Technological Advances in Track Spike Design Facilitate Enhanced Running Performance

by

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Abstract

The purpose of this study was to investigate the potential impact that super spikes have on step measures and running speed. Here, we aimed to evaluate middle distance spikes using a novel effort-based approach; rather than at maximum effort, 12 collegiate track runners were instructed to run 200m repeats at self-perceived mile race pace, in different spikes while we recorded their interval times and lower limb running biomechanics using inertial measurement units (IMUs). For each trial, we calculated average speed, average step frequency, average step length, and estimates of contact time, flight time, and peak ground reaction forces (Day et al., 2021). Running in the super spikes resulted in faster interval times, greater running velocities, and longer step lengths when compared to the traditionally constructed track spike. Our data suggests that with the use of super spikes, experienced track athletes could run faster across various distance track events.

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Chapter 1. Introduction & Literature Review

1.1 Introduction:

In the past three years, records have been broken in distance track events, ranging from 800 to 10,000 meters, in parallel with the introduction of modern track spike designs—coined as "super spikes" (World Athletics, 2021; Bermon et al., 2021). This influx begs the question: how much is related to the shoes? Previously, there has been a large surge in marathon performances among world class athletes, and, at least in part, this can be attributable to footwear technology innovations that reduce the metabolic cost of running (Lao, 2021; McKnight, 2019; Muniz-Pardos et al., 2021; Senefeld et al., 2021; Hoogkamer et al., 2016; World Athletics, 2020). Like these modern marathon racing shoes, super spikes feature a combination of a stiff midsole plate and a lightweight, compliant, and resilient midsole foam. In the case of these performances on the track, Healey et al. (2022) in a scoping review speculated that besides the use of super spikes, potential explanations for the influx of notable performances could be related to pace-light technology implemented at high-profile track meets, new track surfaces (i.e., new Mondo surface with greater compliancy), and/or long durations of uninterrupted training during the heights of the COVID-19 pandemic. However, as the design of super spikes take inspiration from that of the modern marathon racing shoes, Spike Lee's adage from Nike's 1989 Jordan ad "It's Gotta Be the Shoes" has become an increasingly popular joke for athletes, designers, and researchers (NIKE INC., 1989). As much as it is usually said in a light-hearted manner, maybe there's some validity to it too?

Traditionally, track spikes were designed with the same functional purpose as studded winter tires, that being to provide grip while in contact with the ground, while not compromising the ride (in this case, the ride of the shoe). This was in part because running ovals were primarily a cinder-based surface; with the typical surface then changing to a synthetic rubber in the late 1950's. Originally, traditionally designed track spikes utilized a very simple construction: an upper (usually leather or suede based as most shoes were back then) with a plastic spike plate, and a small wedge (at most) of Ethylene-Vinyl Acetate (EVA) foam acting as a midsole. In contrast, the controversial design of super spikes re-invents the wheel to an extent, as gone is the traditional design in favour of a new modern approach: a lightweight design, stiff midsole plate (usually carbon based) used in tandem with a plastic spike plate, and a thick, compliant, and resilient midsole foam (usually a given footwear brand's polyether block amide (PEBA) based foam). Funny enough, innovations in track spike designs have caused pandemonium long before this as in 1968, PUMA released a spike with sixty-eight micro spikes—coined the "Brush Shoe", which was banned in international competition shortly after its debut (Healey et al., 2022). Unlike modern marathon racing shoes, there has been a lack of research on the impact and potential benefits of incorporating these design characteristics into spikes designed for distance and middle-distance running on the track. Addressing this knowledge gap is the primary focus of this work, identifying if and how the use of super spikes may influence running performance.

1.2 What Characteristics make "Super Spikes" so Super?

1.2.1 Midsole Foam:

Popularized in the early 2010's by the footwear brand HOKA as a response to the barefoot running craze, maximal cushioning midsole toolings have taken the running world by storm, with the incorporation of thick slabs of proprietary foams being now commonplace on the road. This alternative approach is now seeping into the design of track spikes too. The benefits of adequate cushioning on running economy have been well documented, with the earliest works stretching as far back as the early eighties (Healey et al., 2022). These works (stemming from Nike's Original Innovation Department) found more compliant EVA foam midsoles and midsoles featuring their famed air units improved steady state running economy by 2.8% (Fredrick, 1984). In a similar manner, albeit not midsole related, classic works of McMahon & Greene (1978 & 1979) showed that compliant and resilient track surfaces improved race times over a collegiate season by 2.9%. Thirty years later, Tung et al. (2014) utilized a novel approach to further assess the impact of midsole cushioning free of the many cumbersome confounders (e.g., shoe mass). The treadmill-based study, controlled for footwear geometry, comfort, and mass, requiring participants to run on a compliant EVA foam treadmill deck. An improved running economy of ~ 1.6% was observed when compared to running on a rigid treadmill deck.

Although the concept of improved cushioning through the increase of stack height (foam under foot) is by no means a ground-breaking concept; traditionally, conventional foams (i.e., EVA) have been heavy and lacked the ability to return a suitable portion of mechanical energy from ground contact, both negative factors to performance that negate the advantage of increased cushioning (Hoogkamer et al., 2016; Healey et al., 2022). Up until recently, track spike design was formulated around these pragmatic constraints, trading-off cushioning for the minimization of mass with early track spikes resembling a modern-day ballet flat in terms of under-foot feel. Such constraints have been overcome as modern foams have enabled spike design to break free of this limitation. These new foams are so lightweight that they allow for the optimization of cushioning, comfort, and energy return, all while not adding significant mass.

As Healey et al. (2022) alludes, the metabolic cost of cushioning hypothesis noted in Frederick (1984) and Tung et al. (2014) suggests that compliancy is paramount when considering the proposed benefits of midsole cushioning. Further supporting this notion, McMahon & Greene (1979) determined through testing a range of compliances, that a longer ground contact time from a more compliant foot–ground interaction is accompanied by a longer step length (i.e., the distance covered during ground contact). Healey et al. (2022) indicates that increased ground contact times also allows the muscles more time to produce force; therefore, elongating contact time could decrease metabolic cost, or allow the runner to produce more force (through a favorable shift on the force–velocity curve) and thereby increase their running speed (Takahashi et al., 2016; Kram & Taylor, 1990). This was quite a radical finding as traditionally, shorter ground contact times are associated with increased running performance (Morin et al., 2021).

However, when considering the economical benefits; midsole resiliency should not be ignored. For very compliant surfaces, McMahon & Greene (1979) determined that the benefits faded. Highly compliant foot-ground interactions resulted in decreased maximal running velocities, and reduced performance. Beyond the midsole mass issues, footwear brands were reluctant to change to more complaint midsoles for this very reason. Wear testers and athletes considered these new foam compounds too soft and voiced their concerns over a lack of 'snappiness' for track running; however, recent develops in midsole construction have drastically improved foam's ability to return energy back to the runner (Healey et al., 2022). To put this into perspective, traditional EVA foams return less than 70% of absorbed energy for each foot strike; whereas new PEBA foam returns beyond 85% of energy absorbed at impact (Hoogkamer et al., 2018; Worobets et al., 2014). This innovation and associated findings were consequential, as World Athletics (Track & Field's governing body) established stack height rules, limiting midsole thickness to 20 mm for track events shorter than 800 m, and 25 mm for events 800 m and longer shortly after PEBA foam midsoles toolings were made available to the public (World Athletics, 2020).

While the spring-like nature of this new foam has been suggested as one of the major factors for the observed improved running performance associated with the use of modern marathon racing shoes, its impact on track spikes is yet to be quantified (Hoogkamer et al., 2018 & 2019). Furthermore, the variations in compliancy's effectiveness (McMahon & Greene, 1979) suggests that the impact of midsole cushioning compliancy and resiliency on running performance is likely individualistic; however, this requires further exploration to confirm.

1.2.2 Bending Stiffness:

Longitudinal bending stiffness (LBS) is another characteristic that may be contributing to a track spike's "super-ness". Typically, a heightened LBS is achieved through the implementation of a midsole shank or plate. These stiffening components are commonly constructed using carbon-fibre as it is a fairly strong and durable compound, yet incredibly lightweight, only contributing a negligible addition to shoe mass. One would imagine that the incorporation of such a novel characteristic as implementing carbon-fibre plates would be just that, novel; but this is far from the case. Increasing LBS through the incorporation of carbon-fibre plates in the midsole and/or outsole of track spikes has been a common practice in the running footwear industry for two-plus decades; yet the effect of increasing LBS on running performance remains not well understood. This lack of understanding may be in part due to the implementation of heightened stiffness only really being (up until quite recently) implemented within sprinting track spikes, specifically in the form of a spike plate.

Now a characteristic featured in most modern marathon racing shoes, heightened LBS within the distance running context as discussed extensively in the academic works leading up to Nike's Breaking 2 event, results in a reduction in energy lost at the metatarsophalangeal (MTP) joint. During running gait, specifically the stance phase, the MTP joint absorbs mechanical energy through the act of dorsiflexion; then remains dorsiflexed throughout most of heal and toe-off phases, returning a small percentage of originally absorbed mechanical energy (Healey et al., 2022). At each given toe off, on average, while sprinting at 7.1-8.4 m/s, an athlete loses ~48 J of energy (Stefanyshyn & Fusco, 2004). That lose of energy decreases to a range of 13-21 J for an athlete running at 4.0-4.4 m/s (Hoogkamer et al., 2019). However, this observed lose of energy can be reduced through the implementation of a stiffening midsole plate. Heightened LBS aids in the reduction of energy lose by reducing the MTP joint's ability to dorsiflex during the stance phase, and thus reduces the amount of energy lost during the terminal portion of stance. Healey et al. (2022) notes that heightened LBS, along with stiffening the MTP joint, also shifts the point force application more anteriorly, generating a greater moment arm at the ankle, which in turn is speculated to facilitate a more effective application of horizontal force, resulting in improved running performance (Willwacher et al., 2014). However, recent work by Ortega et al. (2021) suggested that heightened LBS may also increase the force demands of the plantar flexors, which may in turn negate the supposed advantageous properties of increased LBS noted in Healey et al. (2022) and Willwacher et al. (2014) rendering altered LBS in running shoes futile. Furthermore, recent works have suggested that heightened LBS may be a complete gimmick, citing no changes in ground reaction force variables consistent with improvement in the acceleration or upright phases of sprinting (Ding et al., 2016; Nagahara et al., 2018). Yet, the argument may still be able to be made for increasing LBS, albeit in an individualistic manner.

Both Stefanyshyn & Fusco (2004) and Smith et al. (2016) featured similar study designs, altering participants' spikes' LBS for sprint intervals of 40m. Intervals were run in spikes with increasing LBS, beginning at 42 N/mm, to 90 N/mm, finishing at 120 N/mm. No significant impact on sprint times were observed with increasing LBS at the group level in either work; however, on an individual level, some athletes displayed improvement. This finding, although seemingly insignificant is important to note as it supports the concept of individualized optimal LBS. Further supporting this individualistic idea, Willwacher et al. (2016) also observed no change at the group level, but at the individual level, participants saw some improvements while sprinting in different stiffness conditions. It was suggested that this individualized response to stiffness may be linked to the musculature (plantar flexor strength) of the participants, with participants employing different strategies to overcome the increased ankle joint moment demands due to the increased LBS of the shoes depending on their strength capabilities. For stronger participants, Willwacher et al. (2016) observed an increased ankle joint moment and with near identical ground contact times. Weaker participants were incapable of increasing the joint moment at their ankle, and instead increased their ground contact time resulting in a reduction in sprint performance. As Healey et al. (2022) points out, usually the term metabolic cost does not pop up when discussing sprinting since sprint performance is predicated much more on factors like acceleration and top end speed; however, classic works of Hill (1938) and Bancroft (1947) make it abundantly clear that to produce a greater plantar flexor force, without a longer contact time as seen in stronger participants, an increased metabolic cost incurs. One must then appreciate that even for sprinting, increased metabolic demands will impact how long an athlete can maintain their top speed. Notably, literature has neglected to extensively consider how athlete's mass or foot strike pattern may contribute to the effectiveness or lack thereof of heightened LBS. In regard to foot strike pattern, this lack of literature is likely due to the reality that sprinters simply do not heal strike; however, for athletes running 800m and up, such a pattern is not uncommon. Ultimately, it appears there is an optimal bending stiffness for everyone, and how much a given athlete can benefit from a particular stiffness is predicated primarily on strength capabilities.

1.2.3 Geometry:

Innovation in the design of track spikes has facilitated drastic changes to spike geometry, with the most notable being the aforementioned increased stack height and implementation of the novel forefoot rocker system—sometimes referred to as "toe spring" (the rounding of the radius of the outsole at the forefoot) (Healey et al. 2022; Wilkie et al. 2022). Healey et al. (2022) notes that increased stack heights have mainly been seen in distance and middle-distance spikes, rather than sprint spikes, as sprinters rarely (if ever) heel strike, and therefore do not benefit from increased cushioning. Interestingly, since being published, brands have also begun to incorporate increased stack heights into their sprint spike models as well; although, unlike middle-distance and distance spikes, the majority of the additional stack height for sprint spikes is located in the forefoot, underneath the ball of the foot. It is important to note that while the stack height of super spikes is often much greater than that of traditionally designed track spikes, the World Athletics (WA) has now set the aforementioned legal limits for stack heights for events on the track shorter than 800m, and for events 800m and longer (World Athletics, 2020). These amendments were mostly based on the findings noted in the two previous sections of this review.

In contrast, the impact of the newly implemented toe spring forefoots on running performance is yet to be quantified (Healey et al. 2022). In a study on the Vaporfly (a modern marathon racing shoe with a rocker design), Nigg et al. (2016) suggested that most of the metabolic savings observed while running in the shoe came from a “teeter-totter’ effect, but as noted in Healey et al. (2022) this proposed mechanism remains merely a speculation and is yet to be experimentally verified. Regardless, additional studies have shown that a rocker can be expected to facilitate an improved ride (midfoot to toe transition during the stance phase of gait), and when combined with increased LBS, could reduce ankle plantar flexion moments and their associated plantar flexion muscle force demands which may in turn render some of the limitations of increased LBS not applicable (Farina et al., 2019; Clermont et al., 2021).

1.3 Challenges:

Quantifiable performance, outside of race conditions, can be measured in long distance running through steady-state oxygen consumption, and this can be accurately measured with only several minutes of running and not running to failure, and therefore can be replicated several times in a single session (Barnes & Kilding 2019; Hoogkamer et al., 2016, 2018; Hunter et al., 2019; Hébert-Losier et al., 2020). The benefits of modern marathon racing shoes have been quantified through this approach as improvements in running economy (Hoogkamer et al., 2018; Barnes & Kilding, 2018); which translate to changes in performance, even for events as short as the 3000m. However, this approach is simply not feasible for assessing middle-distance running performance. Middle-distance spikes are specifically designed to provide benefits at high running speeds which do not allow for valid quantification of running economy (Hoogkamer et al., 2019; Day et al., 2021).

On the other hand, sprinting performance can be quantified through acceleration and top speed (Senefeld et al., 2021; Stefanyshyn & Fusco, 2004; Nagahara et al., 2018). Sprint performance testing is essentially a completely anaerobic process, and, given sufficient rest and short sprint duration, these measurements can too, be replicated several times in a single session. Sprint spikes are commonly evaluated based on this method of top speed measures during maximum-effort sprints. Simply put, evaluating middle-distance spikes provides a unique challenge as they are used at speeds faster than can be used to quantify running economy, but slower than full-out sprinting. In taking this into account, it becomes apparent that determining how various parameters affect middle-distance running performance is consequently difficult to examine. To address this, we propose the use of a novel effort-based method previously assessed (Wilkie et al., 2022) to quantify changes in middle-distance performance with enough sensitivity to catch small alterations in parameters (e.g., track spikes worn). Utilizing this approach, we aimed to provide essential findings to improve our understanding of middle-distance running performance and footwear construction for Track & Field.

It is important to note that, in aerobic steady-state distance running, factors that affect running economy can often be related to biomechanical factors such as contact time, stride length, and duty factor (Willwacher et al., 2016; Ding et al., 2011). Additionally, these same step parameters are often seen to be associated with changes in top speed and accelerations in sprinting (Stefanyshyn & Fusco, 2004; Ding et al., 2011; Nagahara et al., 2018). Therefore, these measurements may be a proxy to measurements in middle-distance running performance. Typically, these parameters are measured using in-lab equipment such as force plates and motion capture systems; however, in-lab testing is arduous for middle-distance speeds and has the fault of not accurately reflecting "true" track running due to potential differences in surfaces and environments. Inertial measurement units (IMUs) have been increasingly used in biomechanics as an alternative to in-lab motion capture due to their versatility in being effective in realistic settings.

1.4 Research Goals:

Our primary research goal was to compare IMU measured differences in step parameters in elite male track athletes. We conducted this at a perceived effort (Mile-pace effort) in various footwear conditions (e.g., changes in midsole foam and geometries) and utilized our cutting-edge effort-based approach for the assessment of middle-distance running performance. Additionally, we looked to assess the potential validity of the performance enhancing capabilities of super spikes. Our hypotheses were that we would observe changes associated with enhanced running performance.

We hypothesized that the use of super spikes would have the following significant impact on running biomechanics:

- faster interval times;
- higher running velocities;
- longer step lengths;
- decreased step-time and increased step frequency;
- increased estimated contact time;
- greater peak vertical, horizontal, and resultant ground reaction forces (GRFs).

We also looked to assess “super spikes” by using a previously established (industry formulated) questionnaire. This questionnaire assessed measures (i.e., overall fit, overall comfort, ride, etc.) that were otherwise challenging to assess in a biomechanical manner. We hypothesized that participants would rate aspects of the three super spikes utilized in the methodology more favorably (i.e., prefer them) when compared to ratings associated with traditionally designed spikes. We reported these results to provide context to potentially why particular spikes performed better than others beyond strictly step parameters.

Chapter 2. Methodology

2.1 Ethics:

The data utilized for this investigation was originally collected in tandem with R&D work aiming to examine the performance of a prototype version of Puma's evoSPEED Distance Nitro Elite track spike against competing brand's track spike lineups. The acquired data was obtained by means of strict adherence to our experimental protocol. Prior to testing, all participants read and signed all ethics and consent forms in accordance with the Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans and with UNB Policy (UPRIH). A research ethics certificate was granted by the UNB Fredericton Research Ethics Board ("Assessing Running Performance in New Track Spikes" -- REB #2021-079)

2.2 Participants:

In total, twelve elite male track and field athletes between the ages of 19-45 years of age participated in this study (Table 1). This sample size was based on our previous works (Bertschy et al., 2023; Wilkie et al., 2022) that found significant differences between shoe conditions, respectively, as well as due to pragmatic constraints (i.e., shoe size availability). Elite status was defined as competing at the Canadian U Sports Track & Field level or (if not Canadian) being capable of performing at said performance level. Recruitment of participants was done through means of personal contacts, local track clubs, and university track teams located within the state of Massachusetts and province of New Brunswick. Participants had to be free of any orthopedic, cardiovascular, or neuromuscular conditions, and had not undergone any surgery or sustained an injury within 3 months prior to participation. Participants must also have trained in track spikes in the past six months prior to participation in the study. Lastly, participants had to wear US Men's size 9 track spike to be eligible to participate. All participants were required to give written informed consent per the University of New Brunswick's Research Ethic's Board. Consent was obtained from the participants via a signed consent form which was only available to the researchers prior to, during and post data collection to ensure participant confidentiality.

Table 1. Participants' Descriptive Statistics (m ± SD).

Height (cm)	**Weight (kg)**	**Age (years)**	**PR 800m (mins:s)**	**PR 1500m (mins:s)**	**PR 3000m (mins:s)**
180.7 ± 7.4	69.09 ± 8.30	22 ± 3	2:02 ± 7.65	4:12 ± 17.36	8:59 ± 28.16

Note. (n =12) *&* PR is defined as Personal Record.

2.3 Instrumentation

2.3.1 Inertial Measurement Units:

This work was a continuation of a research collaboration with Puma SE and the University of Massachusetts, Amherst with Dr. Wouter Hoogkamer and his Ph.D. candidate, Montgomery Bertschy. This builds on my honours work that utilized an IMU and effort-based methods for the assessment of middle-distance running performance. IMUs provide a portable, relatively inexpensive solution to obtain functional measures similar to those captured with three-dimensional gait analysis; but their feasibility has yet to be extensively explored for the assessment of running, specifically at speeds > 6 m/s. Three IMUs were used to measure kinematics and estimate step parameters and kinetics associated with athletes' gait at self-perceived mile-effort pace (IMU; Vicon Blue Trident sensor, Vicon, Oxford, UK) . Each IMU sensor was connected via Bluetooth to an Apple device and was synchronised and triggered to record acceleration data onto an on-board secure digital (SD) card at a rate of 1600 Hz in the high G setting. Notably, these IMUs also collect at 1125 Hz in their low G setting, although it was determined in our previous work that the high G setting was more appropriate for the nature of our desired outcome measures. These IMUs, along with acting as accelerometers, feature magnetometers and gyroscopes to collect angular velocities, direction, and position data.

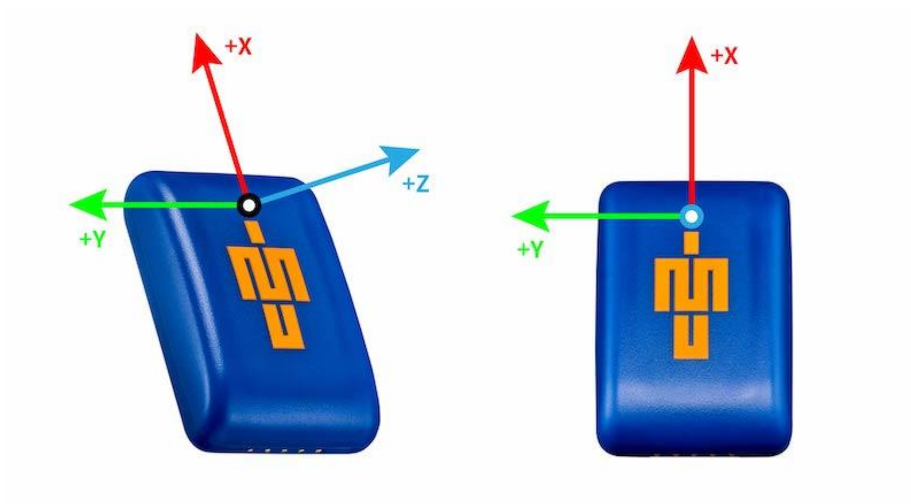

Figure 1. Vicon Blue Trident IMU with displayed 3-dimensional coordinates system (IMU; Vicon Blue Trident sensor, Vicon, Oxford, UK). Visual from Vicon (2022).

A calibration was performed following the instructions within the included user guide for the IMUs when they were initially received before data collection began (Vicon, 2022). Before every data collection, IMUs were assessed to ensure no further calibrations were needed. This was done by utilizing the associated mobile application, Capture.U (Vicon, Oxford, UK). In total, three IMUs were utilized, with an IMU attached at the trunk via a custom 3D printed waistband clip (see Figure 4 in appendix) and on each right and left track spike, upon the top of the lacing system via double-sided tape and Hypafix medical tape (Hypafix Wound Dressing Tape, BSN Medical, Charlotte, U.S.A). The tibial IMU sensors were removed from collections due to excessive movement during test runs and malfunction leading to excessive noise and erroneous acceleration data. Each IMU was triggered to record data for each session via the application, Capture.U (Vicon, Oxford, UK) for the duration of each 200m repeat. Each IMU sensor was waterproof with a 12-h battery life; however, when scheduling participants, factors of weather, specifically, rain, wind, and temperature were considered as to limit potential external influences. The accelerometer data on the IMUs were recorded to the apple device and uploaded once a participant completed all their trials to the Capture.U desktop application. We then viewed and analysed each trial on the cloud dashboard and exported trials as comma separated values files for further data and statistical analysis.

2.3.2 Footwear - Track Spike Conditions:

The four track spike conditions were unfamiliar to the participants and differed from each other regarding the materials utilized (both midsole and upper), geometry, and construction. The foam compound used for the midsole of the TRADITIONAL condition was a low-profile EVA based foam forming a flat geometry with a stack height of 7 mm in the forefoot and 12 mm in the heel. Overall, the TRADITIONAL condition can be categorized as a so-called traditional track spike, being lightweight in construction, while providing only minimal cushioning properties and no additional bending stiffness using a midsole plate. In contrast, the midsole of NEW condition consists of PUMA’s Nitro foam, a lightweight PEBA-based foam compound, forming a much thicker geometry with stack heights of 17 mm in the forefoot and 21 mm in the heel. Unlike the TRADITIONAL condition, a longitudinally embedded carbon fibre midsole plate was integrated into the midsole of NEW condition to offer an increased bending stiffness. Overall, the NEW condition can be categorized as a so-called super spike, providing a compliant and resilient midsole cushioning experience, along with a heighted bending stiffness and lightweight design. The TRADITIONAL spike model utilized by the participants was denoted as a control for all three of the remaining conditions to be compared against. For each participant, fitting models of TRADITIONAL and NEW were assigned based on the individual shoe size. For our analysis, we also utilized two competing brand's track spike models. Much like the NEW spikes, these models also provided compliant and resilient midsole cushioning experiences with use of PEBA (or in house TPU) based foams, along with heighted bending stiffness and lightweight designs. These track spikes were defined as the SS1, and SS2. The SS1 featured a geometry with stack heights of 14 mm in the forefoot and 19 mm in the heel. The SS2 featured stack heights of 19 mm in the forefoot and 27 mm in the heel. Shoe anthropometrics are displayed below (see Table 2). Notably, we determined each one of these descriptive measures for each spike condition by use of an electronic scale and electronic caliper.

Table 2. Spike Condition Descriptive Statistics.

Measures	TRADITIONAL	NEW	SS1	SS2
Offset (mm)	5	4	5	8
Forefoot Stack Height (mm)	7	17	14	19
Heel Stack Height (mm)	12	21	19	27
Foam Type	EVA	PEBA	PEBA	TPU (UD)
Midsole Stiffening System	No	Yes	Yes	Yes
Mass (grams)	155	154	140	163

2.3.3 Questionnaire

The questionnaire was provided by PUMA and was administered to participants via a QR code or hyperlink through their email. Said link took them to the questionnaire, which was formulated utilizing Qualtrics software (Qualtrics, Provo, UT). The assessment consisted of 16 questions, 14 of which being rating scale, and 2 being open-ended. The 14 rating scale questions utilized a slider scale construction, with the scaling including scores from 0 to 100. What represented the two extremes of the scales varied per question. The Appendix displays the complete questionnaire, denoting each specific question/prompt (see Appendix).

2.4 Protocol: Track Spike Testing Protocol

2.4.1 Experimental Setup

A single-blinded crossover methodology was implemented as part of the protocol for our collections. All collections took place at an outdoor 400-meter track facility on days with little to no wind or on an indoor 200m flat track facility. Differences between surfaces and bend lengths were negligible between facilities. The middle-distance track runners enrolled in the study performed a series of 200m repetitions at self-perceived mile race pace. Series of 200m repetitions are a common component of middle-distance training, and all participants were familiar with this type of workout. This was important as the premise of the used protocol was to measure differences in performance, while controlling effort. For middle-distance running we could not use maximal effort trials and the effectiveness of the protocol depended on the participants' ability to run every trial at a similar sub-maximal effort. Theoretically, for experienced middle-distance runners, running a series of 200m repetitions at mile race pace effort lends itself for this. To minimize any confounding effects of participants running the first (excitement) or last (‘emptying the tank’) intervals at a higher effort, we told participants that they would run more intervals than actually needed. Their first interval was considered a habituation trial and was not included in the evaluation, then after the ninth experimental interval, we informed the participants that the data collection was complete. We asked participants to run 10 repetitions, but we only included 8 experimental trials, respectively (two repetitions in each spike condition). The order of spike conditions was randomized for each participant prior to each session.

As noted in the instrumentation section, participants experienced four track spike conditions. For the purpose of this research, the spikes were identified as: A = PUMA (TRADITIONAL), B = PUMA (NEW), C = SS1 & D = SS2. The order in which participants ran in these spikes for the duration of the nine 200m trials was randomized, with each participant running two interval repeats per each spike condition. The order in which spikes were randomized included all 24 possible permutations of “ABCD” (e.g., 1. ABCD, ABCD; 2. BADC, BADC; etc.). Each permutation had a number associated with it (see above). The order of the spikes was decided by using the google assistant function on a Google Pixel 6 Pro Smartphone, with the phrase “OK Google, pick a number between 1 and 24”. The number returned determined the order. After each participant received a number, said number was removed from the pool to ensure no duplications in spike order. This was done to limit chance of order of effects. Once the spike order was determined, the order was noted on the data collection sheet for future reference during data processing. Participants performed each 200m repetition from a standing start (similar to a middle-distance race start) with the commands “three, two, one, go”. Participants were unaware of the times they were running for each repetition as they were not wearing a watch and we did not disclose the times they recorded until after the data collection was complete. Rest between each trial was ten minutes, to allow for changing spikes, filling out questionnaires, and walking to the start of the next repetition.

2.4.2 Prior to Collection

Prior to the start of a collection session, we ensured that all the IMUs were charged, calibrated, and in good working order. Following this, all track spikes were assessed for spike replacement and the Velcro glued to the midsole of the shoes that the blinders attached to were checked to ensure they were still properly attached. Following this, IMUs were prepped for attachment. Micropore tape was added on top of IMUs marked with location to be placed (e.g., "P" (Pelvis)) and stayed consistent through all sessions. Once this was complete, Micropore tape was added on the bottom of the IMUs, followed by double-sided tape in order to facilitate adequate adhesion to the shoelaces that they were placed on (see Figure 5 in the appendix). On the data collection sheet, positions, and orientations of each IMU were noted.

2.4.3 During Collection

When the participant arrived at the track facility, we explained the study protocol to them, and they signed all the necessary forms (i.e., the Get Active Questionnaire (CSEP, 2017) and Consent Form (see Appendix)). We asked participants to run a warmup as they would for a 200m interval session, followed by drills and stretches as they saw fit. After their warmup, we placed an inertial measurement unit (IMU; Vicon Blue Trident sensor, Vicon, Oxford, UK) at the participant's sacrum with a sacrum clip attached to the back of the participant's waistband on their shorts (Day et al., 2021).

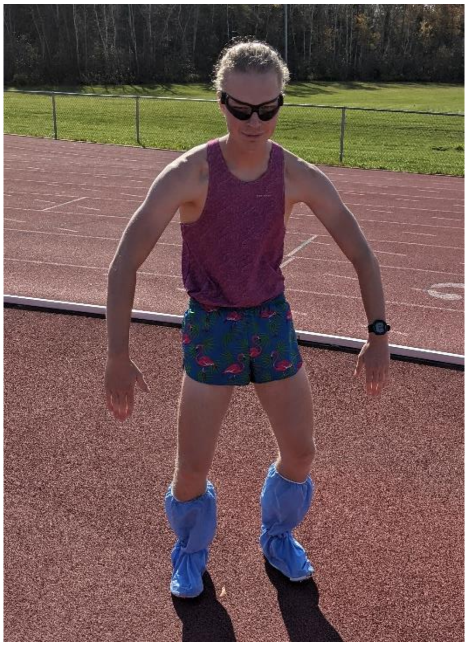

Figure 2. Participant prepared for a 200m interval, with spike blinders of our own design and peripheral limiting eyewear on (Dribble Goggles Training Aid, Spalding, Bowling Greene, U.S.A).

Next, participants removed their shoes (socks could be left on as it made the spikes easier to switch, but this was up to the given participant's preference, and we put fabric spike blinders on the participant's legs (see Figure 2). Then we asked them to put on peripheral limiting eyewear (Dribble Goggles Training Aid, Spalding, Bowling Greene, U.S.A), and we put on the spikes on the left and right feet, while making sure laces were loosened prior (see Figure 2). We tightened each rung of laces tight, but comfortable, once the spikes were on. Once the spikes were securely on and tightened, IMUs were attached with double-sided tape directly on the laces, with a square of HYPAFIX tape on top (this was done to enable IMUs to be transferred between spikes conditions). Following this, spike blinders were pulled down over the spikes. Starting with the front seem in the center, we attached the spike blinders to the Velcro strips we had previously glued around the spikes. Next, we pulled the top of the spike blinders down to the ankles. Spike blinders fit around the participants spikes and lower legs in a non-restrictive fashion, providing a negligible addition to track spike mass. Finally, the participant removed the peripheral limiting eyewear and walked with us to the 200m start line. Once on the line, the Capture.U app was opened and sinked to the Apple device for collection with the IMUs.

At the 200m line we started the IMU recording and then moved towards the finish line. We named each IMU capture on the application and noted the place of collection, interval number, and spike condition (i.e., UNB-9-PUMA-2) prior to starting the capture. We then counted down the runner to start the interval. For the timing of each repeat, we started our stopwatches when the participant started running following the end of the spoken countdown, and stopped their stopwatches when the participant crossed the finish line. Once a trial was complete, the 200m time was saved on a collection sheet and the IMU capture was stopped. Following this, each participant completed a spike questionnaire provided by PUMA (displayed in the appendix), while we changed the spikes. This series of events at the end of each trial was repeated until the nine trials were completed.

2.4.4 After Collection:

Following the completion of a collection session, we removed all the tape and IMUs from the participant and thanked them for their participation. Following this, all IMUs were plugged into a computer with the Capture.U Desktop application to upload all the data from each session Each session's data was then exported as a comma separated values files for data analysis. Lastly, we assessed any wear on the spike blinders or other materials utilized in the collection process and made the appropriate repairs.

2.5 Data Analysis

All data processed through the Capture.U Desktop application in the form of the comma separated values files were imported into Visual Studio code (VS Code) (Version 3.9.7 64-bit, Microsoft, Redmond, WA, U.S.A.) and custom python scripts following a similar methodology to that of Day et al. (2021) were formulated to read these files and calculate and/or estimate the desired outcome measures of interval time, running velocity, step length, step time, step frequency, and estimations of peak vertical, horizontal, and resultant ground reaction forces, as well as flight time and contact time. Within the custom scripts, comma separated values files were opened, and interval specific repeat times were manually imputed to acquire running velocity by utilizing the equation: ***Running Velocity = 200 Meters / Interval Time.*** Following this, the given participant's body mass was manually inputted in kilograms, and participants' body weight was then calculated by multiplying the given mass by gravity (9.81 m/s^2). Three-dimensional (X, Y, Z) high G accelerometer data sampled at 1600 Hz from the corresponding files were then read by the python script and converted to seconds utilizing the said sample rate as a conversion factor.

Estimated peak vertical ground reaction force (GRF) was then determined in a manner previously validated (Day et al. 2021). In-line with this methodology, vertical acceleration data from the pelvis IMU was filtered with a low-pass fourth order Butterworth filter, with a 10 Hz cut-off frequency. Due to the nature of the placement of the pelvis IMU, vertical acceleration data had to be multiplied by a factor of negative one in order to correct its directional component. Following this, the vertical acceleration data was windowed to only include data from the 50% time mark of the interval to the 75% time mark of the interval (approximately representing the 100m to 150m mark of trials) ensuring data was only from when participants were on the straightaway. This was done to limit error from centripetal forces required to run on the bends and minimize the chance of assessing data where athletes may be decelerating (i.e., slowing right before the finish line). A peak finding algorithm was then formulated to find all the maximum peaks in the vertical acceleration data within the given window range. Said algorithm had a minimum distance between peaks set at 200 frames to ensure the only peaks found were in-fact maximum peaks. These peaks were then multiplied by the given participants body mass to acquire peak vertical GRF using Newton's second law formula: ***Est. Peak Vertical GRF = Mass * Acceleration***. Upon this, the mean of these peak vertical GRF values were then taken using the NumPy library package. To normalize the data, we then divided the mean peak vertical GRFs for each participant by their given bodyweight.

Estimated peak horizontal GRF was determined using a very similar method. Adopting the general approach of Day et al. (2021), horizontal acceleration data from the pelvis IMU was filtered with a low-pass fourth order Butterworth filter, with a 10 Hz cut-off frequency. This cut-off frequency was chosen as it followed the previously validated methodology (Day et al., 2021). Again, due to the nature of the placement of the pelvis IMU, horizontal acceleration data had to be multiplied by a factor of negative one in order to correct its directional component. Following this, the horizontal acceleration data was windowed to match that of the vertical, only including data from 50% time mark of the interval to 75% time mark of the interval (approximately representing the 100m to 150m mark of trials). A similar peak finding algorithm was then formulated to find all the maximum peaks in the horizontal acceleration data within the given window range. Said algorithm had a minimum distance between peaks set at 200 frames to ensure the only peaks found were in-fact maximum peaks. These peaks were then multiplied by the given participants' body mass to acquire peak horizontal GRF using Newton's second law formula: ***Est. Peak Horizontal GRF = Mass * Acceleration.*** Upon this, the mean of these peak horizontal GRF values were then taken using the NumPy library package. To normalize the data, we then divided the mean peak horizontal GRFs for each participant by their given bodyweight. Once acquired, we determined an estimate for peak resultant GRF during the specified approximate 50-meter window between the 50% time mark of the interval to 75% time mark of the interval (approximately representing the 100m to 150m mark of trials) for each participant. Using the math function in python and the formula below, estimated peak resultant GRF was determined in terms of bodyweight.

Est. Peak Resultant GRF =

$$\sqrt{(\boldsymbol{EST.Peak\,Vertical\,GRF^2 + EST.Peak\,Horizontal\,GRF^2})}.$$

Following the determination of the peak GRF variables, we sought to determine an estimate for contact time. Similar to our method for determining GRF variables, again we adopted the suggestions made within Day et al. (2021) and filtered our raw vertical acceleration data from the pelvis IMU with a low-pass fourth order Butterworth filter, using a 5 Hz cut-off frequency. Again, this cut-off frequency was chosen as it was in-line with the validated methodology of Day et al. (2021). In-line with our GRF variable data, our filtered vertical acceleration data again was multiplied by a factor of negative one in order to correct its directional component. It was also windowed to match that of the GRF variables, only including approximately 50 meters of data, from the 50% time mark to the 75% time mark of the trials. The data was then multiplied by the given participant's body mass. Following this, a threshold crossing algorithm was formulated to determine when foot strike and toe-off occurred. This algorithm counted the number of times the vertical acceleration data crossed a specified threshold from both the upper and lower ends. In this case, the specified threshold was participant dependent, as the threshold was set to be 5% of a given participant's bodyweight. Required inputs for the algorithm were signal, sample rate, and threshold value. The points in which the signal rose above the threshold were defined as rising indices (foot strike) and the points where the signal dropped below the threshold were defined as falling indices (toe-off). Again, a minimum distance of 200 frames was implemented to correct for any erroneous threshold crossings. Contact times were then calculated via a function that concatenated the difference between each rising and falling index. These were then divided by the sample rate, and the mean was taken using the NumPy library so that average contact time was in seconds.

Average flight time, step time, step frequency, and estimated step length were then determined. Again, a peak finding algorithm was implemented to enable the assertation of these measures. Max peaks above 5% of a given participant's body weight were located and denoted as where a step occurred. Length (in frames) was then determined between consecutive steps and divided by the sample rate to acquire step frequency using the following equation: ***Estimated step Frequency = (2 / ((peaks [i + 1] - peaks[i]) / sample rate)),*** *where i represents the index of a given peak.* Step time was determined in a similar manner, using the following equation: ***Estimated Step Time = ((peaks [i + 1] – peaks [i]) / sample rate/ 2),*** *where i represents the index of a given peak.* Both appendices of determined step frequencies and step times were then windowed to match that of the GRF variables, only including approximately 50 meters of data, from the 50% time mark to 75% time mark of trials. Following this, the average of both these variables was determined using the NumPy library. Estimated step length was then determined using the following equation: ***Estimated Step Length = Running Velocity * Average Step Time.*** Lastly, flight time was determined by subtracting estimated contact time from estimated step time. Notably, the running velocity utilized here included the average of the entire 200m interval, based on interval time, rather than simply a 50m window due to pragmatic constraints. Once complete, all outcome measure data was exported to comma separated values files trial-by-trial via the pandas library for further statistical analysis.

2.6 Statistical Analysis

All statistical analyses were performed within Microsoft Excel (Version 2302, Microsoft, Redmond, WA, U.S.A.). We calculated means and standard deviations (mean ± SDs) for all assessed step parameter variables including interval time, running velocity, step length, step time, step frequency, and estimations of peak vertical, horizontal, and resultant ground reaction forces, as well as flight time and contact time. These were calculated for each individual participant in each spike condition first, where the mean reflected the average of the two trials ran by a participant in a given spike condition. Following this, spike condition means for each step parameter were determined by taking the combined average of each of the participants' means pertaining to the same given spike condition. We then compared all outcome parameters between the traditional and super spike conditions, as well as super spike conditions by super spike conditions. However, for the purpose of this work, we only report comparisons made between the traditional and super spike conditions. Bonferroni corrected paired t tests were utilized to determine which spike-by-spike comparisons differed significantly. A series of paired t tests rather than an ANOVA was chosen as we were focused on strictly assessing the TRADITIONAL versus each super spike condition individually, rather than comparing all conditions against each other. Additionally, we utilized paired t tests to stay in-line with our additional on-going spike studies, in essence to foster consistency and enable appropriate comparisons between works. A traditional level of significance ($\alpha = 0.05$) was employed. Post Hoc, the level of significance was adjusted ($\alpha = 0.0167$), in line with Bonferroni correction methodology. Additionally, we calculated effect size (ES) as Cohen's d and reported percent differences for each measure with the intention of providing relevant context for our determined p values so that an athlete/user may better appraise.

In a similar manner, data from Qualtrics (Qualtrics, Provo, UT) was exported as an Excel spreadsheet, and results from each questionnaire question were compiled and re-organized. Results pertaining to each of the fourteen questions were organized on a spike condition basis and were then graphed in the form of box plots, displaying results pertaining to each spike condition. This enabled comparisons to be made between each condition with ease. These plots displayed mean response score, as well as extremes.

Chapter 3. Results

The following section presents the analyses of the step parameters and questionnaire responses. Notably, significant, and substantial differences between super spike track spike conditions and the traditional track spike condition were the main factor of interest when reporting these results.

3.1 Step Parameters: TRADITIONAL vs. NEW

Mean step parameter outcome measures associated with the TRADITIONAL and NEW spike conditions are delineated in Table 3. Participants ran significantly faster 200m intervals times and reached a significantly higher average running velocity in the NEW spike condition. Additionally, participants achieved these velocities in the NEW spike condition while running with a significantly (~5%) longer step length to that observed in the TRADITIONAL spike condition. Step time and step frequency did not differ significantly between the two spike conditions, remaining near identical. A small reduction in peak vertical GRF was observed while running in the NEW spike condition; however, this result was not significant and displayed a small effect size indicating no notable difference. The same can be said for horizontal and resultant GRFs, where no significant differences were observed between conditions. Additionally, both estimated contact and flight times remained similar between the two conditions, with only minor reductions in flight and contact times observed in the NEW spike condition; however, this result was not deemed to be significant. Refer to Table 3.

Table 3. Participants' (n=12) step parameters associated with use of the TRADITIONAL and NEW track spike conditions during 200m repeats at self-perceived mile effort (m ± SD).

Measures	TRADITIONAL	NEW	P-value	% Difference	Effect Size
Interval Time (s) *	31.89	31.20	**0.004**	-2.15	0.30
Running Velocity (m/s) *	6.30	6.44	**0.006**	2.14	0.29
Step Length (meters) *	1.92	2.02	**0.010**	4.99	0.63
Step Time (s)	0.32	0.32	0.443	-1.78	0.19
Step Frequency (Hz)	3.21	3.21	0.504	1.18	0.16
Peak Vertical GRF (BW)	3.41	3.35	0.549	-1.53	0.08
Peak Horizontal GRF (BW)	0.36	0.35	0.907	-1.99	0.03
Estimated Resultant GRF (BW)	3.23	3.23	0.929	0.21	0.01
Estimated Contact Times (s)	0.14	0.14	0.501	-0.58	0.07
Estimated Flight Time (s)	0.19	0.18	0.281	-4.35	0.28

* Indicates a significant difference between track spike conditions ($p<0.0167$)

3.2 Step Parameters: TRADITIONAL vs. SS1

Mean step parameter outcome measures associated with the TRADITIONAL and SS1 spike conditions are delineated in Table 4. Participants ran significantly faster 200m intervals times and reached a higher average running velocity in the SS1 spike condition. Additionally, participants achieved these velocities in the SS1 spike condition while running with a substantially (~3%) longer step length to that observed in the TRADITIONAL spike condition. These results, although notable in their difference, in post hoc were deemed to be non-significant. Step time and step frequency did not differ significantly between the two spike conditions, with step time remaining near identical, and step frequency being slightly greater in the SS1 spike condition. Peak vertical GRF did not differ significantly and displayed a minuscule effect size between the two conditions. The same can be said for peak horizontal GRF, where no significant differences were observed between conditions. Notably, estimated resultant GRF was non-significantly

(~3%) greater in the SS1 spike condition. Both estimated contact and flight times remained similar between the two conditions, with only minor reductions in contact and flight times observed in the SS1 spike condition, similar to the results associated with the NEW spike condition. Refer to Table 4.

Table 4. Participants' (n=12) step parameters associated with use of the TRADITIONAL and SS1 track spike conditions during 200m repeats at self-perceived mile effort (m ± SD).

Measures	TRADITIONAL	SS1	P-value	% Difference	Effect Size
Interval Time (s)*	31.89	31.40	**0.016**	-1.52	0.20
Running Velocity (m/s)	6.30	6.41	0.019	1.62	0.21
Step Length (meters)	1.92	1.98	0.069	3.21	0.41
Step Time (s)	0.32	0.31	0.240	-3.89	0.46
Step Frequency (Hz)	3.21	3.25	0.300	2.69	0.35
Peak Vertical GRF (BW)	3.41	3.42	0.902	0.29	0.01
Peak Horizontal GRF (BW)	0.36	0.41	0.454	15.66	0.20
Estimated Resultant GRF (BW)	3.23	3.34	0.068	3.45	0.21
Estimated Contact Time (s)	0.14	0.14	0.508	-2.04	0.22
Estimated Flight Time (s)	0.19	0.18	0.257	-6.89	0.60

* Indicates a significant difference between track spike conditions ($p<0.0167$)

3.3 Step Parameters: TRADITIONAL vs. SS2

Mean step parameter outcome measures associated with the TRADITIONAL and SS2 spike conditions are delineated in Table 5. Participants ran faster 200m intervals times and reached a higher average running velocity in the SS2 spike condition. Additionally, participants achieved these velocities in the SS2 spike condition while running with a substantially (~4%) longer step length to that observed in the TRADITIONAL spike condition. These results, although notable in their difference, in post hoc were deemed to be non-significant. Step time and step frequency did not differ significantly between the two spike conditions, with step time remaining near identical, and step frequency being slightly greater in the SS2 spike condition. Similar to the results pertaining to the other super spike conditions, peak vertical GRF did not differ significantly and displayed a minuscule effect size between the two conditions. The same can be said for peak horizontal GRF, where no significant differences were observed between conditions. Notably, estimated resultant GRF was non-significantly (~3%) greater in the SS2 spike condition. Both estimated contact and flight times remained similar between the two conditions, with only minor reductions in contact and flight times observed in the SS2 spike condition, similar to the results associated with the NEW and SS1 spike condition. Refer to Table 5.

Table 5. Participants' (n=12) step parameters associated with use of the TRADITIONAL and SS2 track spike conditions during 200m repeats at self-perceived mile effort (m ± SD).

Measures	TRADITIONAL	SS2	P-value	% Difference	Effect Size
Interval Time (s)	31.89	31.63	0.102	-0.81	0.11
Running Velocity (m/s)	6.30	6.36	0.096	0.84	0.11
Step Length (meters)	1.92	2.01	0.112	4.31	0.56
Step Time (s)	0.32	0.32	0.500	-1.71	0.24
Step Frequency (Hz)	3.21	3.29	0.664	0.74	0.10
Peak Vertical GRF (BW)	3.41	3.40	0.967	-0.09	0.00
Peak Horizontal GRF (BW)	0.36	0.34	0.735	-4.06	0.06
Estimated Resultant GRF (BW)	3.23	3.32	0.053	2.88	0.15
Estimated Contact Time (s)	0.14	0.14	0.815	-1.61	0.16
Estimated Flight Time (s)	0.19	0.18	0.439	-3.48	0.35

* Indicates a significant difference between track spike conditions (p<0.0167)

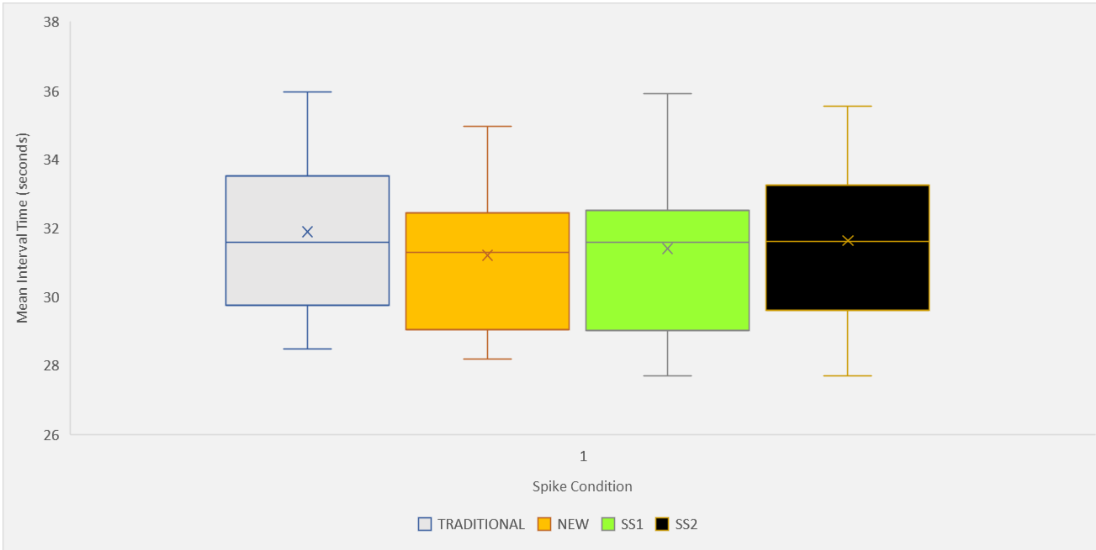

Figure 3. Mean 200m interval times recorded in seconds for participants (n=12) in each spike condition are displayed above. Whiskers indicate the spread of mean interval times (including extremes) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean 200m interval time for the given spike condition.

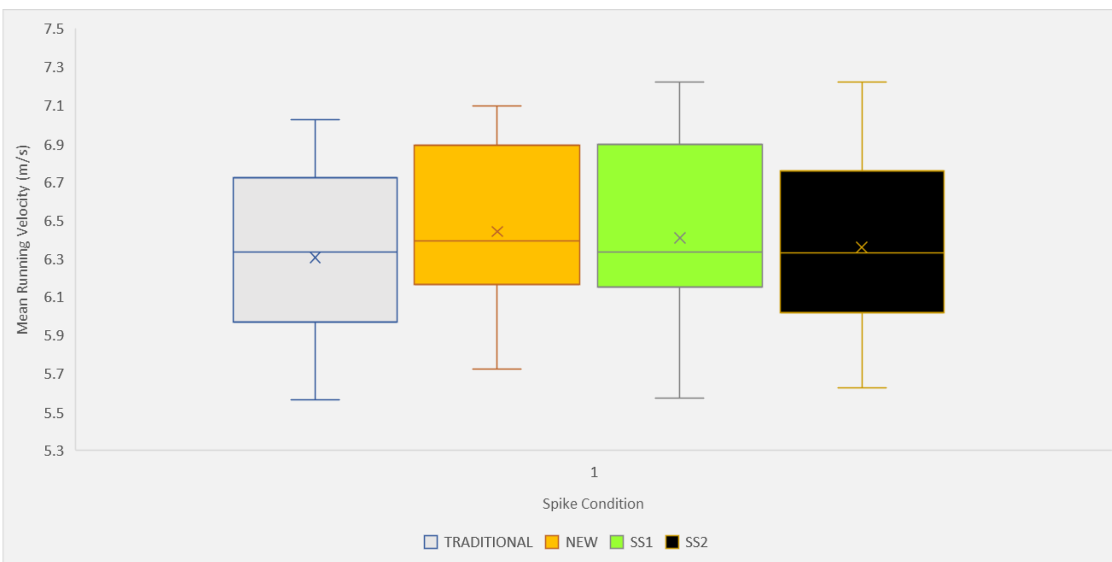

Figure 4. Mean running velocities during 200m intervals recorded in meters per second for participants (n=12) in each spike condition are displayed above. Whiskers indicate the spread of mean velocities (including extremes) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean running velocity for the given spike condition.

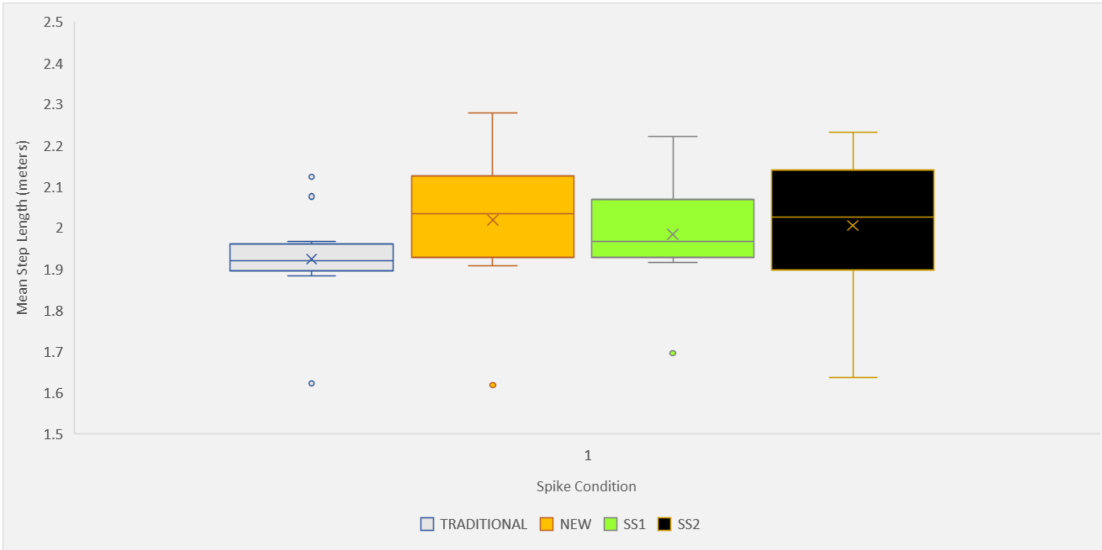

Figure 5. Mean step length during 200m intervals estimated in meters for participants (n=12) in each spike condition are displayed above. Whiskers indicate the spread of mean step lengths (including extremes – denoted by the dots) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean step length for the given spike condition.

3.4 Questionnaire Results

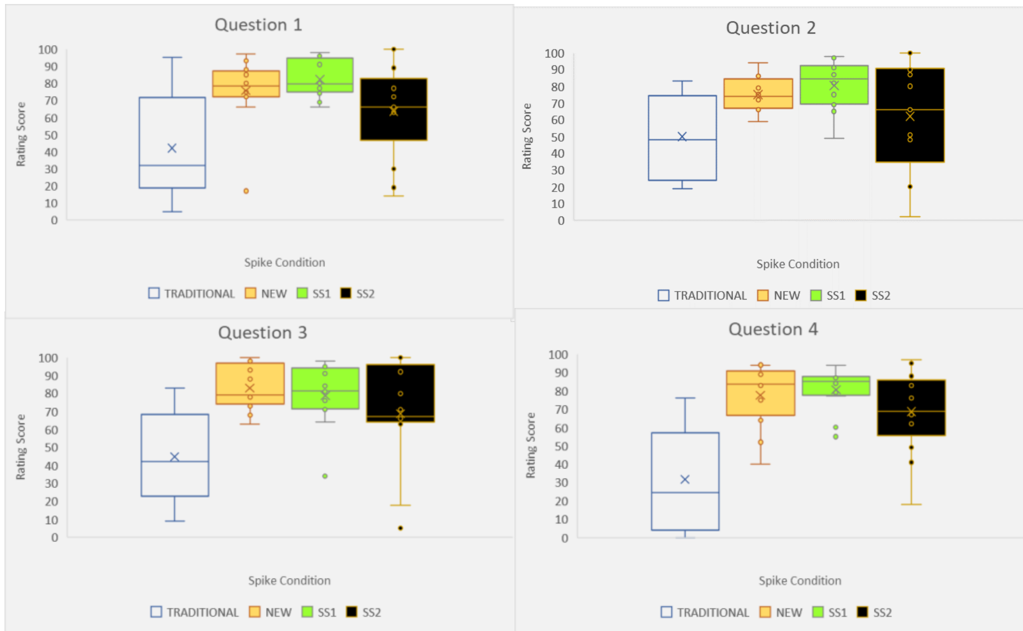

Figure 6. Mean response scores (n=12) for questionnaire questions 1: How would you rate your overall satisfaction with the shoe? 2: How would you rate the overall fit of the shoe? 3: How would you rate the overall comfort of the shoe? & 4: How would you rate the forefoot cushioning? Responses for questions 1, 2, & 4 were recorded on a scale of 0 – corresponding to very unsatisfied, to 100 – corresponding to very satisfied. Responses to question 3 were recorded on a scale of 0 – corresponding to very uncomfortable, to 100 – corresponding to very comfortable. Whiskers indicate the spread of response scores (including extremes – denoted by the dots) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean response score for the given spike condition.

Mean response scores for questionnaire questions 1 to 4 associated with the TRADITIONAL, NEW, SS1, and SS2 spike conditions are delineated in Figure 6. On average, participants were more satisfied with the super spike track spike conditions. Participants rated the overall fit and overall comfort for the super spike conditions higher on average than the control TRADITIONAL condition. Similarly, forefoot cushioning was also rated higher on average in the super spike conditions.

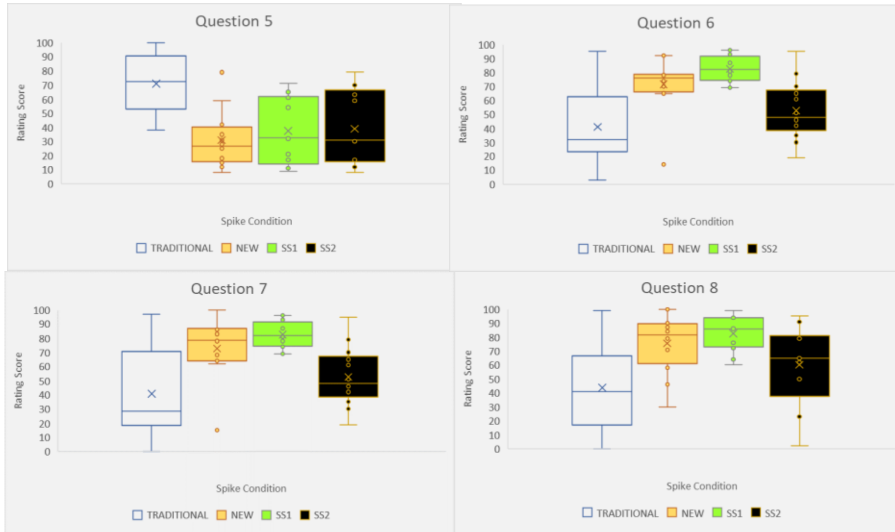

Figure 7. Mean response scores (n=12) for questionnaire questions 5: Was the forefoot cushioning soft, or firm? 6: How would you rate the rebound/responsiveness of the shoe? 7: Was the rebound/responsiveness dead or bouncy? and 8: How would you rate the ride? Responses for questions 6 & 8 were recorded on a scale of 0 – corresponding to very unsatisfied, to 100 – corresponding to very satisfied. Responses to question 5 were recorded on a scale of 0 – corresponding to very soft, to 100 – corresponding to very firm. Responses to question 7 were recorded on a scale of 0 – corresponding to very dead, to 100 – corresponding to very bouncy. Whiskers indicate the spread of response scores (including extremes – denoted by the dots) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean response score for the given spike condition.

Note. "Ride can be defined as 'the feeling of the shoe during running as the foot transitions from heel to forefoot during the stance phase of gait, i.e., how smoothly your foot transitions from touchdown to toe-off" (Lam et al., 2018)

Mean response scores for questionnaire questions 5-8 associated with the TRADITIONAL, NEW, SS1, and SS2 spike conditions are delineated in Figure 7. Participants found all three of the super spike conditions softer in the forefoot than the control TRADITIONAL spike condition. Participants rated the rebound and responsiveness of each super spike condition more favourably than the TRADITIONAL condition and noted that each super spike tended to feel bouncier during their intervals.

Participants on average also rated the overall ride of the super spike conditions higher than that of the TRADITIONAL.

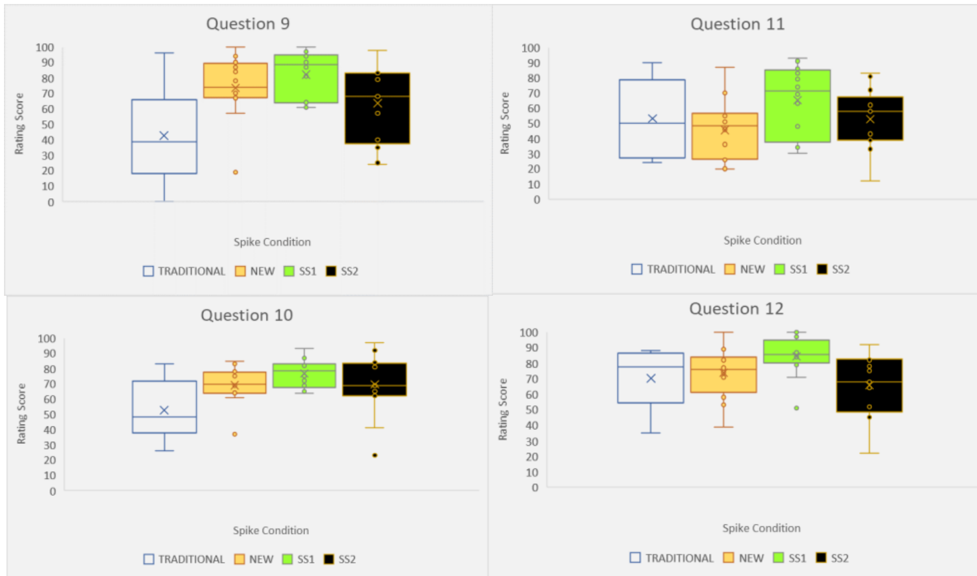

Figure 8. Mean response scores (n=12) for questionnaire questions 9: Was the ride slappy or smooth? 10: How would you rate the forefoot flexibility? 11: Was the forefoot flexibility flexible or stiff? & 12: How would you rate the weight of the shoe? Responses to question 9 were recorded on a scale of 0 – corresponding to very slappy, to 100 – corresponding to very smooth. Responses to question 11 were recorded on a scale of 0 – corresponding to very flexible, to 100 – corresponding to very stiff. Whiskers indicate the spread of response scores (including extremes – denoted by the dots) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean response score for the given spike condition.

Note. “Ride can be defined as 'the feeling of the shoe during running as the foot transitions from heel to forefoot during the stance phase of gait, i.e., how smoothly your foot transitions from touchdown to toe-off” (Lam et al., 2018)

Mean response scores for questionnaire questions 9-12 associated with the TRADITIONAL, NEW, SS1, and SS2 spike conditions are delineated in Figure 8. When asked if the ride of the given spike condition was more slappy or smooth, participants found the three super spike conditions smoother to run intervals in than the TRADITIONAL.

Satisfaction with forefoot flexibility was rated at a similar margin for each spike condition. In a similar manner, the stiffness of the forefoot of each spike condition was rated at a similar margin, even though stiffness between each condition varied drastically. No noticeable difference was observed in satisfaction with the weight of the shoe, as each spike condition varied on minutely, with a slight increase in satisfaction for the SS1 condition over the others.

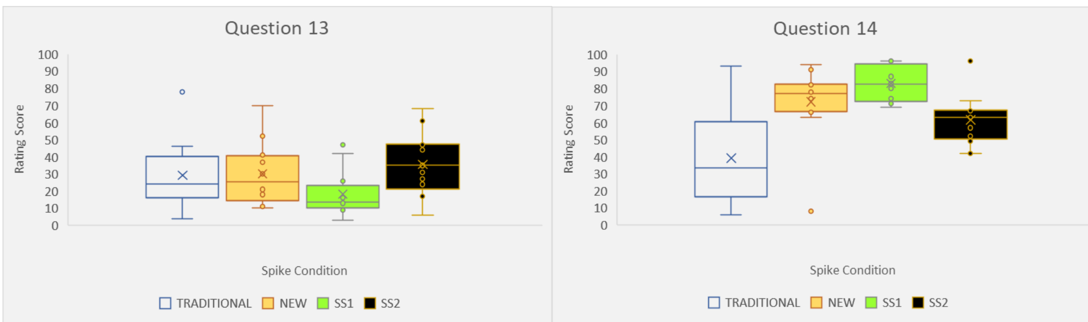

Figure 9. Mean response scores (n=12) for questionnaire questions 13: Was the shoe light or heavy? 14: Was the shoe slow or fast? Responses to question 13 were recorded on a scale of 0 – corresponding to very light, to 100 – corresponding to very heavy. Responses to question 14 were recorded on a scale of 0 – corresponding to very slow, to 100 – corresponding to very fast. Whiskers indicate the spread of response scores (including extremes – denoted by the dots) associated with each of the four spike conditions. The X mark within each boxplot represents the overall mean response score for the given spike condition.

Mean response scores for questionnaire questions 13 & 14 associated with the TRADITIONAL, NEW, SS1, and SS2 spike conditions are delineated in Figure 9. Similar to the results pertaining to question 12, participants responses identified no noticeable difference in shoe mass, as responses suggested each spike condition was light. Regardless, participants rated the super spike conditions as feeling faster to run the intervals in than the TRADITIONAL condition.

Chapter 4. Discussion

The purpose of this study was to investigate the potential impact that super spikes have on running performance. Using our novel effort-based approach, we aimed to evaluate middle distance spikes using IMUs, with a focus on identifying potential changes in outcome measures that are associated with enhanced performance. Our results indicate that supporting our first hypothesis, participants completed, on average, the 200m repeats faster in the super spike conditions. 200m interval times were significantly faster in the NEW condition, with a 2.15% reduction in interval time when compared against the control TRADITIONAL spike. Similar trends were present for the SS1 and SS2 conditions when compared against the TRADITIONAL. Interval times were significantly faster in the SS1 condition, with a 1.52% reduction in interval time when compared against the TRADITIONAL. Use of the SS2 spike condition was determined to have a non-significant impact on interval time. Nevertheless, participants experienced a 0.81% reduction in interval time when running in the SS2. The difference in results between these three super spike conditions may be chalked up to different geometries and designs, with certain design aspects (e.g., toe spring, fit or plate shape) working/feeling better for certain participants; however, this is merely speculation. Notably, results from the questionnaire data allude to this speculation.

In a similar manner, we accept our second hypothesis, as participants generally ran at significantly higher running velocities in the super spike conditions. Running velocities during the 200m intervals were significantly greater in the NEW condition, with a 2.14% increase in running velocity when compared to the TRADITIONAL. Again, similar trends were present for the SS1 and SS2 conditions when compared against the TRADITIONAL, although these conditions were determined to have a non-significant impact on running velocity. Nevertheless, participants also experienced a 1.62% increase in velocity when running in the SS1, and a 0.84% increase in velocity when running in the SS2. Much like interval time, the observed difference in results between these three super spike conditions may be a result of different designs being more/less effective for certain participants. Results from the questionnaire give a window into this speculation as participants did note that the significantly faster NEW condition felt fast, however, it was not rated the fastest feeling of all the super spike conditions.

We also accept our third hypothesis; step lengths were significantly longer in the NEW spike condition than that associated with the TRADITIONAL spike condition. Participants displayed a 5% increase in step length when running in the NEW condition. Much like interval time and running velocity, a similar trend was present for the other two conditions, albeit to a non-statistically significant extent as participants ran with longer step lengths in the SS1 (3.21% increase) and SS2 (4.31% increase) spike conditions. Again, these differences in performance attributed to each super spike condition could potentially be a result of individualistic factors. We reject our fourth hypothesis; mean step time was slightly reduced, and mean step frequency was slightly increased when running in the super spike conditions. However, these findings were non-significant and generally speaking, step time and step frequency remained nearly identical between spike conditions. Regardless, these findings are notable considering step length increased significantly for the NEW condition, and substantially for the SS1 and SS2 conditions. These findings are logical as if one was to see only a minor change in step time and frequency, but a sizeable increase in running velocity, one would expect a notable increase in step length.

Interestingly, we observed a small reduction in contact time when participants ran in super spike conditions; thus, we reject our fifth hypothesis. This trend remained quite similar across all three super spike conditions, with the NEW resulting in a 0.58% reduction, the SS1 resulting in a 2.04% reduction, and the SS2 resulting in a 1.61% reduction in contact time. Logically this makes sense, as running gait literature has generally observed a decrease in contact times when running velocity increased (Morin et al., 2012). Our results regarding our GRF variables seem to be equivocal as participants produced the same vertical, horizontal, and resultant GRFs in the NEW condition when compared to the TRADITIONAL. In contrast, participants produced greater vertical, horizontal, and resultant GRFs in the SS1 condition when compared to the TRADITIONAL. Falling in the middle, running in the SS2 condition resulted in increased vertical and resultant GRFs, but a decreased horizontal GRF. With this variation present, our data does not support our sixth hypothesis. Since a longer step length was observed in each super spike condition, we would expect participants to display increased GRF variables to facilitate a longer step length and thus an increased running velocity.

Lastly, we had hypothesized that participants would rate aspects of the super spikes utilized in our methodology more favorably (i.e., prefer them) when compared to ratings associated with traditionally designed spikes. This was observed to be the case. Mean response scores associated with the super spike conditions for each of the fourteen questions present on the questionnaire generally scored more favorably than the TRADITIONAL. There were some exceptions, as ratings associated with shoe mass did not differ; however, this was expected as each spike condition only varied in shoe mass by a couple of grams. Notably, forefoot stiffness was also rated very similarly for all spike conditions which was unexpected as some conditions had embedded spike plates which made the forefoots extra stiff.

Pragmatically, the study was limited by shoe size restriction. Our research was limited to athletes fitting a US Men’s Size 9 spike. It is important to note that factors such as spike plate stiffness and effectiveness of foam compliancy and resiliency, as well as spike weight may all be impacted as spike size increases or decreases (Nagahara et al., 2018; Willwacher et al., 2016). This size constraint made acquiring a larger cohort a near impossible task, as participants were already from a relatively niche group. Future research should look to incorporate a larger breadth of shoe sizes to assess if such characteristics may need to be altered as spike size changes. Strictly interpreted, our findings are limited to experienced male Track and Field athletes. Again, this was a function of the limited sizes of track spikes made available for our research, rather than an omission of female participants. Further studies would need to be conducted to confirm if such performance related results were consistent and if they were to the same extent for female and less-experienced athletes. If the trend in results were similar to that of modern marathon racing shoes, alterations in running biomechanics should be present for non-tested groups; however, the extent to which they are altered would still need to be determined and confirmed. An increased inclusion of sizes would enable more female participation, which in turn would increase the generalizability of the results and could present a possibility of addressing these gaps. From this, spike geometry and construction could potentially be optimized specifically for female athletes, assuming significant differences were found. Along with this, incorporation of less-experienced athletes would also provide an excellent addition to the generalizability of the results. However, as Healey et al. (2022) suggests, that due to the niche market that track spikes reside in, it is more important for brands to optimize track spikes for elite athletes, rather than inexperienced or average-caliber runners. So, the likelihood of numerous larger scale studies assessing super spikes, featuring runners from a variety of running backgrounds like that of modern marathon racing shoes (e.g., Barnes & Kilding, (2018); Hoogkamer et al., (2019); Hunter et al., (2019); Hébert-Losier et al., (2020)) may never come to fruition. However, this does not close the door on incorporating female athletes into future works.

Clipping associated with the use of the IMUs for this research also limited the results to an extent, as filtering and corrections had to be applied to correct this. Additionally, GRF measures were estimated which could impact how truly representative the results are to that of the actual GRF experienced by the participants. Future studies should look to utilize an alternative method of assessing GRF using a force sensitive track surface. However, a much more realistic alternative may be attempting to refine the estimation process utilized within this study to be more representative of "true" peak GRF. Similar comments can be said regarding contact time and flight time measures, as they too, featuring an estimative nature, may not be truly representative of athletes' exact contact and flight times. Again, further refining of our utilized methodology may be in order. Despite these limitations, this work represents a successful use of IMU wearable technology.

As super spikes are beginning to be optimized for specific track events (i.e., distance, middle-distance, sprints, and some jumping events) it is becoming increasingly important to assess how these noted construction characteristics may impact athletes' event specific performances. Future studies should look to control for these characteristics, enabling the assessment of each individual characteristics, free from confounders. Additionally, assessing how super spikes may impact block start mechanics and the acceleration phase of the sprinting, when compared to traditionally constructed sprint spikes could be an interesting topic to assess. Potential benefits from super spikes could be hyper-inflated due to the short nature of the sprint events. This then could be extended to jumping events (i.e., long, and triple jump) as much of the early portion of the events feature a similar sprint build up.

As research on super spikes and their potential impact on running performance is a relatively novel area due to the nature of the spikes only being recently constructed and made available to track athletes; there is an absence of previously conducted research to build upon and make comparison to. However, in having an appreciation for the aforementioned construction characteristics shared between super spikes and modern marathon racing shoes, the now vast and vibrant collection of studies conducted on the impact of modern marathon racing shoes and their impact on running performance can be utilized, albeit with some extrapolation. Even so, it is a challenge to directly compare our findings related to our first and second hypotheses to previously conducted research, as much of the modern marathon racing shoe studies have been conducted at fixed speeds on treadmills, focusing on running economy rather than on a track surface at self-selected efforts. Regardless, numerous marathon racing shoe studies (Bermon et al. 2021; Hoogkamer et al. 2016, Kipp et al. 2019; Muniz-Pardos et al. 2021; Senefled et al. 2021) have noted findings such as: increased step length and increased GRF associated with the presence of compliant and resilient midsole foams, increased longitudinal bending stiffness, and lightweight construction in a shoe that correspond to increased running velocity. Castellanos-Salamanca et al. (2023) recently tested modern marathon racing shoes using a similar protocol construction to this work and determined that the use of modern marathon racing shoes (specifically the Nike Vaporfly Next% 2) resulted in faster 1000m intervals times. This (with some degree of extrapolation) supports the findings associated with our first and second hypotheses as interval time and running velocity were expected to (to a degree) display homogenous results.

In-line with the findings of numerous studies featuring Nike's Vaporfly racing shoe - a now well-known modern marathon racing shoe (Barnes & Kilding 2019; Hata et al. 2022; Hunter et al. 2019; Hébert-Losier et al. 2020; Whiting et al. 2021), an increase in step length during 200m intervals was observed when participants ran in the super spike conditions. As noted, increases in step length varied for each spike condition (on average all super spikes resulted in a ~ 8.33 cm increase). This remained within a similar range to that observed in modern marathon racing shoes (on average ~6cm increase) (Castellanos-Salamanca et al., 2023), even though participants were running at much greater running velocities during the 200m intervals. This result may be explained in part by the work of McMahon & Greene (1979) as they suggested that while a more compliant foot–ground interaction results in a longer ground contact time, it does not necessarily result in a reduction in running velocity as many presume. Work on sprinting has stemmed this assumption as generally, a reduction in contact time is associated with increased sprint performance. A longer contact time while sprinting has been associated with a longer step length, which in turn allows the athlete's body more time to produce greater force, potentially enabling a decrease in metabolic cost, leading to an increase in running velocity (McMahon & Greene, 1979). And with an increase in running speed, comes a potential and likely increase in race performance. Again, extrapolation is tricky here as middle-distance and distance running on the track constitutes speeds much quicker than the average marathon speeds, but slower than maximal sprinting. Interestingly, although we observed an increase in running velocity and increase in step length, we did not observe an increase in contact time, but rather the opposite. Participants even at self-perceived mile effort pace (well below maximal sprinting velocity) displayed trends while running in super spikes similar to findings from Morin et al. (2012) which linked a reduction in contact time with an increase in sprinting performance. Notably, the range of running velocity that Morin et al. (2012) considered sprinting, fell within the range of velocities achieved by participants within our work. So, do super spikes follow along more with the traditional ideology of running, where reducing contact time is favorable for performance? It appears to be the case.

In having an appreciation for this, the findings associated with our fourth hypothesis are plausible as an increase in step length and decrease in contact time would likely result in a nominal decrease in step time and a small increase in step frequency, since both are a function of velocity (Morin et al., 2012). As our results regarding the GRF variables seem to be equivocal, it is challenging to make conclusive comparisons. Regardless, findings associated with the SS1 and SS2 conditions align with Hoogkamer et al. (2018) who also observed an increase in peak vertical GRF associated with running in shoes featuring construction characteristics also utilized in super spikes. Considering that step length was observed to increase, while step frequency only slightly increased, we expected GRF to increase as such a change would be required to facilitate the increased step length observed. Unlike Hoogkamer et al. (2018) and our previous work (Wilkie et al., 2022) featuring a similar Puma super spike, we observed miniscule change in participants' vertical, horizontal, and resultant GRFs in the NEW condition when compared to the TRADITIONAL. We were surprised by this result, as much like the other two spike conditions, we expected participants to display increased GRF variables as to facilitate the significantly longer step length and increased running velocities observed in the NEW condition. What may partially explain this oddity in our results is our method that we utilized to ascertain the GRF data, as much of previous research determining GRF with modern marathon racing shoes used force-measuring treadmills, rather than an IMU-based estimative methodology.

Previous work addressing athlete's ratings of characteristics of super spikes, or similarly constructed modern marathon racing shoes is limited. Work addressing this topic is usually kept in house by footwear manufacturers for their own design process and are rarely made public. Castellanos-Salamanca et al. (2023) asked participants to self-report muscle fatigue following use of modern marathon racing shoes when compared to a control racing shoe. Participants generally reported a reduction in muscular fatigue when using the modern marathon racing shoe. We generally found positive results attributed to super spikes too; however, as we did not ask an equivalent question, no appropriate comparisons can truly be made.

Chapter 5. Conclusion

5.1 What is the deal?

Running in the NEW spike condition resulted in significantly faster interval times, running speeds, and longer step lengths when compared to the traditionally constructed Puma Spike. Similar trends were present for the other two super spike conditions when compared to the TRADITIONAL condition, albeit to a non-significant extent. Along with this, participants generally favoured the design characteristics and on-foot performance of the super spike conditions to that of the TRADITIONAL condition. Our data suggests that with the use of super spikes, experienced track athletes could run faster across various distance track events. This may partially explain the influx of notable performances over the recent years in the world of Track & Field; however, this is not a definitive answer. It is still unknown to what extent each super spike characteristic plays in the observed enhanced performance. Ultimately, our IMU-based methodology has shown to be a reliable and sensitive measure of distance running performance and will enable the creation of context for current and future records in distance running performance by giving a number to approximate changes expected from differing shoes, as has been seen in the marathon racing scene. Moreover, our methodology can enable shoe designers to be more conscientious of their designs and innovations, aiding in the determination of design factors (as a whole) that facilitate performance enhancement. This knowledge can then be put into action and on to the track to create better footwear for athletes of all abilities and backgrounds, regardless of if their aim is a personal best or a world record.

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Appendix

Protocol Instructional Booklet:

Prior to Session:

- Ensure all IMUs are charged.

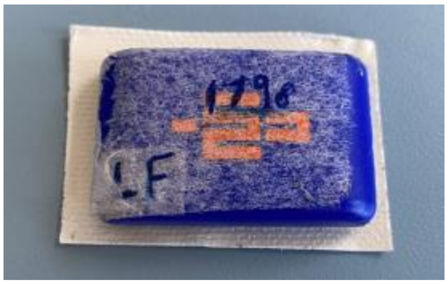
Figure 1: IMU in charging port

- Check all spikes for inserts and that the Velcro is attached.
    - Velcro can be Superglued if necessary.

Prep IMUs:

- Micropore tape on top of IMU marked with IMU number and location to be placed ("P" (Pelvis), "LS" (Left Shank), etc.) *this does not need to change between sessions.
- Micropore tape on the bottom of the IMU, followed by double-sided tape (otherwise double-sided tape will remove the identification label on IMU)
- On data collection sheet, note down IMU numbers with position, and mark the orientation/positions (instruction for this are later in this document)

Figure 2: Labelled IMU ->



Spikes are identified as:

A = PUMA (Old)

B = PUMA (Experimental)

- Assign random order for spikes, order will be repeated twice. Spike order will include all 24 possible permutations of "ABCD" (ex., see below)
    - 1) ABCD, ABCD
    - 2) BADC, BADC
    - 3) CABD, CABD
    - 4) DBAC, DBAC
- The order of spikes will be decided by using the google assistant function on a Google Pixel 6 Pro Smartphone, with the phrase "OK Google, pick a number between 1 and 24". The number returned will determine the order. After each participant has been given a number, said number will be removed from the pool to ensure no duplications in spike order. This will be done to limit chance of order of effects.
- Note the order down in data collection sheet

During Session:

Prep:

- Participant arrives at track
    - Explain protocol to participant and have them sign documents:
        - Tell them they will do 10 x 200m at mile race-effort, standing starts (like that of an 800m start), full recovery (approx. 10 minutes between reps)
        - Note: They will only be doing 9 x 200m, this will prevent them from finishing strong on the last rep. The first rep will also be ignored during data processing to control for outliers in interval time.
        - You will simply tell them they are finished after the 9th rep.
    - Consent form – fill out GET ACTIVE QUESTIONAIRE or PARQ (depends on country of collection)
    - Instruct them to run a warmup as they would for a 200m interval session, followed by drills and stretches as they see fit
    - After their warmup, you will attach IMUs to their Right Shank (head of IMeasureU man pointed towards sky):
    - IMU with double-sided tape directly on skin, followed by pre-wrap, finished off with Micropore tape

Figure 3: Shank IMU Setup

- Attach Sacrum IMU:
- Place IMU in Sacrum clip. Place clip at the back of the runner's shorts

Figure 4: Sacrum IMU

- Instruct runner to shake out and do a few strides (as they see fit) in their own shoes before they put on the spikes
- Once they are ready, they will remove their shoes (sock can be left on, it makes the spikes easier to switch)

Collection:

- Have the runner put on the blinding glasses.
- Put spike blinders on both legs
- Put spikes on left and right foot, making sure laces are loosened prior, and each rung of laces are tightened comfortably once spikes are on
- Attach IMUs to the top of each foot:
    - IMU with double-sided tape directly on laces, with a squared of HYPAFIX tape on top (this should be able to be transferred between spikes, but retape at your own discretion)
- Pull spike blinders down. Starting with the front seem in the center, attach Velcro and work toward the back of the spike. The excess material will be folded to the lateral side of the foot. Top of spike blinder can be pulled down to the ankles.

Repeat on other foot

Figure 5: Shoe Setup

- Have the runner remove glasses
- Collector and runner will walk to the start of the 200m.
- On the Capture.U app, you must be relatively close to the sensors (~10 meters) to start and stop. https://www.vicon.com/software/capture-u/

Instructions for runner:

- Standing start for 200m (like that of an 800m)
    - With one hand in the air, they will drop their hand as they cross the start line of the 200m
    - They should run at perceived mile race pace (they should not be aware of the time they are running i.e., looking at splits on their watch), researchers will also refrain from disclosing their interval times during collection

Instructions for researcher:

- Name the session on app: place, interval number, spike condition (i.e., UNB-9-NIKE-2), and select sensors (there should be 4)
- Start capture while you are close to the runner
- Move towards the finish line, telling the runner to begin when the researcher can comfortably reach the finish line before the runner
- Start timer when they drop their hand, stop when they cross the finish line
- Do not tell the runner their time, return to setup location, write time down in data collection sheet
- Stop recording IMU data shortly after runner slows to a walk

Repeat "Collection" section for each condition

Have runner fill out questionnaire survey while changing the spikes (survey link below)

Do not forget to have them fill out the survey after the last 200

After Session:

- Remove tape from bottom of IMUs (top tape with labels can stay)
- Plug in IMUs to computer, open Capture.U Desktop
- Upload sessions one at a time, with however many IMUs can be plugged in at a time
- Make sure that spike blinders do not need any repair

Research Participants Needed for Study on Track Spikes

Spike Flyer

The Integrative Locomotion Lab at the University of Massachusetts Amherst & the Faculty of Kinesiology at the University of New Brunswick are looking for volunteers to take part in a study on **track spikes and running performance.**

All experiments are completely non-invasive.

To take part you must:

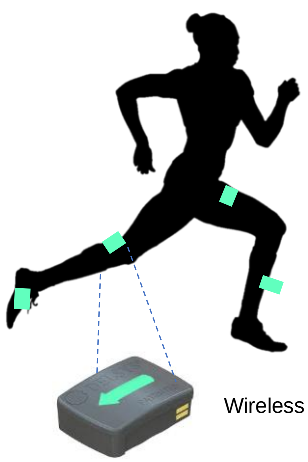
- Be 19-45 years old.
- Wear ~ a US size 9 track spike.
- Have trained in track spikes before.

You should not:

- Have had a lower extremity injury or surgery in the past 3 months.
- Have any existing orthopedic, cardiovascular, or neuromuscular conditions that affect running or high intensity exercise.

Testing procedures involve running 8 200m cruising reps.

It will take place outdoors at the runner's local track.



Wireless IMU sensor

You will have wireless inertial motion units (IMUs) placed on your feet, legs, thighs, and pelvis to track your movement.

Your legs will also be recorded with timing gates and a high-speed camera.

This experiment consists of a single 1.5-hour session.

If you are interested, please send an email to ewilkie@unb.ca for more information.

This research has ethics approval: ("Assessing Running Performance in New Track Spikes" -- REB #2021-079)

Data Collection Sheet

SPIKE STUDY TYPE: _______________

Participant Number: _______________

Notes during collection:

Date: ________________________

Location: ______________________

Weather Description: ________________

Wind & Direction: _________________

SPIKE ORDER:

ORDER:

A= PUMA OLD

B= PUMA EXP

C= NIKE

D= ADIDAS

Trial 200m Times :

1. _____________

2. _____________

3. _____________

4. _____________

5. _____________

6. _____________

7. _____________

8. _____________

9. _____________

This research has ethics approval: ("Assessing Running Performance in New Track Spikes" -- REB #2021-079)

Consent Form for Participation in a Research Study University of New Brunswick

Researcher(s):

(Primary Investigator) Ethan Wilkie, B.Sc. (Hon) UNB
email: ewilkie@unb.ca phone: (778) 245 0228
(Co-Investigator) Laura Healey, M.Sc. UMASS
email: laurahealey@umass.edu phone: 413-545-1337
(Co-Investigator) Montgomery Bertschy M.Sc. UMASS
email: mbertschy@umass.edu phone: 413-545-1337
(Supervisor) Jeremy Noble, Ph.D. UNB
email: Jeremy.Noble@unb.ca phone: (506) 447-3289
(Supervisor) Wouter Hoogkamer, Ph.D. UMASS
email: whoogkamer@umass.edu phone: 413-545-1390

Study Title: Assessing Running Performance in New Track Spikes

Funding Agency: PUMA North America

ETHICS: *This research has ethics approval: ("Assessing Running Performance in New Track Spikes" -- REB #2021-079)*

You are being invited to participate in this study because you are:

- within the age of 19-45 years old
- A member of the University of New Brunswick's Track & Field program or affiliated with a local New Brunswick based Track and Field club.
- free of any orthopedic, cardiovascular, or neuromuscular conditions, and have not undergone any surgery or sustained an injury within 3 months prior to participation.
- have trained in track spikes in the past.
- wear US size 9 men's spikes.

This is a joint study between the Faculty of Kinesiology at the University of New Brunswick and University of Massachusetts Integrative Locomotion Lab to assess the effect of different track spike designs and characteristics on running performance. This information will allow researchers to work with industry partners in the hopes of optimizing Track & Field spike design. This project has been reviewed by the UNB Research Ethics Board and is on file as REB 2021-079.

1. What is this form?

This form is called a Consent Form. It will give you information about the study so you can make an informed decision about participation in this research. We encourage you to take some time to think this over and ask questions now and at any other time. If you decide to participate, you will be asked to sign this form and you will be given a copy for your records.

2. What are some of the important aspects of this RESEARCH study that I should be aware of?

1) Consent is being sought for research and participation is voluntary;
2) The purpose of this study is to gain an understanding of how different track spikes affect your running performance
3) This study involves one track testing session which will take approximately 1.5 hours.
4) After completing this informed consent form and a physical activity readiness questionnaire, and if deemed eligible, you'll perform a total of 8 200m cruising reps and 8 20m all out runs while wearing different track spikes models. While you are running, we will take high speed camera footage of your legs and we will use timing gates to time your performance. We will also put small coin-sized measuring units on your feet, shins, and thighs. After each running trial, you will have a break during which you will be asked to fill out a questionnaire rating your satisfaction of the shoe.
5) While you are running, we will take high speed footage of your legs to assess your running mechanics. No identifiable video will be recorded (i.e. all footage will only be of your legs and feet)
6) During any type of exercise there are slight health risks. These include the possibility of fatigue and muscle soreness. A risk of breach of confidentiality always exists and we have taken the steps to minimize this risk.

3. WHY ARE WE DOING THIS RESEARCH STUDY?

The purpose of this study is to gain an understanding of the influence of track spike design on the energetic running performance. This information will allow researchers to work with industry partners in optimal footwear design.

4. WHO CAN PARTICIPATE IN THIS RESEARCH STUDY?

Participants must be between the ages of 19-45 years to participate. Participants must also be a member of the University of New Brunswick's Track & Field program or affiliated with a local New Brunswick based Track and Field club. Participants must also be free of any orthopedic, cardiovascular, or neuromuscular conditions, and have not undergone any surgery or sustained an injury within 3 months prior to participation. Participants must also have trained in track spikes in the past. Finally, participants must wear US size 9 men's spikes.

5. WHERE WILL THIS RESEARCH STUDY TAKE PLACE AND HOW MANY PEOPLE WILL PARTICIPATE?

The study will take place at the Canada Games Stadium, Saint John N.B & the Outdoor Track, Oromocto N.B.
In total, 12 participants are expected to be enrolled.

6. WHAT WILL I BE ASKED TO DO AND HOW MUCH TIME WILL IT TAKE?

If you agree to take part in this study, you will be asked to arrive at the track for one biomechanical testing session which will take approximately 1.5 hours. You will be asked to arrive in athletic clothing. First, you will first be asked to complete an informed consent form and a Get Active Questionnaire (GAQ). Depending on the results of the GAQ you may be deemed ineligible to participate. If you are determined ineligible to participate, your completed questionnaire will be destroyed. If you are deemed eligible to participate, we will explain a questionnaire which we will administer after each shoe condition asking your perceptions of cushioning, stability, flexibility and overall satisfaction of the shoes (see attached). Then, your height and weight will then be recorded.

You will be asked to complete a warm-up of your choice. After, we will put small sensors called inertial measurement units (IMUs) on your feet, shins, and thighs with athletic tape. In total, the study will consist of 8 200m cruising reps and 8 20m all out sprints. While you are running, we will measure the time it takes you to run, the acceleration of your legs using the IMUs, and will we analyze your form using high-speed camera recordings of your legs. After each running trial, you will have a break during which you will be asked to fill out a questionnaire rating your satisfaction of the shoe (see attached).
This study consists of a single testing session which will take approximately 1.5 hours.

7. WILL BEING IN THIS RESEARCH STUDY HELP ME IN ANY WAY?

You may not directly benefit from this research, other than getting a bout of physical exercise; however, we hope that your participation in the study may help us understand the effects of different footwear types on running biomechanics and how to best design shoes for runners.

8. WHAT ARE my RISKS OF being in THIS RESEARCH STUDY?

During any type of exercise there are slight health risks. These include the possibility of fatigue and muscle soreness. However, any health risks are small in subjects who have no prior history of cardiovascular, respiratory or musculoskeletal disease or injury. Any ordinary fatigue or muscle soreness
is temporary. Any unforeseen risks include the same risks as exercising on your own.

A risk of break of confidentiality always exists and we have taken the steps to minimize this risk as outlined in second 9 below.

9. HOW WILL MY PERSONAL INFORMATION BE PROTECTED?

Your privacy and confidentiality are important to us. The following procedures will be used to protect the
confidentiality of your study records (electronic files with IMU, video, and performance data, shoe satisfaction questionnaires, physical activity readiness questionnaire). The researchers will keep all study records, including any codes to your data, in a locked file cabinet in a locked room. Research records will be labeled with a code. A master key that links names and codes will be maintained in a separate and secure location. The master key will be destroyed three years after the close of the study.

All electronic files (IMU, video, and performance data) do not contain any identifiable information. Any computer hosting such files will have password protection to prevent access by unauthorized users. Only the members of the research staff will have access to the passwords. At the conclusion of this study, the researchers may publish their findings. Information will be presented in summary format and you will not be identified in any publications or presentations.

The signed consent documents will be stored securely locked filing cabinet and separately from the research data.

10. WILL MY INFORMATION (BIOSPECIMENS OR PRIVATE INFORMATION) BE USED FOR RESEARCH IN THE FUTURE?

Identifiers will be removed, and the de-identified information may be used for future research without additional informed consent from you.

11. WILL I BE GIVEN ANY MONEY OR OTHER COMPENSATION FOR BEING IN THIS RESEARCH STUDY?

No compensation will be given to participants in this study, participants will participant entirely voluntarily.

12. WHO CAN I TALK TO IF I HAVE QUESTIONS?

Take as long as you like before you make a decision. We will be happy to answer any question you have about this study. If you have further questions about this project or if you have a research-related problem, you may contact the lead researcher (Jeremy Noble: email: Jeremy.Noble@unb.ca phone: (506) 447-3289).

If you have any questions concerning your rights as a research subject, you may contact the University of New Brunswick Faculty of Kinesiology at: (506) 453-4575 or contact the Dean of the Faculty Dr. Wayne Albert: walbert@unb.ca.

13. WHAT HAPPENS IF I SAY YES, BUT I CHANGE MY MIND LATER?

You do not have to be in this study if you do not want to. If you agree to be in the study, but later change your mind, you may drop out at any time. There are no penalties or consequences of any kind if you decide that you do not want to participate.

14. WHAT IF I AM INJURED?

The University of Massachusetts & University of New Brunswick do not have a program for compensating subjects for injury or complications related to human subjects research, but the study personnel will assist you in getting treatment.

15. SUBJECT STATEMENT OF VOLUNTARY CONSENT

When signing this form, I am agreeing to voluntarily enter this study. I have had a chance to read this consent form, and it was explained to me in a language which I use. I have had the opportunity to ask questions and have received satisfactory answers. I have been informed that I can withdraw at any time. A copy of this signed Informed Consent Form has been given to me."

________________________	____________________	__________
Participant Signature:	Print Name:	Date:

By signing below, I indicate that the participant has read and, to the best of my knowledge, understands the details contained in this document and has been given a copy.

____________________________	______________________	___________
Signature of Person Obtaining Consent	Print Name:	Date:

16. CONTACT FOR FUTURE STUDIES

Would you liked to be contacted about future studies you may be eligible for? (Please circle)

YES NO

Email: ____________________________________

EST. 1785 UNB UNIVERSITY OF NEW BRUNSWICK | Kinesiology Fredericton

Participant Debriefing Information

Study Title: Assessing Running Performance in New Track Spikes
This research has ethics approval: ("Assessing Running Performance in New Track Spikes" -- REB #2021-079)

MSc KIN Candidate: Ethan Wilkie (ewilkie@unb.ca, (778) 245-0228) UNB Faculty of Kinesiology

Supervisor: Dr. Wayne Albert, (walbert@unb.ca, (506) 453-4576), UNB Faculty of Kinesiology

Dear: _________________

Thank you for participating in our study on how newly designed track spikes may influence running performance. Your participation in the study is greatly appreciated. We also hope that participating in this study has been a valuable experience for you.

We hope to conclude data collection for this study by **April 1st, 2023**. After this the data will be analyzed, and papers will be prepared based on this data. It is hoped that this data will be presented at national conferences and submitted for publication in peer-reviewed journals. We want to remind you that any data presented in these publications will be completely anonymous. Any video presented in presentations of this work will also be made anonymous.

At the end of this study, you can receive verbal feedback on whether new track spikes alter or influence running performance. If you wish to receive feedback on the overall results of the study, please fill out the portion on the bottom of this sheet and email or return a copy to the principal investigator (Ethan Wilkie). It is anticipated that some preliminary results will be available on **June 1st, 2023**.

Thank you again for your participation.

Best wishes,

Ethan Wilkie
MSc KIN Candidate

I wish to receive information regarding the results of the study entitled: **Assessing Running Performance in New Track Spikes**

Name: ____________________________
E-mail Address: _______________________

Participant Questionnaire

UMass Amherst

Default Question Block

Subject code

Shoe

A

B

C

D

How would you rate your **overall satisfaction** with the shoe?

Very dissatisfied Very satisfied

How would you rate the **overall fit** of the shoe?

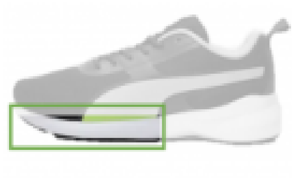
Very dissatisfied Very satisfied

How would you rate the **overall comfort** of the shoe?

Very uncomfortable Very comfortable

Please answer the following questions about the **fit** of the shoe

Please answer the following questions about the **performance** of the shoes



How would you rate the **forefoot cushioning**?

Very unsatisfied | Very satisfied

Was the **forefoot cushioning**:

Very soft | Very hard

How would you rate the **rebound/responsiveness** of the shoe?

Very unsatisfied | Very satisfied

Was the **rebound/responsiveness**:

Very dead | Very springy

Ride can be defined as 'the feeling of the shoe during running as the foot transitions from heel to forefoot during the stance phase of gait, ie how smoothly your foot transitions from touchdown to toe-off' (Lam et al., 2018)

How would you rate the **ride**?

Very dissatisfied | Very satisfied

Very dissatisfied Very satisfied

Was the **ride**:

Very slappy Very smooth

How would you rate the forefoot **flexibility**?

Very dissatisfied Very satisfied

Was the forefoot **flexibility**:

Very flexible Very stiff

How would you rate the weight of the shoe?

Very unsatisfied Very satisfied

Was the shoe:

Very light Very heavy

Was the shoe:

Very slow Very fast

Please comment on anything else you **liked** about the shoes

Please comment on anything else you **disliked** about the shoes

End of survey - thank you!

Powered by Qualtrics

Curriculum Vitae

Candidate's Full Name: Ethan Wesley Cox Wilkie

Universities Attended: Bachelor of Science (Hons) Kinesiology, University of New Brunswick, 2022

Publications:

Wilkie, E., Bertschy, M., Noble, J., & Hoogkamer, W. (2023). Comparing Middle Distance Running Spikes Using a Novel Effort-Based Approach. *Footwear Science*. [Manuscript in Works]

Bertschy, M., Wilkie, E., Healey, L., & Hoogkamer, W. (2022). Assessing Possible Methods to Model Middle-Distance Running Performance. *Sports Medicine.* [Submitted For Publication]

Wilkie, E., & MacMillan, L. (2023) Biomechanical Assessment of Paced & Maximal Effort Acute Symmetrical Lifting in Canadian Soldiers – [Manuscript in Works]

Conference Presentations:

North American Congress on Biomechanics. Ottawa, Canada (2022) Comparing Middle Distance Running Spikes Using a Novel Effort-Based Approach [Poster Presentation]

16th Biennial Footwear Biomechanics Symposium. Osaka, Japan (2023) Technological Advances in Track Spike Design Facilitate Enhanced Running Performance [Oral Presentation]

Academic Awards:

UNB Graduate Research Assistantship (2022/09-2023/08)

UNB Graduate Teaching Assistantship (2022/09-2023/08)

NBIF Graduate Fellowship (2022/09-2023/08)

Lieutenant Governor Silver Medal (2021/09-2022/05)

Dr. Chris & Diane Stevenson Scholarship (2021/09-2022/05)

Edwin Jacob Scholarship (2020/09-2022/05)

Alumni Merit Award (2019/09-2022/05)

Barry Wishart Community Merit Award (2019/09-2022/05)

Class of 1941 Scholarship (2018/09 - 2022/05)

U Sports Academic All-Canadian (2018/09-2023/05)

Dean’s List (2018-2022)

McGill KPE Sports Science Fellowship (2022) (Declined Offer)