RUNNING TO THE BEAT: DOES LISTENING TO MUSIC AFFECT RUNNING CADENCE AND LOWER EXTREMITY BIOMECHANICS?

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This aimed to determine if music with specific target beats per minute (bpm) could be used for treadmill running cadence training to alter lower extremity biomechanics and, thus, reduce injury risk. Motion analysis and a synchronized triaxial accelerometer collected data from eighteen runners during treadmill running. Participants ran at a self-selected speed (SS) to determine their baseline cadence. They also ran to music where the bpm of the songs was increased by 5% and 10% over SS cadence. Post hoc tests showed significant differences in heart rate from SS. There were no significant differences between cadence or peak acceleration. In the current study, music was not shown to be a viable method for cadence training in runners. Our findings led to methodology recommendations for future work in using music to effectively improve running cadence.

KEYWORDS: biofeedback, injury prevention, tibial stress fracture

INTRODUCTION: Despite the health benefits of running (Lee et al., 2014), studies of long-distance runners show an incidence of lower extremity injury ranging from 19.4-79.3% (Van Gent et al., 2007; Fredericson & Misra, 2007). Stress fractures account for almost 15% of overuse injuries in runners, with 50% being located at the tibia (Matheson et al., 1987). Recent studies have demonstrated that higher vertical ground reaction force (vGRF) and peak positive acceleration (PPA) values are present in runners with a history of tibial stress fractures (Crowell & Davis, 2011; Wood & Kipp, 2014; Crowell et al., 2010; Milner et al., 2006). Runners using a heel strike pattern are at greater risk of tibial stress fractures compared to mid- or forefoot runners due to their increased vGRF and PPA values (Yong et al., 2018).
Gait retraining, specifically stride rate (cadence) modulation, is a proven method to alter running biomechanics and reduce PPAs (Crowell & Davis, 2011; Wood & Kipp, 2014; Hobara et al., 2012; Hafer et al., 2015; Schubert, Kempf & Heiderscheit, 2014). Previous studies have used both visual and audio biofeedback to modulate cadence (Crowell et al, 2010; Heiderscheidt et al., 2011; Hobara et al., 2012; Hafer et al., 2015). In audio biofeedback, a metronome is frequently used to modify cadence, but may not provide motivational support and has limitations to real-world applications (Heiderscheidt et al., 2011; Hobara et al., 2012; Hafer et al., 2015). In interest of motivational factors, use of musical playlists with varying tempos has been proposed to bridge this gap. Music containing a specific tempo could potentially replace the monotony of a metronome while providing appropriate biofeedback to achieve similar means. The objective of this study was to evaluate the effects of using music with specific beats per minute (bpm) to increase cadence and decrease the tibia PPA during treadmill running. Based on the findings of a systematic review of studies using stride frequency to alter running mechanics (Schubert, Kempf & Heiderscheit, 2014), the reviewed studies saw biomechanics change with as little as a 5% change in cadence with most reporting changes with a 10% change. It was hypothesized that the using music specific bpms would improve cadence and biomechanics, specifically measured by decreased vGRF, PPAs and a less heel strike pattern without a significant increase in heart rate (HR).

METHODS: Eighteen recreational runners (12 F, 6 M; age: 29.3 ± 9.9 years, height: 171.8 ± 8.2 cm, mass: 68.8 ± 9.0 kg) were recruited from the general population. Participants were required to be comfortable running on a treadmill (self-reported) and free of any lower extremity musculoskeletal injuries within the past six months. Subjects completed written informed consent as approved by the Institutional Review Board.
Participants wore their own running shoes. A wireless, tri-axial accelerometer (G-Link-LXRS:

Lord, Microstrain, Williston, VT) was attached to the right anterior medial shin (Wood & Kipp, 2014). Participants were fitted with a chest strap HR monitor (Polar USA, Bethpage, NY). Sixteen reflective markers were applied according to Vicon Nexus' Plug-In Gait model (Vicon Motion Systems Ltd., Oxford, UK). The accelerometer collected data at 617 Hz and data was acquired using a custom LabVIEW program (National Instruments, 2013). Three-dimensional biomechanical data were collected using a 12-camera Vicon MX Motion Analysis System at 250Hz. Participants were instructed to begin running on the treadmill and work up to a self-selected speed (SS) within the first five to ten minutes based on a speed where their HR remained in the range of 70-80% of their max HR. Baseline cadence was calculated using the accelerometer data during SS running. Without altering their speed, runners were instructed to run to the beat of the music for a song with a 5% increase in bpm (+5%) over their baseline cadence for five minutes. Runners were then played a song with a 10% increase in bpm (+10%) over their baseline cadence and instructed to run to the beat of the music for another five minutes. These songs were selected from a group of several songs with varying BPMs. Participants were asked if they had a preferred genre or any they would not want to hear. Runners were given time to listen to the music and attempt to adjust their cadence accordingly before data was collected. HR was recorded in the middle of each bpm data collection.
A custom LabVIEW program calculated the vector sum of the accelerations in the sagittal plane. Raw acceleration data was used for calculating PPAs. Cadence was calculated from foot strikes in the motion analysis data using 10 consecutive right footfalls for each subject during each condition and confirmed with the accelerometer data. Sagittal plane pelvis, hip, knee, and ankle kinematics were assessed during stance phase. This method was confirmed against the cadence calculated by Nexus based on foot strikes.
A one-way repeated measures analysis of variance (ANOVA) was used to test the effect of bpm (SS, +5%, +10%) on cadence, HR and PPA. Significant interactions were determined using an a priori selected alpha value of $p < 0.05$. Mauchly's test of sphericity was used to check for equality of variance between the bpm levels. The sphericity assumption was not met; therefore, the Greenhouse-Geisser correction was used. Bonferroni procedures were used for post-hoc analysis. SPSS statistical software (version 26, IBM Corporation, Armonk, NY) was used to analyze the discrete variables. Statistical parametric mapping (SPM) from the MATLAB SPM package (R2019a, Mathworks Inc., Natick, MA) was used to compare the kinematic data. A SPM one-way repeated measures ANOVA was used to test the effect of bpm on the pelvis, hip, knee, and ankle sagittal plane kinematics.

RESULTS: The average treadmill running speed was 3.0 ± 0.5 m/s. HR increased 6.1% from SS to +5% bpm, 5.2% from +5% to +10% bpm, and 11.6% overall from SS to +10% bpm (Table 1). There was a significant main effect for bpm, F (2.281,38.774) = 1012.349, $p = 0.000$. Post hoc tests showed significant differences in HR from SS to +5% ($p = 0.049$), +5% to +10% ($p = 0.030$), and SS to 10% ($p = 0.013$). There were no significant differences between cadence or peak acceleration. The SPM one-way repeated measures ANOVA indicated no main effect for bpm on sagittal plane kinematics.

Table 1. Repeated measure metric means ± standard deviation

	SS	+5% bpm	+10% bpm
Cadence	167.3 ± 8.7	167.6 ± 9.4	167.7 ± 8.2
HR	153.7 ± 20.2	163.1 ± 13.1	171.5 ± 16.4
PPA	5.5 ± 1.6	5.5 ± 1.8	5.8 ± 1.8

DISCUSSION: The purpose of this study was to explore an alternative and more practical measure to modulate cadence and decrease PPAs outside the use of a metronome to reduce the risk of tibial stress fractures in runners. It was hypothesized that music with a specific cadence could be used to alter biomechanics and, thereby, increase their cadence to decrease tibial PPAs. Contrary to our hypothesis, it was found that the use of music was not an effective means to alter cadence or decrease PPAs. Consistent with this result, SPM analyses of the kinematics signals during stance showed no changes at the pelvic, hip, knee or ankle sagittal plane angles between the bpm levels. Finding ways to incorporate the effectiveness of running to a set beat into more natural environments is the first step in discovering how improvements detected in the laboratory can be implemented into the field.

Willy et al. (2016) implemented in-field gait training with mobile monitoring to decrease vertical loading and load rate through cadence modulation using an accelerometer which transmitted cadence data to a wrist monitor. After a series of laboratory training sessions where intervention group participants were instructed to run at a step rate 7.5% above their preferred, they completed eight training runs where they were instructed to continue to match the increased cadence using the accelerometer with progressively less feedback through the individual training runs. Their participants were able to maintain increased step rate and reduce vertical load rates 30 days post training demonstrating that in-field training is a viable method for reducing biomechanical factors associated with tibial stress fractures (Willy et al., 2016). Music could not only serve as the means for biofeedback but has shown to have a strong motivational component. Motivation has been shown to positively impact performance (Hobora et al., 2012). Thus, music could serve as a means for biofeedback with a strong motivational component. Audio biofeedback with music could be incorporated onto an application on a mobile device. This would allow participants to receive biofeedback in a more realistic, enjoyable, and practical setting.

Participants in the current study were exposed to the audio biofeedback during one episode of data collection in the laboratory. Crowell & Davis (2011) placed subjects into a gait retraining program using visual feedback that included eight sessions over a two-week period. Participants were able successfully decrease PPAs following a more prolonged course of training. Study participants had progressively less exposure to the biofeedback over the two-week period and participants were able to retain these reductions at a one month follow up. While our runners were unable to demonstrate increased cadence or decreased PPAs, it may be in part attributed to the duration of exposure to the biofeedback. Repeating our study design with more sessions to allow for greater exposure may demonstrate different results.

While we aimed to provide a good representation of recreational runners, we did not limit our participants to runners who have adopted a specific striking pattern. Previous studies have screened runners for PPAs prior to participation in efforts to isolate to runners with heel strike patterns (Crowell & Davis, 2011; Clansey et al., 2014). Participants with higher initial PPAs may be most effective in increasing cadence to decrease PPAs when compared to runners with more mid- or forefoot striking patterns and be the most representative population at risk for stress fractures. Runners with lower initial PPAs may already adopt a mid- or forefoot striking pattern. Many participants had baseline cadence greater than 170 steps/minute and may have impacted their ability to adapt to the increased cadence presented to them with an already fast step rate. Pre-participation selection for baseline tibial accelerations, cadence and foot strike pattern may help to subclassify runners that could see the greatest benefit from biofeedback training to reduce risk of tibial stress fractures.

Additional limitations regarding this study include the small population size and predilection towards female runners. To the authors knowledge at the time of this study there is no known data demonstrating differences in gender in terms of biofeedback and running. Further research efforts would expand our population to include a larger group of participants and a more heterogenous mixture in terms of gender. The methodology limitations of a single testing session rather than a multi-week training regimen could have strongly impacted the runners' ability to successfully alter their cadence to match the bpm of specified songs. A multi-week period in a study by Brake et al. (2022) had participants who were able to successfully match their cadence to the bpm of music.

CONCLUSION: Based on our findings, participants were unable to use music to increase their cadence and decrease PPA. This study highlights that methodologic changes should be considered to fully determine if runners can be trained to follow music bpm and alter their cadence accordingly. Cadence training would likely be more effective on runners who have a lower baseline cadence than most of the runners in the current study who already ran in a good cadence range. Further research directed at determining the feasibility of music as biofeedback may help bridge the gap between laboratories and more natural running environments.

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