractional utilisation. Recent literature has begun to look into another physiological determinant of performance called fatigue resistance or resilience (Jones, 2023). These five parameters are important in determining the performance of an athlete as small differences in each parameter can have substantial impacts on race outcomes, with Barnes and Kilding (2019) stating that RE can vary by up to 30% among athletes with similar VO_{2max}.

RE refers to the energy cost of running at a particular speed or intensity level. It is often measured as the oxygen consumption (VO_2) or energy expenditure (W/kg) required to maintain a given speed (Barnes & Kilding, 2015). RE is one of the most important factors in distance running performance (Daniels & Daniels, 1992). The lactate threshold represents the intensity at which lactate begins to accumulate in the blood faster than it can be cleared (Brooks, 1985). Maximal aerobic capacity, or VO_{2max}, is the maximum rate at which an individual can consume oxygen during maximal exercise (Joyner & Coyle, 2008). Fractional utilisation refers to the percentage of VO_{2max} that an athlete can sustain over a given period (Foster & Lucia, 2007). This parameter determines how much of an athlete's aerobic capacity can be effectively used during prolonged exercise. Jones (2023) defines fatigue resilience or resistance as the ability to resist the onset of fatigue and maintain performance. RE is typically assessed in footwear research as RE measures can accurately predict changes in running performance linked with footwear modifications (Hoogkamer et al., 2016). It is estimated that for a 1% improvement in RE in recreational runners, those who typically could run a marathon in 4:30:00 (hr:min:sec) would be predicted to finish their race 1.17% faster, improving their race times by approximately 00:03:07 (hr:min:sec) (Kipp et al., 2019).

RE is typically assessed by measuring the oxygen consumption (VO_2) during treadmill running at a submaximal effort and a constant speed. A duration of three to 15 minutes is commonly used to achieve a physiological steady-state, with other physiological parameters, notably blood lactate and respiratory exchange ratio (RER) monitored to stay below 4.0 mmol/L and 1.00 respectively (Barnes & Kilding, 2015; Yoshida et al., 1987) as indicators of aerobic performance. Therefore, for the purpose of this thesis, oxygen consumption at a constant running speed was used as the main outcome measure.

Shoe mass

AFT shoes are generally lightweight, which is important for RE. Indeed, shoe mass is crucial to performance as an increase in shoe mass of 100 g corresponds to an approximate increase of oxygen consumption by 1% (Franz et al., 2012; Hoogkamer et al., 2016). One of the features contributing to the lightweight nature of AFT is the newer polyester block amide (PEBA) foam used in the midsole (Hébert-Losier & Pamment, 2023). The foam is less dense, lighter, and more resilient and compliant compared to the more traditional ethylene-vinyl acetate (EVA) foam typically used in marathon racing shoes prior to the release of AFT (Hoogkamer et al., 2018).

Research has been completed comparing the oxygen consumption in an AFT shoe the Nike Vaporfly 4% when unweighted, and mass-matched to a control shoe (Barnes & Kilding, 2019; Hoogkamer et al., 2018; Joubert et al., 2023; Knopp et al., 2023). Compared to running in an Adidas Adios Boost 3, participants were on average 2.9 ± 1.3% more economical in the mass-matched Nike Vaporfly 4% shoe (additional 30-35 g) and 4.2 ± 1.2% more economical in an unweighted Nike Vaporfly 4% shoe (Barnes & Kilding, 2019). When mass-matched to an Adidas Adizero Boost 2, the energetic cost of running was 4.01% lower in a Nike Vaporfly 4% prototype shoe (additional 51 g) (Hoogkamer et al., 2018). The authors hypothesised that this performance improvement seen in the Nike Vaporfly 4% prototype when mass-matched to a commercially available marathon shoe would likely lead to an improvement in performance by 4.4% when unweighted.

Midsole foam

The emergence of a more lightweight, compliant, and resilient energy-returning midsole foam is one of the features suggested to contribute to improvements in RE measures reported for AFT shoes. In laboratory settings, the Nike Vaporfly 4% shoe with PEBA foam was shown to return up to 87% of the stored mechanical energy. In contrast, the Adidas Adios Boost 2 with foam made from thermoplastic polyurethane (TPU) and Nike Zoomstreak 6 with EVA foam only returned 75.9% and 65.5% of the stored mechanical energy, respectively (Hoogkamer et al., 2018). In addition to its more compliant and resilient nature, PEBA is more lightweight, which is also important for reducing oxygen consumption during running (Franz et al., 2012; Hoogkamer et al., 2016).

Teeter-totter

It has also been proposed that a teeter-totter effect exists in AFT due to the curved rigid plate in the midsole often made of carbon fibre, and the general curved geometry of the shoes. Nigg et al. (2021) advanced the teeter-totter effect, whereby the ground reaction force moves in an anterior direction towards the front of the carbon fibre plate during the second half of ground contact, thus producing a force at the heel perpendicular to the plate. In other words, the ground reaction force would propel the heel upward and forward if the timing of the return is appropriate in relation to the rocker of the shoe. However, there is a lack of empirical evidence to support this claim. Hoogkamer et al. (2019) report that the peak ankle moment in a Nike Vaporfly prototype occurred later in the stance phase of running than the peak ground reaction force, and the anticipated faster progression of the centre of pressure under the foot was not observed in this footwear compared to shoes without AFT – refuting the existence of a teeter-totter effect.

Longitudinal bending stiffness

Longitudinal bending stiffness refers to "the ability of a shoe to bend, limiting plantarflexion and dorsiflexion of the forefoot joints" (McLeod et al., 2020). Associations between longitudinal bending stiffness and metabolic cost for running have been explored (Flores et al., 2019; McLeod et al., 2020; Oh & Park, 2017), with a potential U-shape relationship linking the two measures whereby too little and too much bending stiffness impair RE (Chollet et al., 2023; Nigg et al., 2023; Ortega et al., 2021). However, it is proposed that optimal longitudinal bending stiffness is athlete and speed-specific (Chollet et al., 2023; McLeod et al., 2020; Nigg et al., 2023; Ortega et al., 2021).

Hébert-Losier and Pamment (2023) proposed that the RE improvements in AFT may be underpinned by how runners interact with the individual properties of the shoe. Therefore, this runner-shoe interaction provides a possible explanation as to why there are responders and non-responders to AFT. However, the individual responses to AFT have not been investigated thoroughly (Barrons et al., 2024).

Running economy and comfort

Comfort is important for the selection of running shoes as increased comfort has been suggested to be related to decreased fatigue (Miller et al., 2000), decreased muscular mechanical work (Nigg, 2001), decreased injury risk (Nigg et al., 2015), and possible improvements in RE (Lindorfer et al., 2020; Luo et al., 2009; Sinclair, Mcgrath, et al., 2016; Sinclair, Shore, et al., 2016). It has been concluded that comfort is the most important shoe selection criterion for recreational runners (Van Alsenoy et al., 2023).

Shoe comfort has been measured in various ways, including yes/no responses, visual analogue scales (VAS), and shoe preference rankings (Bishop et al., 2020; Lindorfer et al., 2019; Mills et al., 2010). VAS used to assess shoe comfort are typically 100 mm in length and include two anchor points to delineate extremes (e.g., 0 = not comfortable at all, and 100 = most comfortable imaginable) (Lindorfer et al., 2019; Mündermann et al., 2002). Mündermann et al. (2002) and Lindorfer et al. (2019) concluded that VAS are simple and reliable for measuring overall shoe comfort as well as perceptions of individual shoe properties. The running shoe comfort assessment tool (RUN-CAT) has been developed by Bishop et al. (2020) to measure the overall comfort of shoes through the assessment of individual shoe properties. The RUN-CAT uses composite scores from the ratings of four shoe properties (heel cushioning, forefoot cushioning, shoe stability, and forefoot flexibility), where a higher score indicates a more ideal shoe. The use of VAS and RUN-CAT combined can provide meaningful information as to how individuals experience comfort while running in different shoes.

Fuller et al. (2015) completed a systematic review of the available literature on shoe comfort and its association with RE, reporting *small* but meaningful improvements in RE when wearing more comfortable shoes. A separate systematic review of the available literature concluded that a *small* positive association between shoe comfort and RE existed in recreational runners (Van Alsenoy et al., 2023); hence, recreational runners wearing more comfortable shoes would likely benefit from improved RE. In contrast, Lindorfer et al. (2020) reported no significant relationship between RE and shoe comfort, therefore, challenging the notion that improved comfort in shoes leads to better RE. Although Fuller et al. (2015) and Van Alsenoy et al. (2023) proposed a relationship exists between superior shoe comfort and improved RE, this proposition has been challenged (Lindorfer et al., 2020) and is likely nuanced by shoe properties (Luo et al., 2009; Sinclair, Mcgrath, et al., 2016; Sinclair, Shore, et al., 2016) and individual responses to shoes (Luo et al., 2009; Miller et al., 2000; Roy & Stefanyshyn, 2006).

Individual studies (Lindorfer et al., 2020; Luo et al., 2009; Sinclair, Mcgrath, et al., 2016; Sinclair, Shore, et al., 2016) investigating the association between superior shoe comfort and improved RE have found contrasting results, which may be partially explained by methodological differences. One could challenge the meaningfulness of the small average 0.7% RE improvement seen in the shoe rated as most comfortable by Luo et al. (2009), for instance. Furthermore, the studies completed by Sinclair, Mcgrath, et al. (2016) and Sinclair, Shore, et al. (2016) saw significant RE improvements in shoes rated to be the most comfortable; however, the shoe properties used in each study were vastly different and confounded results. The aforementioned studies all rely on data from male runners (recreational to highly trained), which can make the generalisation of improved RE due to superior shoe comfort problematic for female runners.

Placebo effect

It has been alluded to in past literature (Hébert-Losier et al., 2022; Hoogkamer et al., 2019; Hunter et al., 2019) that a potential placebo effect of wearing AFT exists; however, this proposition has not yet been specifically examined. The placebo effect is defined as the phenomenon where individuals experience improvements in their condition or outcomes due to their belief in receiving a treatment, despite the treatment having no inherent therapeutic properties (Colagiuri et al., 2015). The placebo effect is linked to the expectancy theory where verbal and social cues are integrated to change a behaviour and/or outcome (Colagiuri et al., 2015). In a sports-specific context, the placebo effect refers to the phenomenon where athletes perceive improvements in performance or recovery after receiving a treatment or intervention that has no physiological basis for enhancing athletic performance or recovery. These perceived improvements are often attributed to psychological factors such as increased motivation, confidence, or reduced perception of effort (Beedie & Foad, 2009).

Prior research examining the placebo effect in non-AFT containing shoes using deception and blinded running found that participants perceived superior comfort in shoes described as a USD 150 shoe designed to maximise comfort using highly expensive material compared to a shoe described as a regular running shoe costing only USD 50. The average difference of 9.8 mm on the 100 mm VAS between the two shoe conditions was clinically meaningful, suggesting that deceptive descriptions and price points can induce a bias in the perceived comfort of footwear (Chan et al., 2020). Furthermore, while not specifically examining a placebo effect, Mohr et al. (2016) aimed to investigate the psychological factors underpinning performance in various basketball-related tasks in three shoe conditions (light, medium, and heavy). Twenty-two male recreational athletes were randomly assigned to two experimental groups (“aware” and “blind”) and completed lateral shuffle-cut movements and vertical countermovement jumps in each shoe condition in a randomised order. Participants were asked to provide feedback on perceived shoe weight using a 5-point Likert scale after each condition. The participants who were aware of the shoe weights performed better in each activity in the lighter shoe, with no significant difference in performance between shoes among the blinded group. Thus, it was suggested that the observed interaction effect was attributable to psychological factors, notably performance expectations based on shoe weight differences.

Research statement

With the above literature in mind, the aim of this thesis was to assess the presence of a potential placebo effect of shoes containing AFT on RE and perceptual measures (notably, footwear comfort) in female recreation runners. It was hypothesised that RE and comfort would be superior in the shoes described as being "super shoes" containing AFT compared to the same shoes described as being a "knock-off" without AFT.

Chapter Two – Experimental Study

The potential placebo effect of advanced footwear technology on running economy and perceptual measures in female recreational runners.

Abstract

Objective: To examine the potential placebo effect of advanced footwear technology (AFT) on running economy and perceptual measures in female recreational runners. **Methods:** Twenty-four female recreational runners (age: 33.3 ± 8.9 y, VO_{2peak}: 45.58 ± 4.17 mL/kg/min) completed 4 x 6-minute running economy trials in two pairs of women's Nike ZoomX Vaporfly Next% 2. One pair was described as a performance-enhancing super shoe with AFT worn by elite athletes, and the other pair were spray-painted black and described as a "knock-off" of the performance-enhancing shoe without AFT. **Results:** Oxygen consumption was not significantly different between the performance-enhancing super shoe and "knock-off" shoe (mean difference: 0.24 ± 0.64 mL/kg/min, $p = 0.077$, $d = 0.11$ [-0.01, 0.23]). Overall comfort on a 100 mm visual analogue scale was significantly greater in the performance-enhancing super shoe than "knock-off" shoe (mean difference: 14.6 ± 15.0 mm, $p < 0.001$, $d = 0.94$ [0.46, 1.40]), with 87.5% of runners preferring the former shoe. Runners perceived running as more enjoyable and less difficult, and perceived an improved running performance and lower injury risk in performance-enhancing super shoes when compared to the "knock-off" shoes ($p \leq 0.009$, $d = 0.72$ to 1.16). **Conclusion:** Contrary to expectations, while no physiological differences were observed, a significant placebo effect was apparent for both perceived comfort and performance based on the shoe descriptions provided.

Introduction

Running is the oldest recognised sport and the only event held during the Olympic Games between 776 to 724 BC (Miller, 2004). While running has fundamentally stayed the same from a mechanical perspective, there is an increasing amount of technology used in the sport, including wearables to monitor training parameters (Toner, 2024), systems to aid with pacing in races (Emig & Adam, 2024), and shoes with advanced footwear technology (AFT) to improve performance (Hébert-Losier & Pamment, 2023).

Shoes with AFT typically refer to shoes with a stiff curved plate embedded in the midsole, curved midsole geometry, and a high amount of lightweight resilient high-energy returning foam made from polyester block amide (Hébert-Losier & Pamment, 2023). Since their release to the global market in 2016, athletes wearing these shoes have broken all men's and women's World records from the 5 km to the marathon (Muniz-Pardos et al., 2021). 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.

Early laboratory-based research on AFT found running economy (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. Running economy is defined as the oxygen consumption at a given submaximal speed (Barnes & Kilding, 2015), and is one of the main factors of running performance. Joubert and Jones (2022) compared seven models of shoes containing AFT from various brands and found that all AFT shoes examined improved RE on average compared to traditional racing flats; however, only three AFT models improved RE by more than 1.5% (Nike Vaporfly 2, Nike

AlphaFly, Asics MetaSpeed). Similar average RE improvements have been seen in recreational runners and in elite runners, with Paradisis et al. (2023) reporting an average 3.8-5.0% increase in RE at slower marathon speeds in Saucony branded AFT compared to more traditional Saucony running shoes. In line with these findings, Knopp et al. (2023) found the RE of recreational runners improved by 3.5-5.0% in AFT 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 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 including foot strike pattern (Hébert-Losier et al., 2022), running speed (Hébert-Losier et al., 2022; Hébert-Losier et al., 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).

Although cited as a potential contributor to improved performances and variability in AFT (Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019), the potential for a placebo effect in runners wearing AFT has not been examined. The placebo effect is linked to the expectancy theory where verbal and social cues are integrated to change a behaviour and/or outcome (Colagiuri et al., 2015). One's positive beliefs in and expectations of an intervention have been shown to enhance performance in endurance sports (de la Vega et al., 2017; Ross et al., 2015; Valero et al., 2024). Furthermore, basketball performance improved in individuals who were told how their performances should improve in different footwear, but not in individuals who were unaware of the functional benefits of the shoes (Mohr et al., 2016). Prior research on non-AFT shoes involving deception of runners found significantly greater perceived comfort levels (p = 0.011, Cohen's d = 0.79) 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. Results from Germann and Garvey (2022) support this proposition, where products from brands that carry strong performance associations, such as Under Armour and Nike, objectively enhanced physical performance outcomes for consumers compared to unbranded products that were materially identical.

Therefore, we aimed to investigate and explore the potential placebo effect of AFT on RE and perceptual measures of shoes. We hypothesised superior RE and comfort ratings in a shoe described as a "super shoe" compared to the same shoe described as a super shoe "knock-off". 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 0.61 in RE between the most and least comfortable shoes (Sinclair, Shore, 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 to complete the experimental protocol after approval from our institutional Human Research Ethics Committee [HREC(HECS)2023#13]. The experimental trial was preregistered in the Australian New Zealand Trials Registry (ACTRN12623000731695). There were no changes to the planned experiment.

We recruited recreational female runners following the taxonomy proposed elsewhere (Honert et al., 2020). Eligibility criteria required participants to have been running for more than six months at least once a 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 running on a treadmill and be able to run for 45 minutes in total. Runners were excluded if they were currently injured or injured within the last month of testing 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's 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

RE and perceptual measures were assessed in two running shoe conditions using a randomised and mirrored crossover study design that required participants to attend one session at the University of Waikato Adams Centre for High Performance laboratory with the experimental protocol detailed in Figure 1. Participants were given written and verbal information regarding the study and were made aware of potential risks associated with participation (those associated with performing physical activities, running, and running in a new pair of running shoes) before giving informed written consent. Runners were told that the study aimed to examine if super shoes improved running economy and comfort in the "everyday" runner compared to a "knock-off" super shoe. Baseline measures of height (stadiometer, Seca model 0123), mass (digital scale, Seca model ESE813), and lactate concentration levels (Lactate-Pro 2 analyser, Arkray Inc., Kyoto, Japan) were collected to the nearest 0.1 cm, 0.1 kg, and 0.1 mmol/L, respectively. The participants' own shoes were assessed using the Minimalist Index, which is a valid and reliable rating scale used to determine the minimalism of running shoes. It uses five shoe characteristics (weight, flexibility, stack height, stability and motion control technologies, and heel-to-toe drop) to determine how "minimalist" or "maximalist" a running shoe is (Esculier et al., 2015).

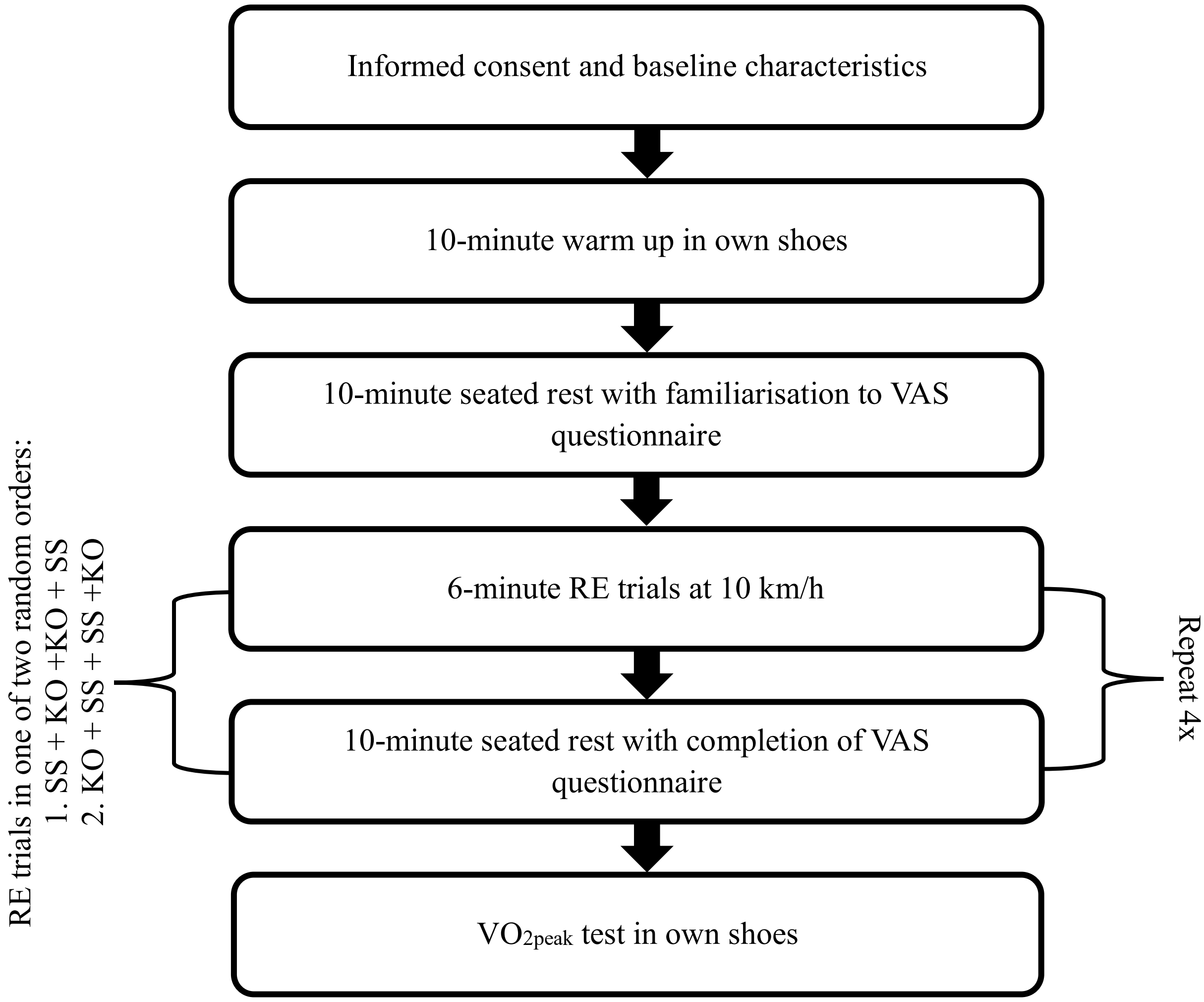

Figure 2. Flow diagram of the experimental protocol. KO, knock-off; RE, running economy; SS, super shoe; VAS, visual analogue scale; VO_{2peak}, peak oxygen uptake.

In the two experimental conditions examined, the same running shoe model (Women's Nike ZoomX Vaporfly Next% 2) was used (for US 7.5 W, 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 that 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.

To ensure participants were unaware the shoes were the same, the "knock-off" shoe was spray-painted black (Figure 3).

Figure 3. Women's Nike ZoomX Vaporfly Next% 2 used for the study. The shoe described as a "knock-off" was spray-painted black (right photo).

Before the experimental trials, participants completed a 10-minute warm-up at a self-selected speed of up to 10 km/h on a motorised treadmill (Steelflex PT10 Fitness, Steelflex Fitness, Taipei, Taiwan) at a 1% incline. The surface stiffness of the treadmill is of 365 kN/m (Hébert-Losier et al., 2022), reflective of a *hard* (350 kN/m) treadmill surface (Hardin et al., 2004) and comparable to an HP Cosmos treadmill (C, Quasar LE 500 CE, HP Cosmos Sports & Medical GMBH, Nussdork-Traunstein, Germany) (Smith et al., 2017). After the first five minutes, participants were fitted with the metabolic cart headgear and mouthpiece. At the completion of the warm-up, participants removed their shoes. For familiarisation, participants completed a 12-question visual analogue scale (VAS) questionnaire on perceived shoe comfort, shoe properties, and overall running experience (Hébert-Losier et al., 2024) that was to be used during experimentation (detailed below).

Thereafter, participants were fitted with the metabolic cart headgear and mouthpiece connected to the calibrated metabolic cart (True One 2400, Parvo Medics, Salt Lake City, Utah, USA) and ran for six minutes at 10 km/h and a 1% incline. Participants completed four RE trials in total, two in each shoe condition, assigned in a randomised and mirrored sequence (super shoe, "knock-off", "knock-off", super shoe or "knock-off", super shoe, super shoe, “knock-off”). Throughout the 6-minute trials, heart rate (HR, Polar RS800CX, Kempele, Finland) was recorded at 15-second intervals and expired gases were continuously measured by the metabolic cart to determine oxygen consumption (VO_2) and respiratory exchange ratio (RER). The highest 30-second mean VO_2 (mL/kg/min) registered in the last minute of each bout for each participant was used as an oxygen consumption measure to determine energy cost (W/kg) and energetic cost of transport (J/kg/min) using the Péronnet and Massicotte (1991) equation. Data were monitored for RER levels above 1.00, which indicates running above the anaerobic threshold with a proportion of energy provided via anaerobic pathways.

Immediately upon completion of each RE trial, ratings of perceived exertion (RPE) using a 6-20 Borg scale (Borg, 1982) and blood lactate concentration levels 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. The same researcher placed and removed the experimental shoes for participants to limit their interactions with the shoes.

The 12-question VAS questionnaire was administered using an Apple iPad (iPad Air 2, MH0W2X/A (15.0)) via the Qualtrics offline survey application (Qualtrics©, Provo, UT (17.1.7)) and examined subjective perceptions of overall comfort, shoe properties, and overall running experience using 0 to 100 mm scales. 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). Four of these properties (heel cushioning, forefoot cushioning, shoe stability, and forefoot flexibility) were used to derive the Running Shoe Comfort Assessment Tool (RUN-CAT) score, where 100 represents the most ideal shoe and 0 the least ideal (Bishop et al., 2020). RUN-CAT was calculated using the following equation:

$$\begin{aligned}\mathrm{RUN-CAT} = &\big((100 - \mathrm{ABS}(50 - \text{heel cushioning}) * 2) * 0.175\big)\\ &+ ((100 - \mathrm{ABS}(50 - \text{forefoot cushioning}) * 2) * 0.311)\\ &+ \big((100 - \mathrm{ABS}(50 - \text{forefoot flexibility}) * 2) * 0.247\big)\\ &+ \big((100 - \text{shoe stability}) * 2\big) * 0.277)\end{aligned}$$

Overall running experience included VAS ratings for pleasure/displeasure, easier/harder, performance, and injury risk. Traditional anchor points were used, where the midpoint reflected “neutral” and the endpoints reflected the two extremes. A higher score indicated greater pleasure, running feeling easier, greater performance, and lower 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. The answers were voice recorded using the Apple Voice Memos application on an Apple iPhone 11Pro (MWC22X/A(17.4.1)) and the primary investigator asked whether runners had additional comments relating to their running experience in the shoes to assess the quality of blinding of participants to conditions. 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 to 8 km/h) based on lactate and RER values during the RE trials. The treadmill was set at a 1% incline, and the speed of the treadmill was increased by 1 km/h every minute until volitional cessation.

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, 2015) using data from the first and second RE trials completed in each shoe. 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 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, 2015). Absolute reliability was deemed acceptable when the CV was < 10% and suboptimal when the CV was ≥ 10% (Atkinson & Nevill, 1998). Paired *t*-tests were conducted to identify significant systematic bias in means between trials, with statistical significance set at $p \leq 0.05$ for all analyses.

To statistically compare RE and perceptual measures between footwear conditions, data from the two RE trials for each shoe condition were averaged. Physiological and perceptual data were analysed using two-tailed paired *t*-tests. Cohens *d* magnitudes with 95% confidence intervals [lower, upper] were extracted and the effect size (ES) differences were interpreted using the following thresholds: < 0.20 *trivial*, 0.20 *small*, 0.50 *moderate*, and 0.80 *large* (Lakens, 2013). All analyses were performed using Microsoft Excel (Microsoft® Excel for Mac, Version 16.82 (24021116), 2024). Ranking data were analysed using an exact binomial probability calculation for hypothesis testing through VassarStats (Lowry, 2023). Statistical significance was set at $p \leq 0.05$ for all analyses.

Results

Twenty-six participants were recruited and completed the experimental protocol. However, two participant data sets were above the aforementioned RER threshold suggestive of running above their aerobic threshold. These data sets 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/min, speed at VO_{2peak}: 15.8 ± 1.3 km/h, minimalist index of own shoes: 23 ± 7.9 %) were used for statistical analyses. The 10 km/h speed used in the RE trials reflected 64 ± 5 % (range: 56% to 77%) of the speed reached at VO_{2peak}. In the exit interview, two of the 24 participants (8.3%) indicated they believed the shoes were the same.

Reliability

Running economy measures. There were no significant differences between the two trials run in each shoe across physiological 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, *good* for oxygen consumption and lactate, and *fair* for energetic cost, energetic cost of transport, and RER. Absolute reliability was acceptable for all physiological measures (CV ≤ 4.0%) except for lactate (CV = 20.8%, Table 1).

Perceptual measures. There were no significant differences between the two trials ran 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 to 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 running economy trial physiological measures from 24 female recreational runners. Data are from the first (1) and second (2) trials ran in each shoe.

Physiological measures	**Comparison**		**Statistics**			
	1 (raw units)	**2 (raw units)**	**TE (raw units)**	**CV (%) [95% CI]**	**ICC [95% CI]**	***p*-value**
Oxygen consumption (mL/kg/min)	32.17 ± 2.41	32.16 ± 2.29	0.82 [0.69, 1.03]	2.6 [2.13, 3.21]	0.88 [0.80, 0.93]	0.966
RER	0.89 ± 0.04	0.90 ± 0.05	0.03 [0.02, 0.03]	3.1 [2.54, 3.82]	0.65 [0.46, 0.79]	**0.028***
Lactate (mmol/L)	1.6 ± 1.0	1.3 ± 0.7	0.31 [0.26, 0.39]	20.8 [17.35, 26.11]	0.87 [0.77, 0.92]	**< 0.001***
Energy cost (W/kg)	11.30 ± 0.93	11.39 ± 0.76	0.46 [0.38, 0.57]	4.0 [3.36, 5.05]	0.72 [0.55, 0.83]	0.333
Energetic cost of transport (J/kg/m)	4.07 ± 0.34	4.10 ± 0.27	0.16 [0.14, 0.21]	4.0 [3.36, 5.05]	0.72 [0.55, 0.83]	0.333
Heart rate (bpm)	148.3 ± 13.2	148.9 ± 13.5	4.00 [3.33, 5.01]	2.7 [2.24, 3.37]	0.91 [0.85, 0.95]	0.445

Abbreviations: CI, confidence interval; CV, coefficient of variation; ICC, intra-class correlation coefficient; RER, respiratory exchange ratio; TE, typical error.

* Significant difference ($p < 0.05$) between trials based on paired *t*-tests

Table 2. Reliability statistics of VAS scores from 24 female recreational runners. Data are from the first (1) and second (2) trials ran in each shoe.

	Comparison		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

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 ($p < 0.05$) 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

Running economy measures. Across all measures, there were no significant differences between conditions ($p \geq 0.077$). The difference in oxygen consumption between super and “knock-off” shoes ranged from -4.3 to 4.1%, and in energetic cost and energetic cost of transport from -4.8 to 4.3%. Descriptive statistics for physiological measures are presented in Table 3.

Perceptual measures. Runners perceived the super shoe as more comfortable overall (*large* ES = 0.94) and felt the super 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 risk of injury 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” shoe, 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).

Table 3. Running economy trial physiological measures from 24 female recreational runners. Data are an average of two trials per shoe condition per participant.

	SS	KO	Difference (SS - KO)		
Physiological measures	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Effect size [95% CI]**	***p*-value**
Oxygen consumption (mL/kg/min)	32.37 ± 2.24	32.13 ± 2.21	0.24 ± 0.64	0.11 [-0.01, 0.23]	0.077
RER	0.90 ± 0.04	0.90 ± 0.04	0.00 ± 0.01	-0.02 [-0.13, 0.10]	0.790
Lactate (mmol/L)	1.5 ± 0.8	1.5 ± 0.9	-0.1 ± 0.3	-0.06 [-0.19, 0.07]	0.335
Energy cost (W/kg)	11.45 ± 0.74	11.36 ± 0.74	0.08 ± 0.24	0.11 [-0.02, 0.24]	0.100
Energetic cost of transport (J/kg/m)	4.12 ± 0.27	4.09 ± 0.27	0.03± 0.09	0.11 [-0.02, 0.24]	0.100
Heart rate (bpm)	148.9 ± 13.1	148.5 ± 13.1	0.4 ± 1.9	0.03 [-0.03, 0.09]	0.274

Abbreviations: CI, confidence interval; KO, "knock-off"; RER, respiratory exchange ratio; SD, standard deviation; SS, super shoes.
p-values are for comparisons between conditions based on paired *t*-tests

Table 4. VAS scores and shoe preference rankings from 24 female recreational runners. Data are an average of two trials per shoe condition per participant, except for rankings.

	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[†∫]	58.3 ± 12.4	49.3 ± 14.9	9.0 ± 19.3	0.65 [0.05, 1.24]	0.033*
Forefoot cushioning[†∫]	53.7 ± 14.0	46.5 ± 10.4	7.2 ± 14.0	0.58 [0.10, 1.06]	**0.019***
Forefoot flexibility[†∫]	49.5 ± 9.8	47.8 ± 9.5	1.7 ± 8.8	0.17 [-0.20, 0.54]	0.366
Shoe stability[†∫]	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 (very bad, neutral, very good)	68.3 ± 18.6	52.5 ± 17.9	15.8 ± 21.6	0.87 [0.32, 1.39]	**0.002***
Easier/harder (much harder, neutral, much easier)	69.7 ± 17.5	50.5 ± 18.6	19.2 ± 21.0	1.06 [0.50, 1.61]	**< 0.001***
Performance (much worse, neutral, much improved)	70.7 ± 14.9	52.1 ± 16.9	18.5 ± 16.5	1.16 [0.62, 1.69]	**< 0.001***
Injury risk (higher risk, neutral, lower 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, %)	21 (87.5%)	3 (12.5%)	18 (75%)		**<0.001***

Shoe preference performance (n, %)	21 (87.5%)	3 (12.5%)	18 (75%)	**<0.001***
Shoe preference injury risk (n, %)	19 (79.2%)	5 (20.8%)	14 (58.3%)	**0.003***

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

* Significant difference ($p < 0.05$) 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.

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. Contrary to our original hypothesis, there were no significant differences in RE measures between the super shoe 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, challenging the notion that superior shoe comfort leads to improved RE measures (Fuller et al., 2015; Luo et al., 2009; Sinclair, Mcgrath, et al., 2016; Sinclair, Shore, et al., 2016). Noteworthy is that all significant differences in perceptual measures between super shoes and "knock-off" shoes (mean difference: 7.2 to 19.2 mm) were above the between-trial difference for a given shoe extracted from our data set, 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 would suggest otherwise. While our results indicate 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 sprints (de la Vega et al., 2017), 3 km race performances (Ross et al., 2015), and 6-minute time trials (Valero et al., 2024). Previous research has identified that inducing a relaxed emotional state leads to RE improvements (Brick et al., 2018). It is possible that the description of the super shoe we used did not encourage such an emotional state, and rather led to an agitated and activated state of mind, not conducive to improving RE measures (Brick et al., 2018). As such, a potential placebo effect from running in AFT for time-trial, maximal, or racing efforts cannot be ruled out based on our observations from submaximal running trials.

Given the apparent absence of a potential placebo effect on RE, 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 basis than a psychological one. The mechanical properties of the shoes themselves – such as their lightweight properties (Hébert-Losier & Pamment, 2023), highly compliant and resilient midsole foam (Hoogkamer et al., 2018), and increased longitudinal bending stiffness via the carbon fibre plate (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 shoe and its 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 description of the shoes significantly influenced the perceptual measures, agreeing with findings from prior shoe research (Chan et al., 2020; Hennig & Schulz, 2011). Chan et al. (2020) blinded participants to two shoe conditions where the same pair of LiNing shoes were used. One pair was described as the latest shoe model worth USD 150 yet to be released, designed to maximise comfort, and made from highly expensive material, whereas the other was described as a regular running shoe available on the market designed for distance running worth USD 50. Participants favoured the former shoe, 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 between shoes was larger (average difference: 14.6 mm, *large* ES = 0.94); together, these results indicate that the descriptions of shoes, marketing, and sales tactics can significantly influence the subjective perceptions of shoes, including comfort. As such, comfort might not be the best guide to shoe selection in the presence of distracting and influencing factors. Noteworthy is that the largest difference in perceptual measures between shoes was for performance scores (18.5 mm, *large* ES = 1.16), which aligns with the performance focus we placed on the description of the super shoe. In contrast, there were no significant differences in RUN-CAT measures between shoes, despite overall comfort and some of the individual components of the RUN-CAT being significantly different (i.e., heel cushioning and forefoot cushioning). This finding questions the validity of the RUN-CAT for measuring the overall comfort of shoes with similar characteristics.

The majority of participants preferred the super shoe over the "knock-off", indicating that a potential bias towards one shoe can be built based purely on product description and price. Hennig and Schulz (2011), found similar results comparing overall running shoe quality from five well-known sports brands and one German discount shoe. Shoes from the well-known brands received higher ratings when participants were not blinded to the shoes, whereas the German discount shoe was rated similarly to the others when participants were blinded to shoe brands. Thus, their results support the existence of a bias to brand names and images. In fact, a review of the footwear literature indicates that when individuals are made aware of the functional benefits of shoes and have positive expectations, performance generally improves (Lam et al., 2022). Collectively, research supports the assertion that shoe description can influence runners' perceptions, and therefore, their likelihood to purchase a given shoe. Furthermore, perceptions may have been influenced by other factors such as shoe colour.

There are many psychological factors, such as enthusiasm, self-confidence, and motivation, that can aid or hinder performance (Sarkar & Fletcher, 2014), which were not assessed herein. Furthermore, 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, participants perceived the shoe increased their running performance. Thus, 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 was physiologically sustainable and would not lead to early onset of fatigue.

Strengths

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 super shoes and "knock-off" shoes (except ratings on technical and supporting features) exceeded the between-trial TE, strengthening the validity of the findings. Furthermore, other researchers can use the physiological and perceptual reliability data to inform the meaningfulness of subsequent between-shoe comparisons. The absolute reliability we observed for oxygen consumption (CV = 2.6%) is similar to those observed by Morgan et al. (1994) at a speed of 11.3 km/h in female runners (CV = 2.2%), whereas the reliability of perceptual measures related to shoe properties and overall comfort (ICC = 0.44 to 0.78, TE = 5.1 to 9.6 mm) were marginally better than those reported by Lindorfer et al. (2019) (Spearman *rho* = 0.52 to 0.69, TE = 15.0 to 17.9 mm). The blinding of the shoe conditions was mostly effective with only 8.3% of runners expressing their belief that the conditions were the same. The data from these participants were maintained for statistical analysis for the ecological validity of findings and our stated intention to attempt to influence perceptions. Also, the use of a randomised mirrored crossover study design meant multiple trials were collected to examine the responses of the intervention in a randomised sequence (Barrons et al., 2024).

Limitations

Limitations exist to our study, including that the testing was completed at only one speed of 10 km/h, representing on average 64% of the runners' speed at VO_{2peak}. This speed was chosen *a priori* based on the targeted population of female recreational runners and to ensure participants stayed below their anaerobic threshold. This study only examined submaximal RE measures, therefore, the potential for a placebo effect from running in AFT cannot be ruled out for time trials and race performances. Although focusing on only female recreational runners is a strength as females are historically underrepresented in sport and exercise science research (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 from wearing AFT does not exist for male or higher-performing runners.

Conclusion

Contrary to expectations, there was no significant placebo effect on RE measures when AFT shoes were described as performance-enhancing, despite these being perceived as more comfortable and making running easier than the same shoe described as a super shoe "knock-off". Therefore, the benefits of wearing AFT on RE appear to be linked with the shoe properties and how runners interact with the shoes. Agreeing with expectations, our study provides evidence that product description significantly influences perceptual measures of shoes, including comfort and expected performance.

Chapter Three – Final Chapter

Summary, strengths, limitations, future research directions, and conclusion.

Summary

Since their release in 2017, shoes containing AFT have been shown to improve RE on average in both elite and recreational runners compared to lightweight and other racing shoes (Barnes & Kilding, 2019; Hébert-Losier et al., 2022; Hoogkamer et al., 2018; Hunter et al., 2019; Joubert et al., 2023). While no consensus definition of AFT exists, the typical features of AFT shoes are their general curved geometry, a lightweight compliant and resilient energy-returning midsole foam, and a curved rigid plate embedded in the midsole that is often made of carbon fibre. These features are proposed to contribute to the improvements seen in AFT. Other than shoe features, it has been proposed that a potential placebo effect of wearing AFT exists (Hébert-Losier et al., 2022; Hoogkamer et al., 2019; Hunter et al., 2019) and may contribute to improvements in RE. Indeed, non-footwear related research suggests performance improvements in maximal running performances due to a placebo effect (de la Vega et al., 2017; Ross et al., 2015; Valero et al., 2024). Furthermore, sporting products from well-known brands such as Nike Inc. have been shown to objectively enhance the performance of its users due to the brands' strong performance associations when compared to unbranded products that are materially identical (Germann & Garvey, 2022). Together, these studies indicate that positive beliefs in and expectations of interventions, such as AFT, as well as branding in sporting contexts, may underpin the RE improvements seen in shoes containing AFT. Contrary to the original hypothesis, there were no significant differences in RE measures of female recreational runners between the super shoe and “knock-off” conditions despite significantly greater comfort and performance ratings in super shoes and runners overall preferring this shoe. There was no significant placebo effect from wearing AFT shoes on RE measures detected.

Furthermore, most runners felt the super shoes were more comfortable and made running easier, as well as preferred the super shoes over the knock-off shoes. These results reinforce how descriptions of shoes can significantly influence the perceptual measures of runners, agreeing with findings from prior shoe research (Chan et al., 2020; Hennig & Schulz, 2011). It has been stated that comfort is the most important shoe selection criterion for recreational runners (Van Alsenoy et al., 2023), and that increased footwear comfort improves RE measures in recreational and trained runners (Luo et al., 2009; Sinclair, Mcgrath, et al., 2016; Sinclair, Shore, et al., 2016). However, this association has been challenged by findings from Lindorfer et al. (2020). The more positive perceptions of the female recreational runners in Chapter 2 towards the super shoes did not translate into improved RE, also challenging the notion that superior shoe comfort leads to improved RE measures (Fuller et al., 2015; Luo et al., 2009; Sinclair, Mcgrath, et al., 2016; Sinclair, Shore, et al., 2016). It is worth noting, however, that a potential placebo effect from running in AFT for time-trial, maximal, or racing efforts cannot be ruled out based on our observations from submaximal running trials. It is also possible that our findings based on female recreational runners do not extend to other cohorts of runners, such as elite and male runners.

Strengths

The findings of this research contribute to the body of literature on AFT, and literature on perceptions of shoes including comfort and performance. The cohort used for the experimental protocol was females, a population who has historically been underrepresented in sport and exercise science research (Cowley et al., 2021; Martínez-Rosales et al., 2021) and is underrepresented in AFT research (Mason et al., 2024). The same researchers delivered the information and experimental protocol to all participants, limiting inter-tester differences within the study. Furthermore, the use of a randomised mirrored crossover study design for the experimental protocol meant multiple trials were collected to examine the responses of runners to shoe conditions, considered best practice for assessing improvements in RE associated with running in AFT (Barrons et al., 2024).

Limitations

Limitations exist to this thesis, including the lack of a maximal running effort in the experimental protocol; therefore, a potential placebo effect from running in AFT for maximal running (e.g., time trials and race performances) cannot be ruled out. A further limitation in the experimental protocol is the use of only one testing speed of 10 km/h, which represented on average 64% of the runners' speed at VO_{2peak}. Although focusing only on female recreational runners is a strength due to the underrepresentation of females in sport and exercise science research (Cowley et al., 2021; Martínez-Rosales et al., 2021), as well as in AFT research (Mason et al., 2024), it limits the generalisation of these findings to other populations such as male or higher-performing runners. It cannot be concluded from the results presented in this thesis that a placebo effect from wearing AFT does not exist in these populations. It was chosen to maintain data from the two participants who thought the two shoes were the same for ecological validity. Excluding these participants from analysis resulted in similar findings with no significant between shoe differences in physiological measures, and these significant differences in perceptual measures being slightly greater.

Future research directions

Future research can build upon the findings presented by addressing the limitations within the experimental protocol, namely including a maximal effort running task and examining higher performing runners or males. Future research could also seek to further explore how individual runners interact with AFT shoes as a possible explanation for the inter-individual differences in RE responses to AFT reported in the literature. For instance, research could seek to examine a range of demographic, anthropometric, neuromuscular, and biomechanical characteristics to explore whether differences exist between responders and non-responders to AFT footwear.

Conclusion

Overall, this thesis provides supporting evidence that product descriptions can influence perceptual measures of running shoes, including comfort and performance expectations, but not necessarily RE measures. There was no significant difference in RE measures between the two shoe conditions examined, suggesting no placebo effect of AFT on RE in female recreational runners despite shoes being preferred, rated as more comfortable, and believed to make running easier when described as performance-enhancing super shoes compared to knock-off shoes. Future research is warranted to ensure the generalisation of results to runners who are not recreational female runners and running efforts that exceed the aerobic threshold.

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Appendices

Appendix A – HECS Ethics Approval

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THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

13 April 2023

Kim Hébert-Losier
Martyn Beaven
Jean-Francois Esculier
Blaise Dubois
Steve Finlayson
Ashlynne Pfister
Peter Lamb

Re: HECS Ethics Approval of Application HREC(HECS)2023#13 "Running economy, biomechanics, and comfort in two different shoes"

Dear Kim:

Thank you for submitting your amended application HREC(HECS)2023#13 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruitment of approximately 26 female recreational runners for a study that examines the potential placebo effect of advanced footwear technology on running economy, biomechanics, and comfort.
- Ensure proper fit of two different shoes (Shoe A and Shoe B) on participants and fit participants with retro-reflective markers and inertial measurement units on shoes and lower-extremity to monitor movement.
- Have participants will warm-up by running on a treadmill for 10 minutes in own shoes (5 minutes without VO2 equipment, 5 minutes with VO2 equipment).
- Have participants complete four running economy trials on a treadmill at 10 km/h, alternating between Shoe A and Shoe B. Between trials, participants will rest for 5 minutes and complete short questionnaires.
- Complete a treadmill running maximal oxygen consumption test to determine aerobic capacity.
- The session should last no longer than 90 minutes.

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

Brett Langley, PhD
Chairperson

Appendix B – RPE & Lactate Collection Sheet

Subject ID #

LACTATE DATA COLLECTION SHEET

Name		**Date**	
Time		**Height (cm)**	
Weight (kg)		**Resting lactate**	

STAGE	**TIME (mins)**	**RPE**	**LACTATE**
RE 1			
RE 2			
RE 3			
RE 4			
VO_{2max}			

Comments:

Appendix C – Qualtrics© Comfort and Shoe Property VAS Questionnaire

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Overall comfort – Consider your overall comfort in these shoes. How did the shoe feel?

Not comfortable at all (0)										Most comfortable imaginable (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Heel cushioning – Consider the cushioning in the heel of the shoe. How do you feel?

Heel not cushioned at all (0)					Ideal (50)					Heel too cushioned (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Forefoot cushioning – Consider the cushioning in the forefoot region of the shoe. How do you feel?

Forefoot not cushioned at all (0)					Ideal (50)					Forefoot too cushioned (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Forefoot flexibility – Consider the flexibility in the forefoot region of the shoe. How do you feel?

Forefoot not flexible at all (0)	Ideal (50)	Forefoot too flexible (100)

0 10 20 30 40 50 60 70 80 90 100

Please move slider

Shoe stability – Consider the overall stability of the shoe. How do you feel?

Shoe not stable at all (0)	Ideal (50)	Shoe too stable (100)

0 10 20 30 40 50 60 70 80 90 100

Please move slider

Shoe stiffness – Consider the overall stiffness of the shoe. How do you feel?

Shoe not stiff at all (0)	Ideal (50)	Shoe too stiff (100)

0 10 20 30 40 50 60 70 80 90 100

Please move slider

Technical and supporting features – Consider the overall technical and supporting features of the shoe (arch, motion control, rigid heel counter, supportive tensioned upper, etc.). How do you feel?

No features at all (0)					Ideal (50)					Too many features (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Shoe weight – Consider the overall weight of the shoe. How do you feel?

Shoe too light (0)					Ideal (50)					Shoe too heavy (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Pleasure-displeasure – Consider overall how you felt running in these shoes (pleasure-displeasure)

Very bad (0)					Neutral (50)					Very good (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Easier-harder – Consider overall how difficult it felt running in these shoes (easier-harder)

Much harder (0)					Neutral (50)					Much easier (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Performance – Consider overall how you feel these shoes might influence your performance (worse-improve)

Much worse (0)					Neutral (50)					Much improved (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

Injury – Consider overall how you feel these shoes might influence your risk of injury (worse-improve)

Much higher risk (0)					Neutral (50)					Much lower risk (100)
0	10	20	30	40	50	60	70	80	90	100

Please move slider

→

Appendix D – Post RE Trial Shoe Condition Ranking

Post RE Trial Shoe Condition Ranking

Overall, which shoe was the most comfortable?

1. ___________________________ (most comfortable)
2. ___________________________ (least comfortable)

Overall, which shoe do you think you would perform the best in under a race or time-trial situation?

1. ___________________________ (best performance)
2. ___________________________ (worst performance)

Overall, in which shoe do you think your injury risk would be lowest?

1. ___________________________ (lowest risk of injury)
2. ___________________________ (highest risk of injury)

Appendix E – Post RE Trial Debrief

Debrief

Thank you for your participation, I really appreciate your help. I have just a couple of questions that I would like to finish with and record your responses

1. What are some stand-out differences between the shoes that you used today?
2. Which pair of shoes would you be most likely to purchase and why?
3. Is there anything else that you would like to share with the research team about your experience today?