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The Effects of Cushioning Properties on Parameters of Gait in Habituated Females While Walking and Running

Paul William Macdermid *, Stephanie Julie Walker and Darryl Cochrane

School of Sport, Exercise and Nutrition, College of Health, Massey University, Palmerston North 4474, New Zealand; walkerstephanie246@gmail.com (S.J.W.); d.cochrane@massey.ac.nz (D.C.)
* Correspondence: p.w.macdermid@massey.ac.nz

Featured Application: Understanding the interaction between running shoe properties and parameters of gait are somewhat scarce, particularly in female runners. This study demonstrates that contrasting energy absorption properties reduce kinetic variables associated with injuries in females while running, but not walking.

Abstract: The purpose of this study was to compare the mechanical properties of a non-cushioned minimalistic shoe and cushioned shoe during walking at 6 and running at 10 and 14 km·h^{-1} in habituated female runners. Twelve habituated female runners completed two trials (cushioned shoe vs. minimalist shoe) with three within-trial speeds (6, 10, and 14 km·h^{-1}) in a counter-balanced design. Flexible pressure insole sensors were used to determine kinetic variables (peak vertical impact force, average loading rate, active vertical peak force, time to active peak vertical force, and impulse) and spatiotemporal variables (stride duration, cadence, ground contact time, swing time, and time to midstance). Cushioned running shoes exhibited greater energy absorption (690%), recovered energy (920%), and heat dissipation (350%). The cushioned shoes significantly reduced peak vertical impact (~12%) and average loading rate (~11%) at running speeds 10–14 km·h^{-1}. However, these effects were not observed during walking, nor did the cushioned shoes influence peak active force, impulse, stride duration, ground contact or swing time. Cushioned running shoes provide significant benefits in energy absorption, energy recovery, and heat dissipation, which decrease impact-related forces and loading rates in female runners without changing the spatiotemporal variables of gait.

Keywords: gait; running; females; injury; ground reaction forces

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1. Introduction

On a global scale, walking [1] and running [2] are some of the most popular physical activities undertaken by the general population. The collision between foot and ground during fast walking or running generates a shockwave of energy on every step, necessitating passive attenuation processes to protect vital systems [3–6]. Both activities face challenges as these passive processes are highly sensitive to factors such as impact force magnitude, loading rate, and repetition [7,8]. All of these are exacerbated at faster paces, particularly at speeds >12 km·h^{-1}, which involve increases in stride length and/or stride frequency [9–14].

To reduce these forces, midsole cushioning serves as an important feature of footwear in providing a foam layer between the outsole and innersole. Its functional definition revolves around the ability to reduce vertical ground reaction force upon impact [15,16] and to enhance energy absorption during loading [17]. Holistically, the properties focus

on absorbed, lost, and recovered energy. To this end, in vitro mechanical tests show that midsoles are effective at absorbing impact energy [18]. However, the findings in the literature regarding the effectiveness of such cushioning capabilities while running are somewhat inconclusive [11,19–22]. Moreover, few research articles report the actual cushioning properties of the shoes being tested, as per industry standards [23–26], making it hard to establish a cause.

Early studies indicated that midsole softness did not reduce peak impact [11,27]. However, it was later found that runners adapt their technique (joint kinematics) to compensate for changes in surface-impact-absorbing characteristics [28] and shoe cushioning [26]. Shoes with greater cushioning tend to result in a narrower range of motion at the ankle in the transverse plane, less internal rotation at the hip, and reduced knee abduction [29]. Consequently, it is believed that runners operate within a personal kinetic bandwidth when responding to impact stresses [30]; they adapt their technique to cope with impact stresses, suggesting that footwear plays a significant role.

Importantly, running or walking barefoot, or with minimal cushioning, alters gait through decreasing stride length and increasing stride frequency, which, in turn, reduces ground reaction forces and their associated metrics [31,32]. Thus, it is hypothesized that the change in stride kinematics, rather than the absence of shoes, leads to the reduction in impact forces [33].

Moreover, the effects of wearing minimalistic shoes whilst running have provided mixed results. Some studies have shown significantly lower impact forces compared to maximally cushioned shoes [34], while others have found no difference or even increased loading rate or peak impact forces compared to cushioned shoes worn when running and/or walking [21,35–38].

The proposition that cushioning does not attenuate impact is not tenable [18] and can be related to force plates reflecting whole-body acceleration rather than lower extremity to predict ground reaction forces [18]. However, the use of pressure insoles align in vivo with in vitro, where comparisons between minimalist and traditional running shoes in female-only populations have shown considerably greater peak pressure and maximum mean pressures for the forefoot, midfoot, and rearfoot in minimalist shoes [19]. Further, maximally cushioned shoes decrease in-shoe plantar loading forces from a total perspective and at the forefoot when compared with minimalist shoes [39]. However, there is currently no link between plantar pressures and impact forces in minimalist and maximally cushioned shoes.

It is no surprise that researchers are calling for more biomechanical studies involving gait kinetics in relation to shoe cushioning [18] and based on gender [40], as female runners are at an increased risk of running-related injuries compared to their male counterparts [7,41,42], have slightly different patterns of gait [40], and present greater shock attenuation than males [43]. This could mean either lower tolerance to peak impact forces or they are experiencing greater forces on impact and may respond differently to different shoe conditions based on gait and anatomy [19,39,44,45].

The popularity of running, combined with the potential negative health effects, particularly for female runners, due to the shockwave generated upon ground contact with every step, underscores the necessity of exploring shoe material properties to mitigate these risks. While in vitro tests show that midsole cushioning is beneficial, these results do not consistently translate to real-world running, where equivocal findings are attributed to factors such as changes in kinematics, running speed, challenges related to habituation to multiple conditions, and protocol design.

This study aims to address these issues by comparing the mechanical properties of a non-cushioned minimalistic shoe with those of a cushioned shoe. Using the same footwear, it will also assess the spatiotemporal and kinetic variables of gait via pressure-

sensitive insoles whilst walking at 6 km·h^{-1} and running at 10 and 14 km·h^{-1} in a group of habituated female runners.

2. Materials and Methods

2.1. Participants

Twelve recreational to nationally competitive female endurance runners (mean ± SD; age (yrs.) 24.2 ± 6.2, height (cm) 167.0 ± 4.4, body mass (kg) 62.3 ± 6.6, and Body Mass Index 22.3 ± 2.1) free of injury participated, after giving written consent in accordance with University Human Ethics Committee approval. All participants grew up in New Zealand where barefoot activity is socially normal [46], and all still participate actively barefoot, to some extent. They were also accustomed to running on asphalt using modern (circa 2023) cushioned shoes.

This sample size was based on an a priori power analysis using G*power (Version 3.1.9.7, Heinrich-Heine University, Dusseldorf, Germany) and the findings of Shorten et al. [18]. The effect size for peak impact force between a minimalist shoe and a less cushioned shoe than used for this study, running at 14.4 km·h^{-1}, was 0.51. For the analysis of variance (ANOVA) with repeated measures within factors, there was an alpha value of 0.05, power of 0.95, and effect size of 0.51. The output suggested 8 participants, providing an actual power of 0.964.

A further power analysis using peak pressure on impact [39], where participants were free to run at a self-selected speed using minimalist and maximal cushioned shoes, presented an effect size of 0.7 with an output sample size of 5 (actual power 0.97). Considering these findings, we aimed for the inclusion of twelve participants.

2.2. Procedures and Measurements

The experimental protocol consisted of two trials (cushioned shoe vs. minimalist-control shoe) and three condition walk–run treadmill speeds (6, 10, and 14 km·h^{-1}) that were typically used by the participants in their everyday running shoe. These speeds have also been shown to produce significant differences in vertical ground reaction forces [12].

Each trial was performed in one session on the same day, performed in a counter-balanced order of shoe conditions, and separated by 15 min to minimise the sequence effect on the dependent variables of interest.

Upon arrival at the laboratory, the participants were measured, weighed, and had their footwear size determined for each foot (Figure 1) by a shoe specialist to ensure best fit based on participant input and expertise. The mean (range) in a United States women's size was 8.5 (7.5–9.5) for the cushioned shoe and 8 (6–10) for the non-cushioned shoe.

Figure 1. Photographic representation of (**A**) the minimalist shoe and (**B**) the cushioned shoe.

Figure 1B shows the cushioned shoe (Asics Gel-Nimbus 25, Asics Corporation, Kobe, Japan), which had a 40.5 mm heel and a 32.5 mm forefoot (8 mm drop) midsole featuring a single layer of FlyteFoam BLAST^{TM} ECO Plus foam cushioning with an extra PureGEL^{TM} insert in the rearfoot, and had a rocker (manually measured using Kinovea,

version 0.9.5 [47]) angle of 15°, rocker radius of 45°, apex position of 70%, apex angle of 75°, and a weight of 235 ± 9 g. The midsole hardness scale C, measured with a durometer (HC), was 30.1 ± 0.1 HC. Figure 1A shows the minimalist shoe [48], which had a 0 mm heel–toe drop, a 5 mm PVC rubber outsole (H&S, The Warehouse, Auckland, New Zealand), and weighed 206 ± 14 g, with a midsole durometer reading of 55.0 ± 6.1 HC. Trial order was selected, and the appropriate footwear was fitted with a flexible pressure insole to record kinetic data (LoadSol® Pro, Novel GmbH, Munich, Germany), whereupon each insole (left and right) was configured for the specific participant and followed the manufacturer's bipedal calibration process.

Each trial consisted of a 5 min warm-up period on the treadmill (Life Fitness, Hamilton, New Zealand) at the participant's preferred running speed. Each condition (shoe*speed) was performed for a period of 1 min, with data logged throughout and analysed during the last 10 s of each condition [49]. The participants were blind to any dependent variables being measured.

LoadSol® time*force data (200 Hz) were uploaded into MATLAB (R2022b, MathWorks, Inc., Natick, MA, USA), re-sampled to 1000 Hz, and processed using force threshold values of 20–30 N to determine the initial foot contact and toe-off [50]. From these outputs, the following dependent variables were calculated using techniques previously described for walking [51] and running [52] and expressed per body weight (N) where appropriate: (a) Peak vertical impact force ($N \cdot BW^{-1}$), identified as the first peak between initial contact and the active peak. If the first peak was not present in running (mid-forefoot strike), it was defined as the force at 13% of the stance phase; (b) Active peak vertical force ($N \cdot BW^{-1}$), which was the second peak for walkers and heel strike runners, or the highest force reading of each step for mid-forefoot strikers. In running, this point (mid-stance) was described where the foot was directly below the centre of mass. In walking, the midstance occurs at the lowest vertical force reading between the two peaks; (c) Time to mid-stance (s), which was the time to the lowest force value between peak 1 and 2 in walking, and the time to the active peak force in running; (d) To calculate the average rate of loading ($N \cdot BW^{-1} \cdot s^{-1}$), the difference between forces at 20% and 80% of the peak impact force was divided by the corresponding time interval (s) between these two points; (e) Impulse (N·s), the area under the force–time curve; (f) Ground contact time (s), the time the foot remained in contact with the floor; (g) Swing time (s), the time the foot had no contact with the ground; and (h) Stride duration, which was the time from one initial impact to the next initial impact for the same foot.

Mechanical Testing

A shoe cushioning property assessment was performed post running trials using a modified industry standard test (ISO 20344:2021 (5.17)) [53]. The Instron (4467, Instron, Norwood, MA, USA) was programmed to compress the midsole in the vertical direction at a deformation rate of 10 mm per minute and applied a maximum force of 2.2 kN. Following 20 conditioning cycles, 5 cycles were performed while recording deformation (mm) and load (N). Energy absorption (J) was calculated as the area under the load–extension curve until peak extension was met. Recovered energy (J) was calculated as the area under the load–extension curve from the peak extension to the return to zero extension. The recovered energy (%) is calculated as (recovered energy/energy absorbed) *100, while heat dissipation (J) is the difference between the energy absorbed and the recovered energy.

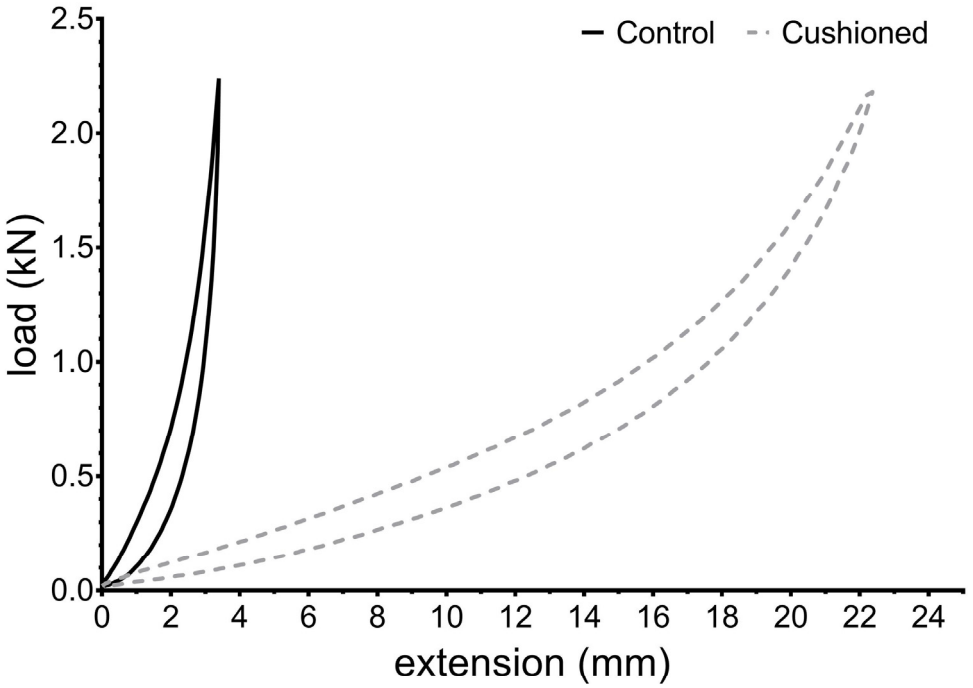
All dependent variable data were calculated per step, with the number of steps, overall mean ± SD, and the mean ± SD of the coefficient of variation (CV (%)) per independent variable presented. Differences between shoes and speed were analysed using a two-way repeated-measures ANOVA, with 2 within-subject variables (speed*shoe). Where signifi-

cant difference was found, Sidak's post hoc multiple comparisons testing was performed. All statistics were performed using GraphPad Prism (V 8.4, GraphPad Software, San Diego, CA, USA). Significance was set at $p < 0.05$.

3. Results

3.1. Mechanical Properties

The mechanical testing resulted in a deformation of 3.39 mm, and 22.37 mm for the fifth cycle in the minimalist-control and cushioned shoe, respectively. The deformation curves and relevant data for the two shoes are presented in Figure 2.



	Energy Absorbed (J)	Recovered Energy (J)	Heat Dissipation	Recovered Energy (%)
Minimalist	2.46	1.46	0.99	59.7
Cushioned	16.86	13.40	3.47	79.4

Figure 2. Force deformation curves and corresponding values of energy absorption, energy return, heat dissipation, and elastic return (%) for the minimalist-control shoe (—) and the cushioned shoe (--).

3.2. Kinetic Data Analysis

A two-way ANOVA of kinetic data identified significant interaction (speed*shoe) for peak vertical impact ($F_{(2,22)} = 11.44$, $p = 0.005$, Figure 3A), with a main effect for speed ($F_{(2,22)} = 22.93$, $p < 0.0001$) but not shoes ($F_{(1,11)} = 0.916$, $p = 0.361$). Key post hoc multiple comparison between shoes indicated decreased impact differences for cushioned shoes versus minimalistic control at both 10 $km \cdot h^{-1}$ (1.42 vs. 1.32 $N \cdot BW^{-1}$, $p = 0.009$) and 14 $km \cdot h^{-1}$ (1.72 vs. 1.51 $N \cdot BW^{-1}$, $p = 0.005$). There was also a significant interaction (speed*shoes) for average loading rate ($F_{(2,22)} = 5.456$, $p = 0.013$, Figure 3C), with main effects for both speed ($F_{(2,22)} = 71.05$, $p < 0.0001$) and shoes ($F_{(1,11)} = 6.596$, $p = 0.028$). Key post hoc multiple comparisons between shoes indicated decreased average loading rate differences for cushioned shoes versus minimalistic control at both 10 $km \cdot h^{-1}$ (44.9 vs. 39.7 $N \cdot BW^{-1} \cdot s^{-1}$, $p = 0.008$) and 14 $km \cdot h^{-1}$ (61.4 vs. 54.7 $N \cdot BW^{-1} \cdot s^{-1}$, $p = 0.004$), but not 6 $km \cdot h^{-1}$ (14.9 vs. 14.6 $N \cdot BW^{-1} \cdot s^{-1}$, $p > 0.999$).

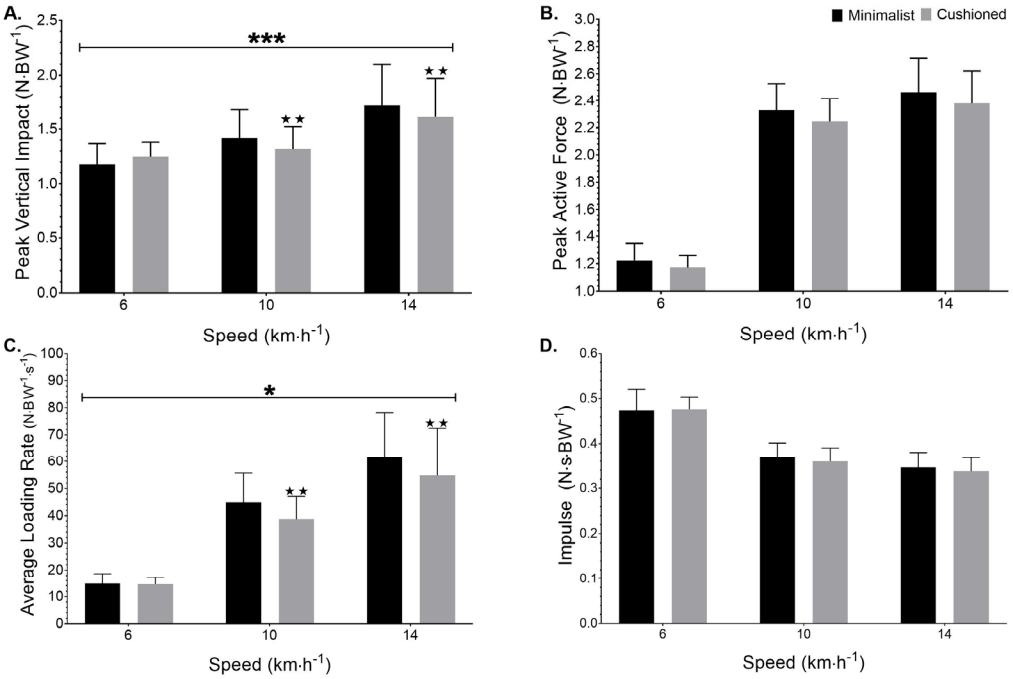


Figure 3. Mean ± SD data for each treadmill running speed (6, 10, and 14 km·h^{-1}) whilst wearing minimalist and modern-day cushioned shoes for (**A**) peak vertical impact (N·BW^{-1}), (**B**) peak active force (N·BW^{-1}), (**C**) average loading rate (N·BW^{-1}·s^{-1}), and (**D**) impulse (N·s·BW^{-1}), where ■ is the minimalist shoe and ■ is the cushioned shoe. * Indicates significant interaction (speed*shoe), and ★ indicates post hoc significance between shoes. Symbol number indicates significance level, e.g., * $p < 0.05$, ★★ $p < 0.01$, *** $p < 0.001$.

There was no speed*shoe interaction ($F_{(2,22)} = 0.427$, $p = 0.659$, Figure 3B) or main effect of shoe ($F_{(1,11)} = 3.695$, $p = 0.084$) for active peak force. However, there was an increased main effect for speed ($F_{(2,22)} = 458.3$, $p < 0.0001$). Time to active peak force presented no speed*shoe interaction ($F_{(2,22)} = 3.444$, $p = 0.052$), but there were decreased main effects for speed ($F_{(2,22)} = 4647$, $p < 0.0001$) and increased main effects for shoe ($F_{(1,11)} = 6.596$, $p = 0.028$). However, shoes only presented post hoc differences at 6 km·h^{-1} (0.449 vs. 0.462 s^{-1}, $p = 0.0004$).

There was no speed*shoe interaction for step impulse ($F_{(2,22)} = 0.365$, $p = 0.204$) or main effect of shoe. However, there was a decreased main effect of speed ($F_{(2,22)} = 1023$, $p < 0.0001$, Figure 3D).

3.3. Kinematic Data Analysis

A two-way ANOVA of kinematic variables found significant interactions for stride duration ($F_{(2,22)} = 3.885$, $p = 0.036$, Figure 4A) with a main effect for speed where stride duration decreased ($F_{(2,22)} = 1249$, $p < 0.0001$). There was no main effect for shoes ($F_{(1,11)} = 2.518$, $p = 0.144$). Further breakdown of the gait cycle presented no speed*shoe interaction ($F_{(2,22)} = 1.896$, $p = 0.176$) for ground contact time (Figure 4B), with no main effect of shoes ($F_{(1,11)} = 2.266$, $p = 0.163$), but a decreased effect of speed ($F_{(2,22)} = 1076$, $p < 0.0001$). There was a significant interaction ($F_{(2,22)} = 22.47$, $p < 0.0001$) for time to mid-stance (Figure 4C) with an increased main effect for shoes ($F_{(1,11)} = 30.77$, $p = 0.0002$) and a decreased effect of speed ($F_{(2,22)} = 1203$, $p < 0.001$. However, shoes only presented post hoc differences at 6 km·h^{-1} (0.276 vs. 0.301s^{-1}, $p < 0.0001$). There was also no interaction ($F_{(2,22)} = 0.147$, $p = 0.864$) or main effect for shoe ($F_{(1,11)} = 2.728$, $p = 0.130$) for swing time. There was, however, a main effect for speed ($F_{(1,11)} = 43.96$, $p < 0.0001$, Figure 4D).

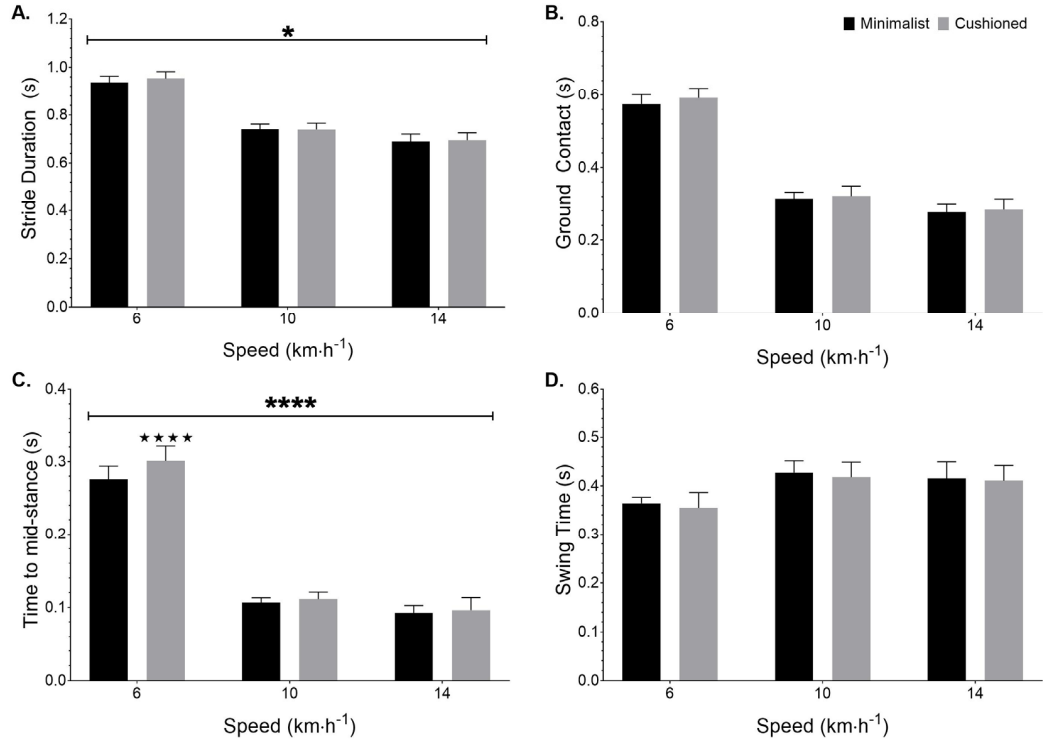


Figure 4. Mean ± SD data for each treadmill speed (6, 10, and 14 km·h^{-1}) whilst wearing minimalist and modern-day cushioned shoes for (**A**) stride duration (s), (**B**) ground contact time (s), (**C**) mid-stance time (s), and (**D**) swing time (s), where ■ is the minimalist shoe and ■ is the cushioned shoe. * Indicates significant interaction (speed*shoe), and ★ indicates post hoc significance between shoes. Symbol number indicates significance level, e.g., * $p < 0.05$, **** $p < 0.0001$, ★★★★ $p < 0.0001$.

Overall, the mean number of steps analysed from all trials were 23 ± 2 steps. It is also important to note that, even with such few steps, there is a certain degree of variance within the participants, as shown in Table 1.

Table 1. The overall mean ± SD for the CV(%) for each trial (speed*shoe) for all dependent variables.

Shoe	**Minimalist**	**Cushion**	**Minimalist**	**Cushion**	**Minimalist**	**Cushion**
Speed (km·h^{-1})	6	6	10	10	14	14
Stride Duration	1.2 ± 0.3	1.1 ± 0.3	1.0 ± 0.2	1.2 ± 0.4	1.1 ± 0.3	1.1 ± 0.3
Stride Frequency	1.3 ± 0.3	1.3 ± 0.4	1.0 ± 0.2	1.2 ± 0.4	1.1 ± 0.3	1.1 ± 0.3
Ground Contact Time	1.7 ± 0.5	2.4 ± 1.3	4.6 ± 0.7	4.6 ± 0.8	4.6 ± 1.7	5.0 ± 1.2
Swing Time	3.8 ± 0.7	4.3 ± 1.4	3.5 ± 0.6	3.2 ± 0.8	3.8 ± 2.0	3.7 ± 1.4
Peak Impact Force	3.5 ± 1.4	3.2 ± 0.8	7.1 ± 1.0	7.0 ± 2.1	6.8 ± 1.8	6.5 ± 1.1
Loading Rate	13.6 ± 4.8	11.2 ± 2.3	10.1 ± 2.4	11.4 ± 3.0	8.4 ± 1.9	7.4 ± 0.9
Active Peak Force	2.9 ± 1.7	2.8 ± 0.8	1.6 ± 0.4	2.2 ± 0.5	1.9 ± 0.4	2.6 ± 0.7
Time to Active Peak Force	2.3 ± 0.6	5.7 ± 0.5	6.1 ± 1.8	7.3 ± 2.4	5.7 ± 1.5	6.3 ± 2.4
Impulse	2.4 ± 0.6	2.7 ± 1.0	3.1 ± 0.4	2.8 ± 0.4	2.7 ± 1.0	2.8 ± 0.9

4. Discussion

The purpose of this study was to assess the mechanical properties of two subjective categories of running shoe—minimalist and cushioned—and then to compare the spatiotemporal and kinetic variables of gait in habituated female runners at treadmill speeds of 6, 10, and 14 km·h^{-1}. The key findings indicate that the cushioned shoe exhibited

greater energy absorption (690%), recovered energy (920%), and heat dissipation (350%). These mechanical property differences resulted in the cushioned shoes significantly reducing the peak vertical impact (~12%) and average loading rate (~11%) at running speeds of 10–14 km·h^{-1}, while not affecting peak active force, impulse, stride duration, ground contact or swing time during walking or running.

As expected (Figure 4) and supported by prior research, increased speed led to higher running cadence [54] due to decreased ground contact time, time to mid-stance, and swing time [55]. Additionally (Figure 3), higher speeds resulted in increases in peak vertical impact, average loading rate, and active vertical peak force, along with a decreased time to active vertical peak force [9,11,13,56]. These kinetic variables have also been associated with running-related injuries [5,7], implicating running speed as a factor in injury aetiology [57].

Understanding strategies to attenuate impact-related metrics is crucial as walkers and runners increase their speed [12]. One such strategy involves the mechanical properties of shoe midsoles, particularly energy absorption (cushioning) and energy recovery [58,59]. The data presented in Figure 2 shows two very different shoe types acquired during 2023 (Figure 1). Although there is no standardised classification for shoe cushioning, the 690% difference in energy absorption capability suggests that one of the shoes used provides much greater cushioning compared to the other.

The overarching purpose of a more cushioned midsole is to attenuate vertical ground reaction forces upon impact [15,16], where females are more susceptible to loading injuries [7] compared to males [43]. It has been suggested [20,21,34] that cushioned shoes either increase loading rates or have no significant impact on peak forces over less cushioned shoes. The equivocal findings are referred to as the 'impact peak anomaly' [18] and related to the method of measure, i.e., a force plate. Classifying shoes as soft (40), medium (52), or hard (65) using the Asker C hardness scale [26] has shown that, as a midsole becomes softer, the vertical peak impact force increases when using a force plate system. However, research specifically involving female participants and using pressure-sensitive insoles has indicated that such shoes can alleviate the plantar pressures [19,39], although no link to impact forces was established. The current study utilised shoes typical of cushioned models from 2023, which were considerably softer (HC 30.1) than those previously studied [26]. Participants' running speed was controlled via a treadmill, using pressure-sensitive insoles, and where data were presented as the mean of multiple steps (n = 23 ± 2). This provides clear evidence for increased (690%) midsole cushioning regarding the attenuation of both peak impact forces (Figure 3A) and average loading rates (Figure 3C) when running at 10 and 14 km·h^{-1}, but not while walking at 6 km·h^{-1}. This finding contrasts with earlier work that presented a decreased effect of shoe type on impact forces during walking barefoot versus athletic shoes at 5.4 km·h^{-1} [3]. However, the differences observed between the minimalistic and cushioned shoes (0.07 N·BW^{-1}) are comparable to those between the street leather-soled shoe and the athletic shoe (0.04 N·BW^{-1}) reported by Lafortune et al. [3].

Explanations for the increased impact forces and loading rate have previously focused on landing hardness [26], suggesting that runners adapt their technique to compensate [30]. Specifically, as the landing becomes softer, ankle and knee joint stiffness increases [26], potentially decreasing stride duration, ground contact time, and swing time [60]. However, Figure 4 shows no changes in stride duration, ground contact time, or swing time because of the shoe. This leads to the plausible assumption that participants' techniques remained relatively unaltered between shoe types, supporting the preferred movement path paradigm [61]. Furthermore, no changes in vertical peak active force (Figure 3B) or vertical impulse (Figure 4D) were observed. This suggests that even though the cushioned shoe had an energy return that was 920% of the minimalist shoe, it either did not affect the vertical oscillation of the centre of mass—reflected through no change in vertical impulse—

or that muscle activation, which typically increases with running speed [62], was reduced when wearing the cushioned shoe. This would also likely equate to a more efficient system and greater running economy at the same speed, while potentially enhancing performance.

The results of this study can be attributed to the acute nature and the extended data collection period compared to previous work and may reflect a true comparison of shoe midsole properties in line with the work of Shorten et al. [18]. This suggests that the protocol used facilitated a control mechanism, preventing changes in gait that could alter the findings. However, this may not accurately represent the true response of the runner in a non-treadmill setting, indicating the need for further research in this area.

5. Conclusions

Cushioned running shoes provide significant benefits in energy absorption, energy recovery, and heat dissipation compared to minimalist shoes, particularly at running speeds of 10–14 $km \cdot h^{-1}$. These cushioned shoes are effective in reducing peak vertical impact and average loading rates, without altering the spatiotemporal variables of gait associated with running economy or performance. Overall, the findings indicate that modern cushioned running shoes could lower the risk of impact-related injuries in female runners while not affecting parameters associated with running efficiency when compared to a minimalistic shoe.

The practical implications of this are that runners could run more efficiently, train more for the same risk, and potentially increase performance. Further research needs to explore the interaction between footwear, running mechanics, muscle activation, running economy, and performance in real-world conditions.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Massey University (4000018780, approved 29 September 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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