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ORIGINAL RESEARCH

ALTERING CADENCE OR VERTICAL OSCILLATION DURING RUNNING: EFFECTS ON RUNNING RELATED INJURY FACTORS

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ABSTRACT

Background: Wearable devices validly assess spatiotemporal running parameters (cadence, vertical oscillation and ground contact time), but the relationship between these parameters and lower limb loading parameters (loading rate, peak vertical ground reaction force [vGRF] and braking impulse) is unknown.

Purpose: To characterize changes in lower limb loading parameters in runners instructed to run with increased cadence or low vertical oscillation, and to determine whether the change in spatiotemporal parameters predicted the changes in lower limb loading parameters.

Study Design: Cross Sectional Cohort Study

Methods: Twenty healthy runners completed three running trials in three conditions: baseline, high cadence, and low vertical oscillation. Spatiotemporal parameters were measured with a wearable device and lower limb loading was measured using an instrumented treadmill. Spatiotemporal and loading parameters were analyzed between running conditions via a repeated measure ANOVA. A hierarchical regression model was used to determine if changes in spatiotemporal parameters predicted the change of loading parameters during conditions.

Results: High cadence and low oscillation conditions reduced average vertical loading rate ($p = 0.013$ and $p = 0.002$, respectively), instantaneous vertical loading rate ($p = 0.022$ and $p = 0.001$, respectively), and peak vGRF ($p = 0.025$ and $p < 0.001$, respectively). Braking impulse was significantly lower in the high cadence condition compared to baseline ($p < 0.001$), but not during the low oscillation ($p = 1.000$). The increase in cadence during the high cadence condition predicted the reduction of instantaneous vertical loading rate ($r^2 = 0.213$, $p = 0.041$) and braking impulse ($r^2 = 0.279$, $p = 0.017$). The reduction in vertical oscillation was more predictive of the change of peak vGRF in both running conditions (high cadence, $r^2 = 0.436$, $p = 0.009$; low oscillation $r^2 = 0.748$, $p < 0.001$).

Conclusion: While both higher cadence and lower vertical oscillation resulted in reduced loading rates during running, cueing to reduce vertical oscillation was more successful in reducing peak vGRF and only the higher cadence condition reduced braking impulse. These findings will inform clinicians who wish to use wearable devices for running gait modification to select injury-specific gait retraining cues.

Level of Evidence: Level 3

Key Words: running retraining, ground reaction forces, wearable devices

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INTRODUCTION

High levels of certain metrics of ground reaction forces during running are associated with the development of common running related injuries. For instance, high average and instantaneous vertical loading rates (AVLR and IVLR, respectively) of the vertical ground reaction forces are associated with runners with tibial stress fracture,[1,2] plantar fasciopathy,[3] and patellofemoral pain.[4] High braking impulses have been observed in runners with Achilles tendinopathy.[5,6] Similarly, high levels of the peak vertical ground reaction force (peak vGRF) have been associated with knee pain[7] and other running-related injuries.[8] For instance, a high peak vGRF relative to measures of tibial bone strength was reported in runners with a recent history of tibial stress fracture.[9] Notably, these running-related injuries are associated with a high rate of chronicity of recurrence.[10–12] Runners with a past history of a tibial stress fracture have, for instance, a six-fold increased risk of sustaining a subsequent tibial stress fracture.[10] Due to the high rates of re-injury, gait retraining has been proposed as a means to address lower extremity biomechanics in the hope to improve rehabilitation outcomes in runners.[13]

Recent advances in wearable technologies provide clinicians with the capability to assess running gait mechanics, cue changes in certain gait parameters, and then measure the runner's adherence with the new running pattern during field-based runs.[14] A commercially available running watch was recently found to be able to offer valid and reliable assessment of running cadence, ground contact time and vertical oscillation of a runner's center of mass.[15] Furthermore, Willy et al[16] used a wearable device to cue a modest increase of 7.5% in running cadence, which reduced AVLR and IVLR at the conclusion of the eight-session gait retraining program. Monitoring of the participants' running mechanics via the mobile device revealed that the runners successfully changed their running mechanics during the field-based retraining sessions and maintained these changes in the absence of feedback during the 30-day follow-up period.[16,17] The results of these studies demonstrate the ability of clinicians to utilize widely available mobile technology to quantify and retrain certain running mechanics without the need for a fully instrumented gait laboratory.[15]

Besides reducing loading rates, a 5-10% increase in preferred running cadence (+5-10% over preferred) reduces the peak vGRF and braking impulse.[16,18] However, there may be additional simple gait modifications that can affect ground reaction forces during running. Wille et al[19] found that both cadence and magnitude of center of mass excursion are associated with vertical ground reaction forces and braking impulse. Thus, instructing a runner to reduce vertical oscillation of their center of mass may be a viable alternative cue to increased cadence if a reduction in loading rates, peak vGRF and braking impulse is desired. To date, it is not known which of these alterations is more effective at reducing lower limb loading patterns associated with running related injuries.

Therefore, the purposes of this study were twofold. First, to characterize the change in loading rates, peak vGRF and braking impulse in runners instructed to run with increased cadence or low vertical oscillation. Second, to determine whether changes in running mechanics predicted the changes in vertical loading rates, peak vGRF and braking impulse during the two running conditions. Understanding the relationship of gait modifications and lower limb loading can provide clinicians and patients with clinically applicable strategies that can be quantified and monitored using accurate and reliable wearable devices.

METHODS

Participants

A convenience sample of twenty active runners (running experience 11.5 $\pm$ 6.9 years and average running distance 37.3 $\pm$ 27.8 Km per week) was recruited to participate in this study. To be eligible, participants were required to be between the ages of 20-55, running at least 60 minutes per week and free of any injuries for the past 12 months. This study was approved by the University of Delaware Institutional Review Board and each participant gave informed consent prior to data collection.

Procedure

Participants wore a commercially available watch (fēnix2; Garmin Ltd, Schaffhausen, Switzerland), paired with a heart rate strap equipped with a triaxial accelerometer (HRM-Run; Garmin Ltd) during the experiment. This watch and associated accelerometer has previously been shown to be a valid and reliable assessment of cadence and vertical oscillation during running.[15] Participants were asked to run on one of the two moving belts of an instrumented treadmill (Bertec Corporation, Columbus, OH).

Participants started running at a speed of 1.5m/s. Running speed was increased 0.1m/s every 10 seconds until participants reported reaching a comfortable self-selected running speed on the treadmill. Once participants reported a comfortable speed, they ran for one minute to become familiar with the treadmill and speed. If changes in speed were requested during the familiarization period, the speed was changed and another minute of familiarization was provided. Subjects continued to run after the familiarization period for one minute while data were acquired (baseline condition).

After the baseline condition, the first ten participants continued to run for two different thirty second running conditions at the same running speed as the baseline condition. In the first condition (high cadence), participants were asked to increase their running cadence. One of the investigators, a board certified orthopedic and sports specialist Physical Therapist, instructed participants to "Increase the number of times your foot hits the ground by 10%". The investigator observed the participant and provided feedback prior to and during the condition. In the second condition (low oscillation), the investigator instructed participants to "keep their body as low to the ground as possible without slouching to reduce "bouncing" when running". The investigator provided verbal feedback prior to and during the condition. Participants had a minimum of thirty seconds of running at their self-selected form before the second condition began.

Running spatiotemporal data (cadence, vertical oscillation, and ground contact time) were collected with the running watch. GRF's were acquired using the instrumented treadmill at 1080Hz. To assure simultaneous data collection, a countdown was provided by one investigator for the start of the collection on both the watch and the instrumented treadmill software. The three conditions (baseline, high cadence, and low oscillation) were separated by at least 30-second intervals, during which time the runners returned to their habitual running mechanics and data were not recorded. The first ten subjects performed the high cadence condition followed by the low oscillation condition, with a reverse order after baseline for the remaining ten subjects.

The second set of ten participants was asked to run a second baseline condition to establish reliability of the loading parameters. Between the two baseline conditions, participants were asked to rest or walk around for several minutes without running. During the second baseline condition, the speed of the treadmill was matched to the speed of the first baseline condition. After one minute of familiarization with the new running pattern, data were collected simultaneously with both the watch and the instrumented treadmill in a similar manner to that of the first baseline condition.

Data analysis

Cadence, vertical oscillation, and ground contact time were calculated using the proprietary algorithm of the Garmin Connect software and the average value for each condition was reported in step/min (cadence), centimeters (COM), and milliseconds (ground contact time).

Visual3D software (version 5, C-Motion, Germantown, MD, USA) and a customized LabVIEW program (National Instruments, Austin, Tx) were used for the analysis of the GRF data. GRF data were filtered using a low-pass, fourth-order Butterworth recursive filter using a cutoff frequency of 50Hz. This filter cutoff frequency is routinely used when calculating loading rate of the vertical GRF during running, as described by Milner et al.[20] A 20N threshold of the vGRF was chosen to identify footstrike and subsequent toeoff and accurate stance detection was confirmed with visual inspection of the individual trials. This stance threshold minimizes the chance of spurious event detection in running data collected on an instrumented treadmill.[21] The GRF's were then normalized to body weight (BW). Ten consecutive right stance phases were retained for calculation of discrete variables of interest.

The braking impulse[22] was calculated as the time integral of the posterior-portion of the anterior-posterior GRF curves during stance and expressed in BW*sec. Next, loading rates of the vGRF's were calculated.

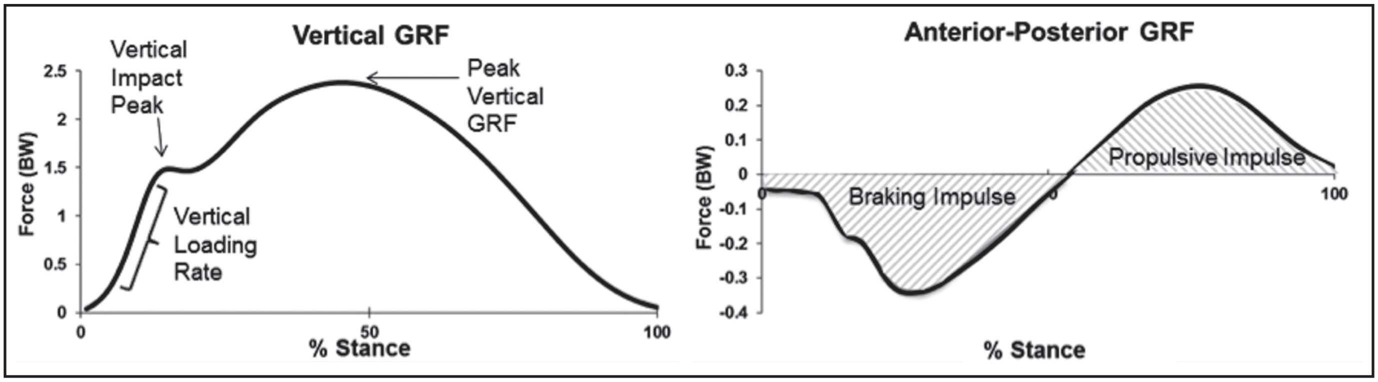

Figure 1. *Calculation of vertical and braking and propulsive ground reaction force variables. A) average vertical loading rate (AVLR) and instantaneous vertical loading rate (IVLR) were calculated in the middle 60% of the vertical ground reaction force (GRF) curve between footstrike and the vertical impact peak. B) braking and propulsive impulse were calculated as the time integral of the respective portions of the anterior-posterior GRF curve.*

AVLR (expressed in BW/sec) was calculated as the average slope of the middle 60% of the vGRF's curve between footstrike and the vertical impact peak.[23] In the case of an absent vertical impact peak, an index of 0.13 of stance length was used, as previously validated.[24] During the same time window, IVLR (BW/sec) was calculated as the steepest part of the curve using the first central difference method.[24] (Figure 1)

Statistical analysis

Reliability analysis

The reliability of the lower limb loading variables (AVLR, IVLR, braking impulse, and peak vGRF) was calculated in the subset of participants who ran two baseline conditions. Average values were compared between the two baseline conditions using Interclass Correlation Coefficient ($ICC_{3,10}$). Pooled standard deviation was used to calculated the standard error of the measurement and minimal detectable change at the 95% confidence interval (MDC95).

Between-running conditions analysis

Running dynamic variables (cadence, vertical oscillation, and ground contact time) and lower limb loading variables (AVLR, IVLR, braking impulse, and peak vGRF) were compared between conditions (baseline, high cadence, and low oscillation) using a repeated measure analysis of variance (ANOVA). In case of a significant within conditions effect, Tukey Post-Hoc test with Bonferroni correction was used to measure differences between each running conditions. To assess clinical magnitude of change and to permit comparison with previous investigations, percent change, confidence interval, and effect size (*d*) were calculated.[25] Two independent hierarchical linear regression models were used to predict the change of lower limb loading variables during the two running conditions (high cadence and low oscillation). The feedback given to participants focused on either increasing running cadence or decreasing vertical oscillation. Therefore, the change in cadence (for the high cadence condition) or the change in vertical oscillation (for the low oscillation condition) were entered first in the regression model. The change in secondary running dynamic variables (vertical oscillation and ground contact time, for the high cadence condition; and cadence and ground contact time for the low oscillation condition) were entered second in the regression model. This was done to understand whether the secondary variables would significantly improve the model prediction after accounting for the change in the primary variable. Statistical analysis was carried out using SPSS software (version 23, IBM, Amrok, NY, USA) and alpha level was set at 0.05.

RESULTS

Reliability analysis

All variables demonstrated excellent reliability, with ICC ranging from 0.985 to 0.999 (Table 1).

Between-running conditions analysis

Both spatiotemporal measures (Figure 2) and lower limb loading variables (Figure 3) were significantly different between running conditions (main effect

Table 1. *Reliability analysis of lower limb loading parameters.*

	Baseline 1 (SD)	Baseline 2 (SD)	$ICC_{3,10}$ (95% CI)	Pooled SD	SEM	MDC_{95}
AVLR	47.04 (26.04)	45.77 (24.24)	0.989 (0.960 - 0.997)	25.14	3.56	9.85
IVLR	66.22 (28.28)	66.17 (25.68)	0.989 (0.959 - 0.997)	26.98	3.72	10.31
Braking impulse	-0.0182 (0.003)	-0.0183 (0.003)	0.997 (0.989 - 0.999)	0.003	< 0.001	0.001
Peak GRF	2.32 (0.27)	2.33 (0.26)	0.998 (0.992 - 0.999)	0.27	0.02	0.05

Abbreviations: AVLR, average loading rate; IVLR, instantaneous loading rate; vGRF, vertical ground reaction force; ICC, interclass correlation coefficient; CI, confidence interval; SD standard deviation; SEM, standard error of the measurement; MDC_{95}, minimal detectible change at the 95% confidence interval.

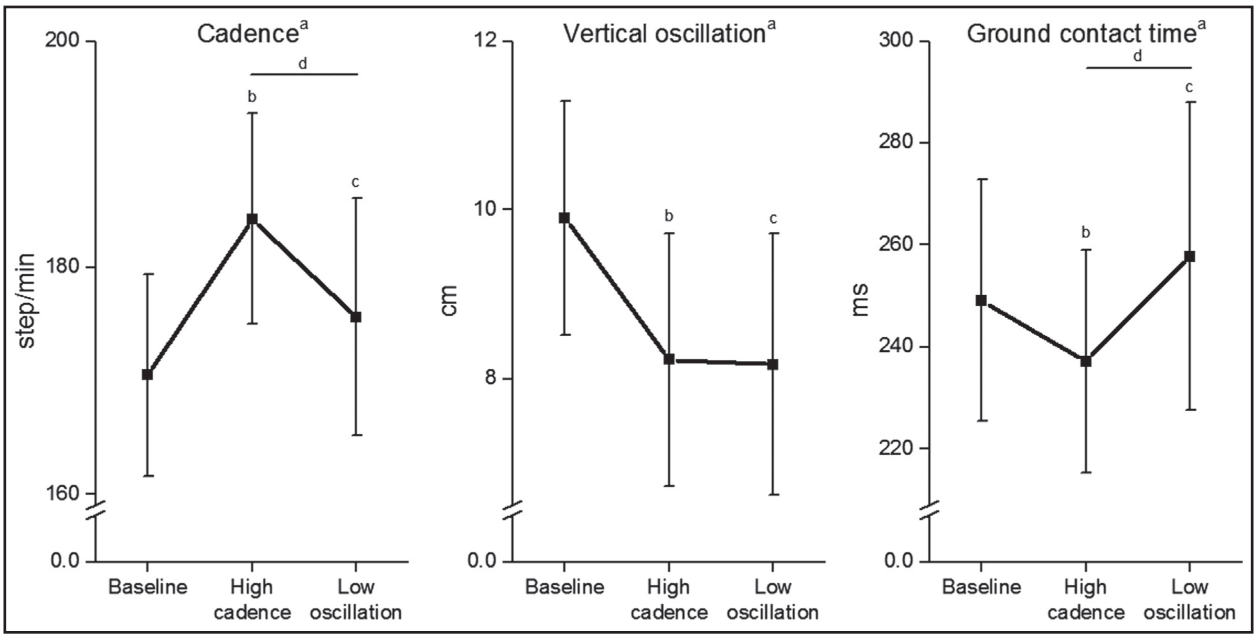

Figure 2. *Average change in cadence, vertical displacement, and ground contact time during the baseline, high cadence and low oscillation running conditions. Error bars represent standard deviation.*
[a,] *Repeated measure ANOVA, main effect of condition ($p < 0.001$)*
[b,] *Tukey post-hoc with Bonferroni correction, baseline vs. high cadence ($p < 0.05$)*
[c,] *Tukey post-hoc with Bonferroni correction, baseline vs. low oscillation ($p < 0.05$)*
[d,] *Tukey post-hoc with Bonferroni correction, high cadence vs. low oscillation ($p < 0.05$)*

of running condition, $p < 0.001$). The post-hoc analyses revealed that cadence increased 8.1% during the high cadence and 2.6% during low oscillation conditions compared to baseline, respectively. Moreover, cadence was higher in the high cadence condition compared to the low oscillation condition (MD: 8.7 step/min, $p = 0.001$). Vertical oscillation decreased 17.1% during the high cadence condition and 21.7% during the low oscillation condition compared to baseline, however no significant differences were observed between high cadence and low oscillation conditions (MD: 0.05cm, $p = 0.999$). Ground contact time decreased 4.7% during the high cadence condition compared to baseline; in contrast, ground contact time increased 3.5% during the low oscillation condition compared to baseline. AVLR significantly decreased 21.2% during the high cadence and 33.4% during the low oscillation conditions compared to baseline. IVLR significantly decreased 16.0% during the high cadence and 25.6% during the low oscillation conditions compared to baseline. Braking impulse significantly decreased

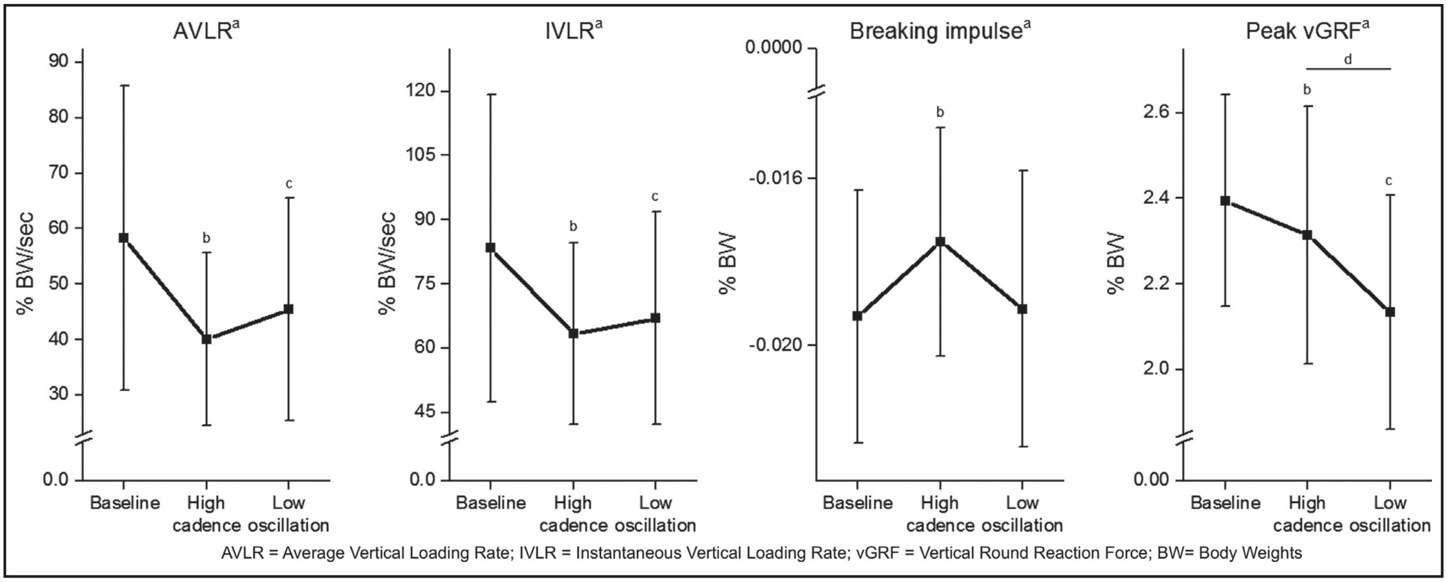

Figure 3. *Average change in loading parameters, average loading rate, instantaneous loading rate, breaking impulse and peak vertical ground reaction force during the baseline, high cadence and low oscillation running conditions. Error bars represent standard deviation.*

[a,] *Repeated measure ANOVA, main effect of condition (p < 0.001)*

[b,] *Tukey post-hoc with Bonferroni correction, baseline vs. high cadence (p < 0.05)*

[c,] *Tukey post-hoc with Bonferroni correction, baseline vs. low oscillation (p < 0.05)*

[d,] *Tukey post-hoc with Bonferroni correction, high cadence vs. low oscillation (p < 0.05)*

9.2% during the high cadence condition compared to baseline, but not during the low oscillation condition. Peak vGRF significantly decreased 3.5% during the high cadence and 11.4% during the low oscillation conditions compared to baseline. Furthermore, peak vGRF was significantly lower in the low oscillation condition compared to the high cadence condition (MD: -0.18 BW, $p < 0.001$). Mean change and effect sizes can be found in Table 2.

The increase in cadence during the high cadence condition significantly predicted the reduction of IVLR ($r^2 = 0.213$, $p = 0.041$) and braking impulse ($r^2 = 0.279$, $p = 0.017$). During the same high cadence condition, the changes in vertical oscillation and ground contact time were more predictive of the change of peak vGRF (r^2 change = 0.436, $p = 0.009$) compared to the change in cadence ($r^2 = 0.026$, $p = 0.493$). The decrease of vertical oscillation during the low oscillation condition was predictive of the reduction of peak vGRF ($r^2 = 0.748$, $p < 0.001$). During the same low oscillation condition, the change in cadence and ground contact time did not significantly increase the prediction of the regression model (Table 3).

DISCUSSION

Gait retraining can be an effective component of a comprehensive rehabilitation program for injured runners,[13] yet it may be challenging to determine which gait parameters to target. Findings from the study revealed that cueing to either increase cadence or reduce vertical oscillation resulted in a decrease of AVLR and IVLR. These findings suggest that both methods of cueing may be used to manipulate spatiotemporal running parameters in patients with injuries related to changes in AVLR and IVLR, such as plantar fasciopathy[3] or patellofemoral pain.[4] Based on these data, cueing an increase in running cadence may be the preferred cue when the goal of the retraining is to decrease braking impulse. For instance, runners with Achilles tendinopathy were reported to run with ~9% greater braking impulse compared with healthy controls,[5,26] which is equivalent to the reduction found in the present investigation during the high cadence condition. A recent report also found that increases in running cadence result in a small reduction in Achilles tendon loads.[27] Taken together, these findings suggest that running with a modest increase in cadence may

Table 2. *Change from baseline of spatiotemporal and loading parameters during the high cadence and low oscillation running conditions.*

Outcome	Mean change (95% CI)[a]	*p* Value[b]	Effect size[c]
Cadence, step/min			
High cadence	13.8 (10.3; 17.3)	< 0.001	1.52
Low oscillation	5.1 (1.6; 8.6)	0.004	0.38
Vertical Oscillation, cm			
High cadence	-1.7 (-2.2; -1.2)	< 0.001	-1.2
Low oscillation	-1.7 (-2.3; -1.1)	< 0.011	-1.0
Ground contact time, ms			
High cadence	-12.0 (-18.3; -5.6)	< 0.001	-0.5
Low oscillation	8.7 (0.3; 17.0)	0.041	0.3
AVLR, % BW/sec			
High cadence	-18.2 (-32.9; -3.5)	0.013	-0.8
Low oscillation	-12.8 (-21.1; -4.5)	0.002	-0.4
IVLR, % BW/sec			
High cadence	-20.0 (-37.6; -2.47)	0.022	-0.7
Low oscillation	-16.4 (-25.8; -7.00)	0.001	-0.4
Braking impulse, BW*s			
High cadence	-0.002 (-0.003; -0.001)	< 0.001	0.6
Low oscillation	0.001 (-0.001; 0.001)	0.999	< 0.1
Peak vGRF, BW			
High cadence	-0.1 (-0.15; -0.01)	0.025	-0.3
Low oscillation	-0.3 (-0.35; -0.17)	< 0.001	-0.8

Abbreviation: CI, confidence interval; AVLR, average loading rate; IVLR, instantaneous loading rate; BW, body weight; vGRF, vertical ground reaction force.

[a]mean change calculated as (high cadenœ or low oscillation - baseline) running conditions

[b]Tukey pot-hoc with Bonferroni correction

[a]Cohen *d*

be particularly helpful for runners recovering from Achilles tendinopathy.

The reductions in AVLR and IVLR noted with both the (-21.2--24.0%) high cadence and (-18.9%--16.8%) low oscillation conditions were associated with moderate to large effect sizes and likely clinically meaningful. Specifically, Milner and colleagues[23] previously reported that runners with a past history of tibial stress fracture ran with AVLR and IVLR that were 16.0% and 13.9% higher, respectively, compared with healthy matched controls. Reductions in loading rates in the present study are consistent with other studies that cued 5-10% increases in running cadence,[16,28] yet lower than interventions that cued a reduction in tibial shock (~ -32%), [29] switching to a forefoot strike (~ -47%)[28] or provided feedback on sound-intensity of footfalls (~ -35%).[30] Future study is required to determine which of these interventions is most effective in reducing injury risk in runners who are thought to be prone to sustaining a tibial stress fracture.

Both methods of cueing also reduced peak vGRF from baseline, but the peak vGRF during the low oscillation condition was significantly lower than high cadence running condition. Further, the change from baseline of vertical oscillation predicted 46% of the variance of the change in peak vGRF during the high cadence condition (after accounting for the change in cadence); and 75% during the low oscillation condition. Previously, a low tibial bone strength relative to peak vGRF was observed in runners with a past history of tibial stress fracture.[9] Due to reduction in both vertical loading rates and peak vGRF, cueing a reduction in vertical oscillation during running may have greater potential to reduce risk of a tibial stress fracture when compared with cueing an increase in running cadence. The kinematic strategies used to increase running cadence are well documented,[31] but less is known for cues targeting vertical oscillation and is a topic for further

Table 3. *Regression analysis to identify predictors of loading based on the change from baseline of spatiotemporal variables during the high cadence and low oscillation running conditions.*

	High Cadence					Low oscillation				
	Regression steps	r	R square	R square change	p-value change	Regression steps	r	R square	R square change	p-value change
AVLR	1 - Δ cadence	0.364	0.133	0.133	0.115	1 - Δ VO	0.169	0.028	0.028	0.477
	2 - 1 + Δ in VO and GCT	0.520	0.279	0.146	0.228	2 - 1 + Δ in cadence and GCT	0.400	0.160	0.132	0.312
IVLR	1 - Δ cadence	0.461	0.213	0.213	0.041*	1 - Δ VO	0.264	0.070	0.070	0.261
	2 - 1 + Δ in VO and GCT	0.628	0.395	0.182	0.122	2 - 1 + Δ in cadence and GCT	0.387	0.150	0.080	0.486
Braking impulse	1 - Δ cadence	0.528	0.279	0.279	0.017*	1 - Δ VO	0.458	0.210	0.210	0.042*
	2 - 1 + Δ in VO and GCT	0.606	0.367	0.088	0.352	2 - 1 + Δ in cadence and GCT	0.699	0.489	0.279	0.031*
Peak vGRF	1 - Δ cadence	0.163	0.026	0.026	0.493	1 - Δ VO	0.865	0.748	0.748	< 0.001*
	2 - 1 + Δ in VO and GCT	0.680	0.462	0.436	0.009*	2 - 1 + Δ in cadence and GCT	0.872	0.760	0.012	0.675

Abbreviations: AVLR, average loading rate; IVLR, instantaneous loading rate; vGRF, vertical ground reaction force; VO, vertical oscillation; GTC, ground contact time.
*, Significant R square change

study. When using cues for vertical oscillation, it is important that runners do not "slouch" or adopt a "groucho" running style.[32]

The use of commercially available wearable devices to measure spatiotemporal parameters of running is on the rise. These devices provide clinicians with reliable and accurate methods to track spatiotemporal running parameters.[15] The results of this study show that changes in spatiotemporal running parameters measured with a wearable device can predict changes in lower limb loading measured with an instrumented treadmill. Clinicians may be able to utilize these devices to provide training feedback outside of a laboratory or clinical settings, and to monitor patients' ability to alter gait mechanics and compliance with the prescribed alterations. Importantly, many wearable devices also record data on both running cadence and vertical oscillation during in-field runs, enabling clinicians to assess patient adherence during gait retraining interventions.[14] Thus, both retraining cues tested in this study can be readily employed outside the clinic in a runner's normal training environment.[14] The customization of gait retraining to certain injury-specific mechanics and the ability to measure adherence with a retraining program may lead to enhanced outcomes for rehabilitation programs for the injured runner.

Although this study focused on running gait mechanics that can be identified using wearable devices outside of the confines of the laboratory, other studies have examined the change of gait mechanics on additional kinematic and kinetic parameters. An increase in cadence has been reported to be accompanied by reductions in peak hip adduction angle, hip external adduction and internal rotation moments,[16,18,33] decrease in vertical impact loading rate,[33] decreases in eccentric knee joint loads[16,18,34,35] and patellofemoral and tibiofemoral joint loads.[34,36,37] One of the temporospatial strategies associated with an increase in running cadence is a shortened step length[31], placing the initial loading closer to the runner's center of mass[18] and a reduction in stance time.[31,38] Furthermore, increased leg stiffness has been reported when cadence is increased,[38] primarily influenced by the reduced stance duration. Thus, it would be expected that our cohort increased leg stiffness in the high cadence condition due to the reduction in stance duration.[38] During the low oscillation condition we found that participants adopted not only reduced vertical oscillation but also a 2.6% increase in cadence from baseline, resulting in a reduction in peak vGRF. These findings are consistent with a prior study that found an inverse relationship between vertical oscillation and cadence with peak vGRF during running.[19] In contrast to the high cadence condition, cueing a reduction in vertical oscillation failed to reduce braking impulse. The unchanged braking impulse, coupled with the lower cadence in the low oscillation condition, is consistent with a slightly longer step length than the high cadence condition.[18] Identification of the key biomechanical contributors for a change in AVLR, IVLR, and peak vGRF during the low oscillation condition requires a full analysis of kinematics and kinetics of the runners.

It is important to consider that this study was designed to measure the immediate effect of altering spatiotemporal parameters on loading variables. Adopting any new running mechanics may require short-term increases in metabolic demand. Large increases in running cadence[39] or an exaggerated decrease in vertical oscillation[40] have both been linked to an increase in the metabolic cost of running. The increase in metabolic demand may potentially negate the benefits associated with cadence or vertical oscillation manipulation, making it difficult for the runner to maintain the change in mechanics. However, Clansey and colleagues found no change in the metabolic demand of running when runners were cued to reduce tibial shock after an eight-session gait retraining program.[41] Sustained changes of cadence and oscillation may produce different effects on metabolic measures. Future studies are required to determine the long-term effect on manipulating cadence or vertical oscillation on metabolic energy costs.

The current study is not without limitations including small sample size, lack of an injured population, and short duration of running. Future studies should look to assess full kinematic, kinetic, and loading rate parameters associated with changes in spatiotemporal measures over a longer duration of running during data collection, as well as in runners with a history of running-related injuries. Future studies should also look to see long-term outcomes for changes in loading rates and metabolic demand.

CONCLUSION

Gait retraining cues for low vertical oscillation may be an effective alternative to increasing cadence for certain running related injuries. While both higher cadence and lower vertical oscillation resulted in reduced loading rates, there may be some advantages of low vertical oscillation in reducing peak vGRF and higher cadence in reducing braking impulse. Clinicians may look to use accurate and reliable wearable devices for gait retraining in a clinical setting to provide feedback to the patient and monitor their ability to modify running gait parameters.

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