



Effect of three different running gait cues on vertical tibial acceleration

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ABSTRACT

Background: Repetitive impacts during running are associated with some running injuries. Tibial acceleration is a proxy for tibial loading, and interventions that can decrease it are likely to be of interest to the running community.

Research question: What effect do running gait cues have on peak vertical tibial acceleration at a comfortable and moderate running pace, and how will these cues be executed?

Methods: Twenty-seven participants ran on a treadmill according to the following cues in random order: run softly and lightly, run with shorter steps, and increase preferred step rate by 7.5 %. Participants maintained each condition for one minute before returning to their 'preferred' running pattern for two minutes. Two tibia-mounted inertial measurement unit sensors were used to collect tibial acceleration data at a 'comfortable' and 'moderate' run pace. A repeated measures analysis of variance test was used to compare the means between running conditions.

Results: Compared to preferred running, the *decrease step length* (−8 %, $p = 0.002$, Cohen's $d=0.33$) and *run softly and lightly* (−9 %, $p = 0.040$, Cohen's $d=0.38$) cues provided a significant reduction in peak vertical tibial acceleration during a comfortable run pace. No significant difference was observed with an *increase in step rate*. Compared to preferred running, there was no significant difference in peak vertical tibial acceleration with any of the running gait cues during a moderate run pace.

Significance: Instructing runners to *decrease step length* or *run softly and lightly* can result in small reductions in peak vertical tibial acceleration during a comfortable run pace, but running gait cues during a moderate run pace provide no effects. Differences in the execution of each cue are likely to influence overall tibial loading throughout the stride cycle. These findings provide novel biomechanical evidence for the potential effects of running retraining strategies for reducing tibial accelerations at different running paces.

1. Introduction

The repetitive impacts associated with running play an important role in the pathophysiology of many common running injuries, such as patellofemoral pain, medial tibial stress syndrome, Achilles tendinopathy and plantar heel pain [1]. Tibial acceleration (TA) is accepted as a proxy measurement for tibial impact forces during running, with correlations between peak TA and both the average and instantaneous loading rate of vertical ground reaction force when using skin-mounted accelerometers [1]. Wearable technology allows for in-clinic measurement of TA that can be used to monitor and manage tibial impact forces [1]. Interventions that can potentially modify impact forces, such as using running gait cues, are likely to be of considerable interest to the

running community.

Running retraining is typically used in the management of an injured runner with the goal to reduce or shift tissue loads away from an injury [2]. Common strategies including verbal or audible cues to alter strike pattern, step length, impact loading, and step rate [3–5], and many of these running retraining strategies are interdependent. When selecting a running retraining strategy with the intention to reduce load at the site of an injury, consideration must be given to both the magnitude of the load, and the number of loading cycles. Running retraining interventions such as increasing step rate and reducing step length, whilst understood to influence peak TA, will also increase the number of loading cycles across a given distance.

Although TA has been shown to decrease when runners are

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instructed to decrease their step length or cued to “run softly” [1,6,7], it remains uncertain which running retraining strategies are most effective in achieving this outcome. It is known that TA is influenced by running velocity, with faster running resulting in increases in peak TA [1]. These increases in peak TA are understood to be associated with changes to stride rate and step length [1]. As runners often follow periodised programmes aimed at achieving specific event goals, which often involves varying running intensities [8], it is important to understand the effects of running gait cues at different speeds when considering the implementation of gait retraining into their training programme.

The primary objective of this study was to evaluate the effect of three different running gait cues (increase step rate; “run softly”; decrease step length) on peak vertical TA at both a comfortable and moderate running pace. The secondary objective was to evaluate the effect of three different running retraining cues (increase step rate; “run softly”; decrease step length) on the root mean square (RMS) of vertical TA at both a comfortable and moderate running pace. RMS relates to the overall average acceleration throughout the stride cycle and may provide key insights into the differences in the implementation of running cues, and the potential implications if integrated into a gait retraining programme. We hypothesised that there would be differences in tibial accelerations among the three running gait cues at both comfortable and moderate running paces.

2. Methods

This study is a randomised, repeated measures, laboratory-based study. The study is reported in accordance with The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [9].

The study was approved by the La Trobe University Human Ethics Committee (HEC21398) and written informed consent was obtained from all participants. All experiments were performed in accordance with the World Medical Association’s Declaration of Helsinki.

Twenty-nine healthy adult participants were recruited between February and July 2022. Participants were eligible to participate if they were aged between 18 and 45 years, ran an average of 20 kilometres per week, had been regularly running and free of injury for at least six months. Participants were excluded from the study if they had a medical condition or injury that would affect their ability to run, were unable to speak English, were not confident with treadmill running, or had previously used any form of running retraining. Technical issues resulted in data not being collected appropriately for two participants. These two participants were removed from data analysis, resulting in a final sample of 27 participants (12 females and 15 males).

An a priori sample size calculation estimated that 23 participants were required to provide 80% power to detect a medium effect size (partial $\eta^2 = 0.06$) for the four running conditions (preferred running pattern and three running retraining cues), with statistical significance for hypothesis tests set at $p < 0.05$ [10]. The four running conditions were recorded in random order according to a computer-generated sequence (Excel, Microsoft, Washington, USA).

All data were collected at a single session at a physiotherapy clinic. Participants ran in their usual running shoes. Two tibia-mounted inertial measurement unit (IMU) sensors (Blue Trident, Vicon Motion Systems, Oxford, UK; sampling rate = 1600 Hz) were firmly secured to the anteromedial aspect of the distal tibia of each leg with double-sided adhesive tape and secured with elastic strapping. Two additional shoe-mounted IMUs (RunScribe Plus, Scribe Labs, Moss Beach, CA; sampling rate = 500 Hz) were fastened to the laces of each shoe (Fig. 1).

Participants ran for five minutes at a self-selected comfortable pace to ‘warm up’ and familiarise themselves with the treadmill and experimental apparatus. Following the familiarisation period, participants completed an additional 500 m calibration run. Data collection was then conducted in two stages, with three minutes of complete rest between each stage.

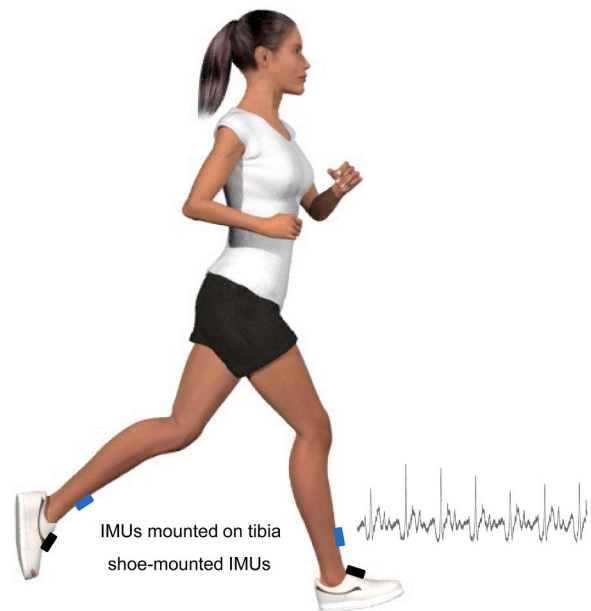


Fig. 1. : Methods set-up. Inertial measurement units (IMUs) were mounted on the tibiae and shoes while participants ran on a treadmill.

2.1. Stage one

The treadmill was set to the participant’s self-selected comfortable run pace, equivalent to 11 out of 20 (‘fairly light, able to maintain a conversation without getting out of breath whilst running’) on the 15-point Borg scale [11]. Participants were instructed to maintain this pace for the duration of stage one. Each participant’s preferred running step rate and foot strike were recorded during the initial three minutes of running. Foot strike was quantified using a numbered scale from 0 to 15 (rearfoot to forefoot), with 6–9 indicating a midfoot strike. Preferred running step rate was determined by both RunScribe IMUs and a manual count over two 30 second intervals; foot strike was determined by both RunScribe IMUs and visual confirmation. After three minutes of running with a preferred pattern (control condition), participants were instructed to run according to each of the following cues in random order (Microsoft Excel, Microsoft Corp, Washington, USA):

- (i) run softly and lightly (verbal cue)
- (ii) run with shorter steps, ensuring a foot landing position under body (verbal cue)
- (iii) increase preferred step rate by 7.5 % (audible cue provided via metronome)

Participants were instructed to maintain each running condition for one minute before returning to their ‘preferred’ running pattern for two minutes. Verbal cues relating to each running condition were provided approximately every 15 s. This was repeated for all three running retraining cues. Data were recorded throughout.

2.2. Stage two

The procedure was repeated as per stage one but at a moderate run pace, equivalent to 16 out of 20 (‘hard, laboured breathing, challenging and uncomfortable but sustainable for 30–60 min’) on the 15-point Borg scale [11]. Data were recorded throughout.

Data processing was conducted using MATLAB (Mathworks, MA, USA). Only data from the left limb were used to meet the independence assumption of statistical analysis [12]. For each participant, the data waveforms were trimmed to include only the middle 30 s of data for each of the four running conditions in both stages. The waveforms were

then low-pass filtered using a fourth-order Butterworth filter with a cut-off of 50 Hz to remove high-frequency noise. The RMS of the vertical TA was calculated using the filtered waveform.

The *findpeaks()* function in MATLAB was used to extract the positive peaks of vertical TA from the filtered waveform, defined as the highest positive vertical TA within a single stride cycle (Fig. 2, right). TA is participant-specific, and a single 30-second window could have a variable number of stride cycles, with the magnitude of peak vertical TA also varying from stride to stride. Therefore, we developed an iterative thresholding approach to ensure that the desired peaks were reliably extracted, with nuisance peaks, including any retained noise, correctly excluded.

In our approach, for each waveform analysed, the minimum peak height threshold parameter of *findpeaks()* was iteratively raised from zero to the maximum value of the signal, and the number of extracted peaks counted at each iteration. Peaks below the threshold were excluded. Therefore, the number of extracted peaks was always monotonically non-increasing as the threshold was raised (Fig. 2, left and right). However, as the peak positive vertical TA tended to be significantly higher than neighbouring nuisance peaks, a threshold window existed within which the number of extracted peaks was constant, i.e., a plateau region, indicating that all nuisance peaks were likely excluded (Fig. 2, left). To detect this plateau region, the gradient of the *number of extracted peaks vs minimum peak height threshold* curve was calculated, and the largest region with zero gradient identified. The peaks extracted in this region were the desired peaks of the positive vertical acceleration for the 30-second window. To improve peak detection, the *minimum peak distance* parameter was set to 640 samples, determined manually based on examination of a small subset of data, to more reliably exclude nearby neighbouring peaks. We validated our iterative thresholding approach by inspection of a randomly-selected subset of our data to ensure that all desired peaks were correctly extracted. For each waveform analysed, the mean and standard deviation of the extracted peaks were calculated.

IBM SPSS Statistics (v.28, IBM Corporation, Armonk, NY) was used to perform statistical analyses. Normality of data were confirmed prior to inferential statistical analysis using eight tests: skewness within the range of -2 – 2 , kurtosis within the range of -2 – 2 , skewness not exceeding double the standard error of skewness, mean equal to or within 10% of the median, standard deviation less than half the mean, minimum value not exceeding three standard deviations from the mean, maximum value not exceeding 3 standard deviations from the mean, and a non-significant Kolmogorov-Smirnov test. If less than five of these tests

are met, then continuous data were considered to be not normally distributed, which was not the case in this study. A repeated measures analysis of variance (ANOVA) with a Bonferroni-adjusted post hoc tests was used to compare the means between running cues (increased step rate, “run softly”, decreased step length) for each of the running speeds. Statistical significance for hypothesis tests was set at the conventional level of $p < 0.05$. Effect sizes for all significant main effects between the four conditions were calculated using partial eta squared (η^2) and were interpreted as small (0.00 to <0.06), medium (0.06 to <0.14), and large (≥ 0.14). Effect sizes were also reported for all significant pairwise comparisons using Cohen’s d [13] and were interpreted as small (0.15 to <0.40), medium (0.40 to <0.75), large (0.75 to <1.10), and very large (≥ 1.10) [13,14].

3. Results

Twenty-seven participants (15 men and 12 women; mean [SD]: age 31.0 [7.4] years, height 176.2 [9.9] cm, mass 72.0 [12.0] kg, average running distance 40.4 [18.6] km/week, comfortable run pace 11.3 [0.99] kmph, moderate run pace 12.8 [1.4] kmph) were recruited. Four participants were habitual rearfoot strike runners, 14 were midfoot strike runners and nine were forefoot strike runners.

Tibial acceleration: During a comfortable run pace (stage one), there was a significant effect for peak vertical TA and RMS of vertical TA between the four running conditions (Table 1). Significant differences were found for post-hoc pairwise comparisons of peak vertical TA and RMS of vertical TA between the four running conditions (mean and % change with respect to the preferred condition are presented in Table 2, with only significant differences reported hereafter). Significant reductions in peak vertical TA were found for: (i) the *decrease step length* (-8% , $p = 0.002$; $d = -0.33$, small effect) and *run softly* (-9% , $p = 0.040$; $d = -0.38$, small effect) cues compared to preferred running; and (ii) the *decrease step length* cue compared to *increase step rate* (-8% , $p = 0.027$, $d = -0.29$, small effect). Significant increases in RMS of vertical TA was found for: (i) the *decrease step length* ($+2\%$, $p = 0.019$, $d = -0.23$, small effect) and *increase step rate* ($+4\%$, $p < 0.001$, $d = -0.49$, medium effect) cues compared to preferred running; and (ii) the *decrease step length* ($+3\%$, $p < 0.001$, $d = -0.36$, small effect) and *increase step rate* ($+4\%$, $p < 0.001$, $d = -0.55$, medium effect) cues compared to *run softly*.

During a moderate run pace (stage two), there was a significant effect for peak vertical TA and RMS of vertical TA between the four running conditions (Table 1). No significant differences in peak vertical TA were found for any of the three running retraining cues compared to preferred

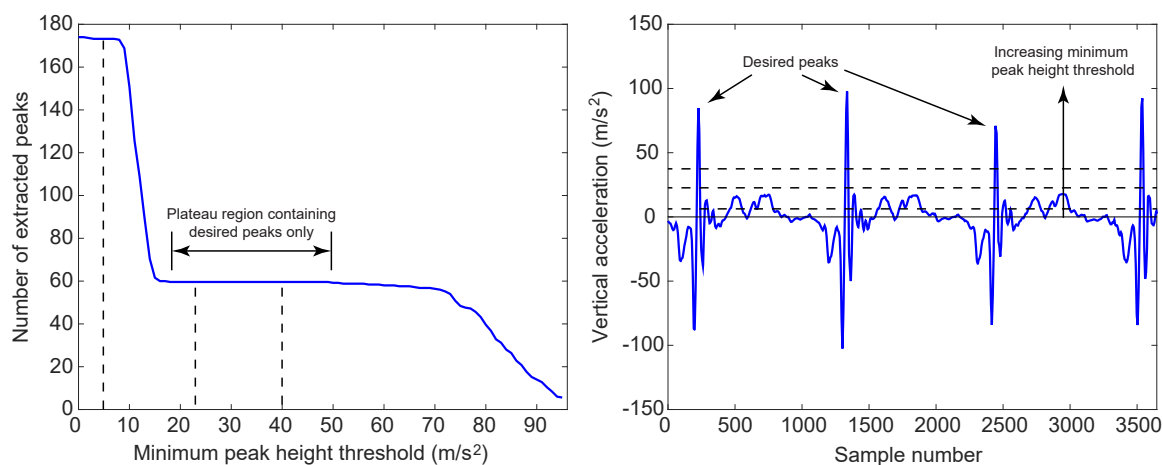


Fig. 2. : Illustrative example demonstrating the extraction of the desired tibial peak positive vertical accelerations from the waveform data using our iterative thresholding approach. Left: Number of peaks extracted is monotonically non-increasing as minimum peak height threshold is raised from zero. The plateau region contains the desired peaks, with all nuisance peaks excluded. Right: Snippet of filtered waveform data from which the peaks are extracted. The desired peaks are substantially higher than the neighbouring nuisance peaks.

Table 1
Repeated measures ANOVA table for tibial acceleration variables and gait parameters.

	Wilks' Lambda	F	η_p^2	p
TA variables				
<i>Peak vertical TA (m/s²)</i>				
Comfortable pace	0.48	8.8	0.53	< 0.001
Moderate pace	0.64	4.5	0.36	0.012
<i>RMS of TA (m/s²)</i>				
Comfortable pace	0.37	12.2	0.60	< 0.001
Moderate pace	0.47	9.1	0.53	< 0.001
Gait parameters				
<i>Step rate (steps/min)</i>				
Comfortable pace	0.07	107.2	0.65	< 0.001
Moderate pace	0.1	76.6	0.51	< 0.001
<i>Step length (m)</i>				
Comfortable pace	0.22	28.6	0.60	< 0.001
Moderate pace	0.2	32.2	0.49	< 0.001
<i>Contact time (ms)</i>				
Comfortable pace	0.52	7.3	0.48	0.001
Moderate pace	0.41	11.6	0.59	< 0.001
<i>Flight time (ms)</i>				
Comfortable pace	0.39	11.7	0.60	< 0.001
Moderate pace	0.26	21.6	0.74	< 0.001
<i>Foot strike</i>				
Comfortable pace	0.47	9.3	0.54	< 0.001
Moderate pace	0.56	6.3	0.44	0.003

Partial eta-squared effect size (η_p^2) was defined as small ($0.00 \leq \eta_p^2 < 0.06$), medium ($0.06 \leq \eta_p^2 < 0.14$), and large ($\eta_p^2 \geq 0.14$)

Statistical significance was set at the level $P < 0.05$

TA: tibial acceleration

Note: Foot strike is represented on a numbered scale from 0 to 15 (rearfoot to forefoot strike; midfoot strike represented by mid-range numbers 6–9)

running (Table 2). A significant reduction in peak vertical TA was found for the *run softly* cue compared to *increase step rate* (-11% , $p = 0.005$, $d = -0.42$, medium effect). Significant increase in RMS of vertical TA was found for: (i) the *decrease step length* cue compared to preferred running ($+2\%$, $p = 0.006$, $d = -0.22$, small effect); and (ii) the *decrease step length* ($+4\%$, $p < 0.001$, $d = -0.36$, small effect) and *increase step rate* ($+4\%$, $p < 0.001$, $d = -0.40$, medium effect) cues compared to *run softly*.

Gait parameters: Significant effects for step rate, step length, contact time, flight time and foot strike between the four running conditions were found for both the comfortable run pace (stage one) and moderate run pace (stage two) (Table 1). Mean and % change with respect to the preferred condition are presented in Table 3.

Table 2
Comparisons of peak vertical tibial acceleration and RMS tibial acceleration for each running retraining cue (N = 27).

Condition	Peak vertical tibial acceleration (m/s ²)				RMS tibial acceleration (m/s ²)			
	Mean (SD)	% change	d	p	Mean (SD)	% change	d	p
Comfortable pace								
Preferred running	55.1 (13.9)	n/a	n/a	n/a	18.1 (1.3)	n/a	n/a	n/a
Step length cue	50.5 (14.2)*§	-8	0.33	0.002	18.5 (1.4)*‡	+2	0.29	0.019
Softly cue	50.2 (12.3)*	-9	0.38	0.040	18.1 (1.2)§	0	0.06	1.0
Step rate cue	54.3 (12.1)†	-2	0.06	1.0	18.8 (1.6)*‡	+4	0.49	< 0.001
Moderate pace								
Preferred running	63.3 (15.6)	n/a	n/a	n/a	20.6 (1.9)	n/a	n/a	n/a
Step length cue	59.9 (16.2)	-5	0.21	0.238	21.0 (2.0)*‡	+2	0.22	0.006
Softly cue	59.0 (15.6)§	-7	0.28	0.158	20.3 (1.9)§	-1	0.15	0.209
Step rate cue	65.3 (14.7)†	+3	0.13	1.0	21.1 (2.1)‡	+2	0.25	0.065

Effect sizes (Cohen's d) defined as small (0.15 to <0.40), medium (0.40 to <0.75), large (0.75 to <1.10), and very large (≥ 1.10).

Statistical significance was set at the level $p < 0.05$.

*Mean difference significant at the 0.05 level compared to the normal condition.

†Mean difference significant at the 0.05 level compared to the step length cue.

‡ Mean difference significant at the 0.05 level compared to the softly cue.

§ Mean difference significant at the 0.05 level compared to the step rate cue.

Note: % change is relative to the preferred running condition.

4. Discussion

The findings of this study support our hypothesis that the running gait cues to increase step rate, run softly and decrease step length result in an immediate difference in peak vertical TA and RMS of vertical TA compared to normal running. However, we found that despite the inverse relationship between step rate and step length, the cues to increase step rate and decrease step length (both of which are understood reduce step length) had differing effects on peak vertical TA and RMS of vertical TA across both a comfortable and moderate running pace.

Previous research investigating the effect of stride length on tibial acceleration [1] and tibial bone strain [15] has indicated that reducing stride length can be an effective strategy in reducing tibial impact loads. The results of our study support the previously established relationship between step length and tibial acceleration when participants were running at a comfortable pace, with cues to increase step rate and decrease step length both resulting in a reduction in peak vertical TA. However, when running at a moderate pace, the cue to increase step rate resulted in an increase in peak vertical TA compared to normal running.

It is widely accepted that faster running leads to an increase in peak tibial acceleration [1], and our findings support this. It is also understood that the extent of the increase is likely influenced by changes to step rate and step length. The difference in response to the *increase step rate* and *decrease step length* cues support previous research findings suggesting that step length changes and the associated kinematic factors such as joint orientation at initial contact may be critical in determining TA magnitude [1,16]. They also suggest that the effects observed with a running gait cue at a comfortable pace are not necessarily predictive of the effects that will occur when running at a greater intensity. Whilst the *decrease step length* and *run softly* cues may continue to provide benefit with respect to accumulated tibial loads at a faster pace but with reduced efficacy, there may be limited or no benefit to the cue to *increase step rate*. This has implications when considering which running retraining strategy to implement, as many runners will be following periodised programmes that include variations in running pace [8].

RMS of vertical TA may reflect not only average acceleration, but differences in the way running cues are executed. When considering the execution of each running gait cue, significant differences in gait parameters were found in our study (Table 3). For example, the cues to *increase step rate* and *decrease step length* should theoretically produce similar changes in RMS due to the inverse relationship between step length and step rate. Instead, we found a twofold increase in RMS with the *increase step rate* cue compared to *decrease step length* when running at a comfortable pace, suggesting that participants may have interpreted

Table 3
Comparisons of gait parameters for each running retraining cue (N = 27).

Condition	Step rate (steps/min)				Step length (m)				Contact time (ms)				Flight time (ms)				Foot strike			
	Mean (SD)	% change	d	p	Mean (SD)	% change	d	p	Mean (SD)	% change	d	p	Mean (SD)	% change	d	p	Mean (SD)	% change	d	p
Comfortable pace																				
Preferred running	167.7 (9.4)	n/a	n/a	n/a	1.1 (0.1)	n/a	n/a	n/a	77.0 (7.1)	n/a	n/a	n/a	84.9 (21.1)	n/a	n/a	n/a	10.1 (3.7)	n/a	n/a	n/a
Step length cue	182.8 (11.4) ^{*‡}	+ 9	1.44	< 0.001	0.9 (0.2) ^{*‡§}	-15	1.075	< 0.001	81.3 (8.0) ^{*‡§}	+ 6	0.566	< 0.001	63.9 (25.1) ^{*‡§}	-25	0.906	< 0.001	10.9 (3.7) [§]	+ 8	0.23	0.269
Softly cue	166.5 (11.9) ^{‡§}	-1	0.11	1.0	1.1 (0.2) ^{‡§}	-4	0.258	0.10	76.9 (7.7) [‡]	0	0.014	1.0	86.7 (27.3) ^{‡§}	+ 2	0.072	1.0	11.1 (4.2)	+ 10	0.25	0.575
Step rate cue	178.2 (10.6) ^{*‡}	+ 6	1.05	< 0.001	1.0 (0.1) ^{*‡‡}	-10	0.764	< 0.001	78.0 (7.3) [‡]	+ 1	0.139	0.554	76.2 (22.0) ^{*‡§}	-10	0.404	0.003	12.1 (3.4) ^{*‡}	+ 20	0.564	< 0.001
Moderate pace																				
Preferred running	173.2 (9.3)	n/a	n/a	n/a	1.2 (0.2)	n/a	n/a	n/a	74.0 (7.0)	n/a	n/a	n/a	92.8 (19.7)	n/a	n/a	n/a	9.7 (3.9)	n/a	n/a	n/a
Step length cue	187.1 (11.7) ^{*‡}	+ 8	1.31	< 0.001	1.1 (0.2) ^{*‡}	-14	1.01	< 0.001	78.2 (7.5) [*]	+ 6	0.582	< 0.001	72.6 (21.5) [*]	-22	0.978	< 0.001	10.8 (3.8)	+ 11	0.278	0.664
Softly cue	173.6 (12.9) ^{‡§}	0	0.03	1.0	1.2 (0.2) ^{*‡§}	-7	0.43	0.007	75.9 (8.4)	+ 3	0.248	.395	86.3 (30.9)	-7	0.251	.886	10.4 (4.5)	+ 8	0.175	0.873
Step rate cue	185.5 (10.2) ^{*‡}	+ 7	1.25	< 0.001	1.1 (0.2) ^{*‡}	-14	1.09	< 0.001	77.4 (7.6) [*]	+ 5	0.456	< 0.001	75.3 (23.7) [*]	-19	0.802	< 0.001	11.5 (3.4) [*]	+ 19	0.501	0.002

Effect sizes (Cohen's d) defined as small (0.15 to <0.40), medium (0.40 to <0.75), large (0.75 to <1.10), and very large (≥ 1.10).

Statistical significance was set at the level $p < 0.05$.

*Mean difference significant at the 0.05 level compared to the normal condition.

‡Mean difference significant at the 0.05 level compared to the step length cue.

‡ Mean difference significant at the 0.05 level compared to the softly cue.

§ Mean difference significant at the 0.05 level compared to the step rate cue.

Note: % change is relative to the preferred running condition; Foot strike is represented on a numbered scale from 0 to 15 (rearfoot to forefoot strike; midfoot strike represented by mid-range numbers 6–9).

and executed these cues differently. This is also supported by the observed differences in gait parameters of flight time and contact time between the two cues. Whilst the neuromechanical and/or psychological factors influencing these differing outcomes have yet to be explored, this finding highlights the importance of considering the changes that must be made to running gait to achieve the desired outcome when implementing a gait retraining programme as an intervention.

Previous research has found that running retraining with real-time and haptic feedback can provide reductions in TA [6,7,17]. Our study also found overall reductions in TA from the three running gait cues used; however, each cue was executed differently, and had different effects for each participant. These results suggest it is important to consider how running retraining cues are executed at a population level, but also by individual runners. Whilst running retraining is commonly used to reduce TA in the management of some running-related injuries [3], the strategy that reduces tibial loading without creating new tissue loads may need to be determined based on the individual, their biomechanics, and their execution of the running retraining cue. Runners should consider a transition period to adapt to new tissue loads when altering their preferred running pattern, as certain cues may pose higher 'risk', as demonstrated by our RMS findings.

Our findings need to be considered in the context of several key limitations. First, measurements were taken indoors on a treadmill so it remains uncertain if the results would differ if the participants were tested running overground. However, a recent systematic review found that spatiotemporal, kinematic, kinetic, muscle activity, and muscle–tendon outcome measures are largely comparable between treadmill and overground running, including no differences in TA [18]. Second, participants included in the study were a mix of rearfoot and non-rearfoot strike runners. The evidence regarding TA and foot strike is conflicting [1,4], however including runners with a variety of strike patterns may enhance the generalisability of our findings to a broader range of runners, although it may have limited applicability runners with a specific strike pattern. Third, it remains unknown what effects the running gait cues have on TA over the longer term due to acclimatisation, as participants only run under each condition for one minute in this study. Fourth, the participants in this study were uninjured, so it remains unclear if the effects observed in this study may differ among injured runners who are most likely to receive running retraining to alter TA. Finally, we recognise that although an association between TA and tibial bone stress injuries has been established [1], this association is yet to be made with other running-related injuries. In consideration of these limitations, it would be beneficial for future studies to investigate if the changes in TA provide clinical benefits when managing running-related injuries.

Running gait cues can be effective in reducing peak vertical TA at a comfortable pace but using running gait cues to reduce tibial loads when running at a moderate pace presents more of a challenge. The differences in the execution of each cue are likely to influence overall tibial loading throughout the stride cycle, and this should be an important consideration when using running retraining with the goal to reduce tissue loads and manage lower limb running injuries.

CRediT authorship contribution statement

Laura Anderson performed conceptualization, methodology, formal analysis, investigation, and writing – original draft. **Daniel Bonanno** performed conceptualization, methodology, writing – original draft. **Prasanna Sritharan** performed methodology, software, formal analysis, writing – review and editing; **Hylton Menz** performed conceptualization, methodology, writing – review and editing and supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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