

ORIGINAL RESEARCH

THE EFFECT OF STEP RATE MANIPULATION ON FOOT STRIKE PATTERN OF LONG DISTANCE RUNNERS

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ABSTRACT

Purpose/Background: Running gait retraining to change foot strike pattern in runners from a heel strike pattern to a non heel- strike pattern has been shown to reduce impact forces and may help to reduce running related injuries. Step rate manipulation above preferred is known to help decrease step length, foot inclination angle, and vertical mass excursion, but has not yet been evaluated as a method to change foot strike pattern. The purpose of this study was to investigate the effect of step rate manipulation on foot strike pattern in shod recreational runners who run with a heel strike pattern. A secondary purpose was to describe the effect of step rate manipulation at specific percentages above preferred on foot inclination angle at initial contact.

Methods: Forty volunteer runners, who were self-reported heel strikers and had a weekly running mileage of at least 10 miles, were recruited. Runners were confirmed to be heel strikers during the warm up period on the treadmill. The subject's step rate was determined at their preferred running pace. A metronome was used to increase step rate above the preferred step rate by 5%, 10% and 15%. 2D video motion analysis was utilized to determine foot strike pattern and to measure foot inclination angle at initial contact for each step rate condition.

Results: There was a statistically significant change in foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern at both 10% and 15% step rates above preferred. Seven of the 40 subjects (17.5%) changed from a heel- strike pattern to a non- heel strike pattern at +10% and 12 of the 40 subjects (30%) changed to a non-heel strike pattern at +15%. Mean foot inclination angle at initial contact showed a statistically significant change (reduction) as step rate increased.

Conclusion: Step rate manipulation of 10% or greater may be enough to change foot strike pattern from a heel strike to a mid-foot or forefoot strike pattern in a small percentage of recreational runners who run in traditional running shoes. If changing the foot strike pattern is the main goal, other gait re-training methods may be needed to make a change from a heel strike to a non-heel strike pattern. Step rate manipulation shows a progressive reduction of foot inclination angle at 5%, 10%, and 15% above preferred step rate which reduces the severity of the heel strike at initial contact. Step rate manipulation of at least +10% above preferred may be an effective running gait retraining method for clinicians to decrease the severity of heel strike and possibly assist a runner to change to a non-heel strike pattern.

Key Words: Foot strike pattern, running gait retraining, step rate manipulation

Level of Evidence: 3

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INTRODUCTION

The popularity of running in the United States is at an all-time high. The running population has grown over 70% in the last decade to nearly 42 million runners who run at least six days per year.¹ In 2013 a record 19 million runners were road race finishers capping 10 consecutive years of record race finisher numbers.¹

With the growing number of runners, especially those running greater mileage in preparation for half and full marathon distances, injuries related to running have also been on the rise. In a 2007 systematic review, Van Gent reported an incidence of running related injuries ranging from 19.4-79.3%. The time frame of studies examined by Van Gent included studies as short as 1 day and as long as 18 months.² As more runners seek care for running related injuries, it becomes increasingly important that health care and rehabilitation professionals are equipped to provide care specific to running related injuries.

In recent years a number of researchers have examined the impact forces of running and have correlated or at least provided a theoretical basis for higher impact forces being a potential cause of various running related injuries.^{3,4,5} It has been well established that impact forces at the knees and hips are typically highest in runners with a heel strike pattern as compared to those with a mid-foot or forefoot strike pattern.^{6, 7, 8,9} Lieberman et al. was one of the first to examine the connection between foot strike pattern, impact forces, and the potential connection to injury.¹⁵ Their research showed that shod runners typically strike with the heel first and that barefoot runners tended to run with a non-heel strike pattern. Impact forces were shown to be much higher in the heel striking shod runners than the barefoot runners and it was suggested that this may have a connection to running related injuries. It has been suggested that if impact forces can be reduced, then distance runners may be able to reduce injuries or rehabilitate from injuries more effectively than if running form and resultant impact forces are not addressed. Changing foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern through running gait retraining may be one way to accomplish a reduction of impact forces and reduce running related injuries.^{10,11} Up to 96% of recreational runners who run in traditional running

shoes have been reported to be heel-strikers making this a very relevant issue for rehabilitation professionals who take care of this population.^{12,13}

Several methods of running gait re-training to modify foot strike pattern have been examined in the literature.¹⁴ Barefoot running has been one of the most prominent methods to accomplish a change in foot strike pattern from a heel strike pattern to a forefoot strike pattern. It has been well documented that barefoot running tends to support a more forefoot biased foot strike pattern, decreased contact time, and a quicker step rate as compared to shod running which tends to support a heel strike pattern.^{15,16,17} McCarthy described a 12 week transition program from shod to simulated barefoot running that resulted in runners changing from a heel strike pattern to a forefoot pattern.¹⁷ Hatala et al., however, found that not all habitually barefoot people prefer running with a forefoot strike pattern and that other factors may dictate foot strike pattern.¹⁸ Barefoot running also may not be for everyone. The feel and comfort of barefoot running is very different than running in shoes and may be difficult for many runners to get used to.

Minimalist shoes have become very popular in recent years marketed to provide similar benefits to runners as barefoot running. This may not be the case, however, as Willy et al. found that runners who switched to minimalist shoes did not change their foot strike pattern from a heel strike pattern to a non-heel strike pattern and actually experienced increased loading forces as compared to running in their traditional running shoes.¹⁹ Bergstraa et al. reported increased plantar pressures in women who run in minimalist shoes and no difference in landing patterns between running in minimalist versus traditional shoes. This raised concern for the potential of metatarsal stress fractures.²⁰ Goss et al. also reported that 50% of runners recently introduced to minimalist footwear still ran with a heel strike pattern after a two week accommodation period.²¹ Those runners who wish to continue to run in traditional running shoes may need to look toward other methods to change their foot strike pattern to reduce impact forces.

Step-rate manipulation was described by Heiderscheidt et al. in 2011 to significantly reduce impact

forces in distance runners with as little as a 5% increase in step rate.⁶ Their research showed that by increasing step rate kinematic variables such as step length, center of mass vertical excursion, and foot inclination angle were reduced in shod runners. Reduction of these variables was associated with decreased impact forces and could theoretically reduce injury risk for distance runners. Multiple other authors have supported the reduction of impact forces through increased cadence or step-rate.^{7, 22, 23, 24} Increasing step rate has also been described to play a role in increasing leg stiffness and enhancing the leg-spring behavior which may be protective against injury.^{25,26,27} Step rate manipulation has also been presented as an easy and practical method of running gait re-training in the clinical environment utilizing metronome cues and faded feedback methodology. While past research has documented many positive changes in running kinematics related to step rate manipulation, step rate manipulation has not been examined as a method to change foot strike pattern nor has the percentage of step rate increase needed to make this change been established.

The purpose of this study was to investigate the effect of step rate manipulation on foot strike pattern in shod recreational runners who run with a heel strike pattern. A secondary purpose was to describe the effect of step rate manipulation at specific percentages above preferred on foot inclination angle at initial contact. This study seeks to provide more specific information to rehabilitation professionals regarding how step rate manipulation above preferred affects foot strike pattern and the position of the foot at initial contact as well as what percentage of step rate increase is needed for a significant change to occur. This information may serve as a useful guide for clinicians using step rate manipulation as a running gait retraining intervention method in the clinical setting.

METHODS

Subjects

A total of 40 healthy volunteers were recruited from local running clubs, running stores, advertisement via various media outlets, and by word of mouth. Participants were eligible for inclusion if they were heel-strikers at their preferred running pace and step

rate, were currently running at least 10 miles per week, and had not had lower extremity pain, a history of ankle or foot surgery, a running injury within the previous three months, or cardiovascular/ neurological compromise. Included subjects were all healthy runners that were comfortable running on a treadmill. All runners had a weekly mileage of at least 10 miles. 43 total runners were recruited for the study. Three runners (2 male, 1 female) were excluded from the study because they were determined to be forefoot strikers at their preferred running pace and step rate during testing and verified upon video review. There were 23 female subjects and 17 male subjects included in the study with an average age of 36 (range 17-56 years old). Informed consent was obtained prior to testing. Prior approval was obtained to conduct this study through the Institutional Review Board of the Cleveland Clinic.

Procedure

All subjects were blinded as to what was being tested. Subjects ran in their standard running shoe. Three pieces of tape were applied to each shoe in the following areas: rearfoot (inferior to the apex of the fibular malleolus at the lateral calcaneus), mid-foot (base of the 5th metatarsal), and lateral forefoot (5th metatarsal head), to be used merely as a reference point to the runner's anatomy when observing foot strike pattern. Prior to data collection, each subject performed a 5 minute warm up on the treadmill and gradually worked up to a comfortable running speed. Running speed was consistent with what the subject determined to be typical of a moderate intensity run. Running speed was recorded by the researchers and the subject then ran at this exact speed for all test conditions. The researchers then validated that each subject was a heel-striker. Foot strike patterns in this study were classified in three categories consistent with Lieberman et al., 2010¹⁵: rearfoot, when the heel is the first region to contact the ground; mid-foot, when the heel and ball of the foot simultaneously contact the ground; and forefoot, when the ball of the foot contacts the ground before the heel. Any subject that was deemed to be a forefoot or mid-foot striker when running at their preferred step rate was eliminated from the study. For all confirmed heel-strikers, the preferred step rate was determined once the subject had been running for

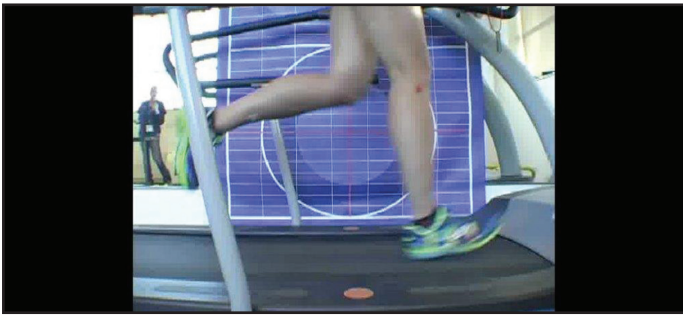


Figure 1. Video image of foot strike during preferred gait cadence.

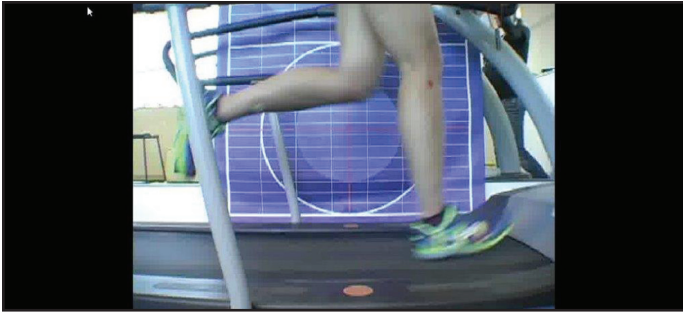


Figure 2. Video image of foot strike at +5% cadence.

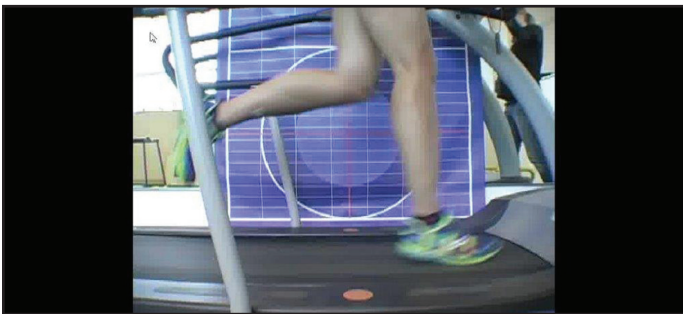


Figure 3. Video image of foot strike at +10% cadence.

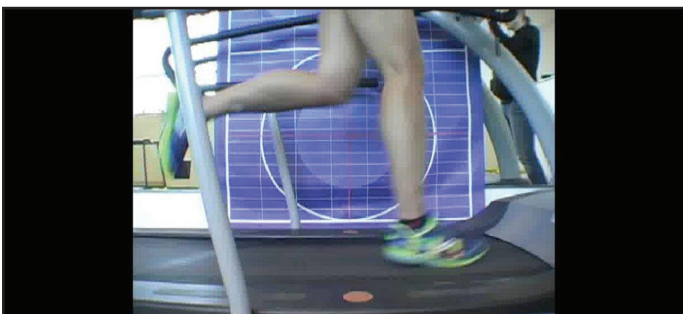


Figure 4. Video image of foot strike at +15% cadence.

at least one minute at their preferred pace. Step rate was determined over a 30 second period by counting the number of times the right foot hit the ground then multiplied by four. This was repeated by two

researchers to ensure accuracy and the average was recorded. Data was then collected for four step rate conditions: preferred, +5%, +10%, and +15%. The various conditions were randomized for each subject by randomly drawing them out of a bag. The change in step rate was achieved through use of a metronome, which provided audible and visual cues to runners. Data collection, which consisted of video footage from the lateral view for 30 seconds, was obtained once the subject was able to maintain the appropriate step rate for at least one minute. The subject walked at a moderate pace for three minutes in between each step rate change in order to help fatigue. After all step rates were performed, the subject walked for a three minute cool down. All subjects were tested according to this protocol.

Data Collection and Analysis

Upon completion of testing, the video footage for each subject was reviewed to determine the subject's foot-strike pattern at each step-rate condition (Figures 1-4). The review was conducted by the testing researcher and then confirmed by the review of a second researcher (licensed physical therapists) independent of each other. In instances when there was disagreement a third researcher was used. Almeida et al. 2015¹² described inter-rater reliability of 96.7% using this method of review. Medical Motion video analysis software (Cardiff, CA) and the video camera (Canon DM-GL2, Japan) were utilized to review the video. The camera captured data at 60 frames per second. Foot-strike pattern and foot inclination angle at initial contact at each step-rate condition was recorded for each subject tested. One researcher performed all measurements of the foot inclination angles to ensure consistency. Foot inclination angle was measured using the Medical Motion video analysis software as the angle between the treadmill and the sole of the foot consistent with previous studies that have reported on this measure (Figure 5).^{6,29} The average foot inclination angle of three randomly selected foot strikes was reported to reduce potential variability.

Statistical Methods

Categorical variables were described using frequencies and percentages, while continuous variables were described using means, standard deviations,

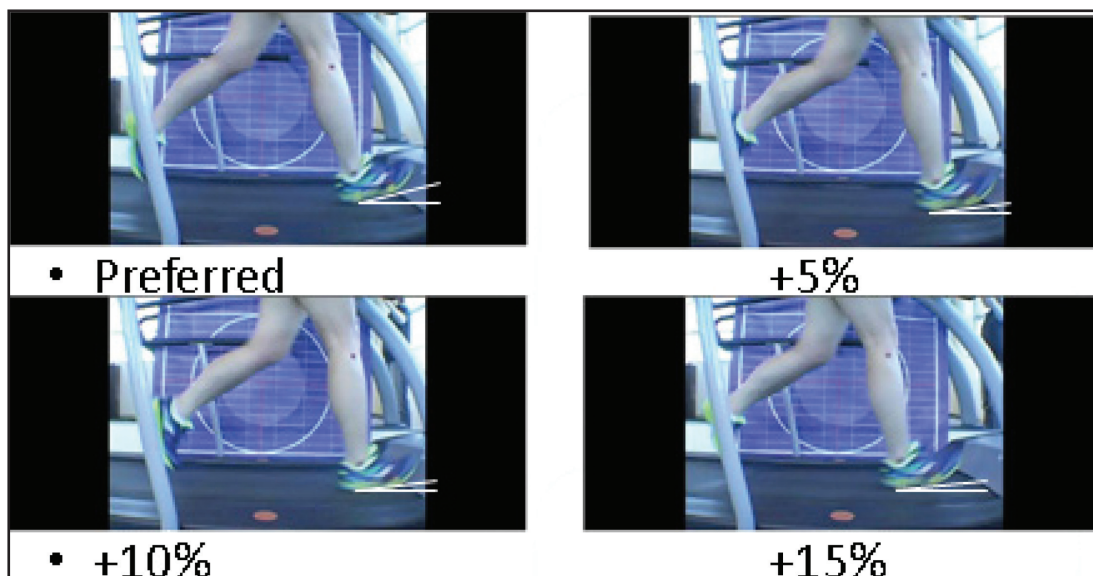


Figure 5. Foot inclination angles at preferred, and plus 5%, plus 10%, and plus 15% cadence.

Table 1. Summary statistics for the cohort are shown below. Continuous variables are presented as Mean \pm SD and Median (Minimum Value, Maximum Value).

Factor	Total (N=40)
Age	36.0 \pm 9.1 37.0 (17.0,56.0)
Gender	
Male	17 (42.5)
Female	23 (57.5)
Mileage per week	24.9 \pm 20.9 19.0 (10.0, 120.0)
Orthotics	
No	32 (80.0)
Yes	8 (20.0)
Self-reported foot strike	
Heel Strike	34 (85.0)
Mid Foot Strike	6 (15.0)

medians, and ranges. Linear mixed effect models were used to evaluate changes in ankle inclination and step rate across study conditions. In the model, the correlation between results from the same runner was modeled using an autoregressive correlation. Trends in foot strike pattern overall and heel strike versus not were evaluated using Cochran-

Mantel-Haenszel tests overall, followed by McNemar tests to compare agreement between conditions in a pairwise manner. SAS Software was used for data management and for generating data summaries (Version 9; Cary, NC). Pairwise comparisons between study conditions used a Bonferroni-corrected significance level of 0.0083 to limit the probability of a Type I error across the six comparisons to no more than 0.05. P-values below this level were considered statistically significant.

Results

Table 1 shows summary statistics for the cohort. Forty subjects were included in the data analysis with seventeen being male and twenty-three female. Average age was 36.0 (\pm 9.1) with age ranging from 17 to 56. Subjects reported that they ran an average of 24.9 miles per week (\pm 20.9) with the median running distance being 19 miles per week (range 10-120). Only eight of the forty subjects reported that they wore orthotics. Thirty-four (85%) subjects were self-reported heel strikers while six (15%) believed that they were mid-foot strikers.

Table 2 shows the comparison of the foot inclination angle. Mean foot inclination angles were: 13.6 degrees (preferred), 10.3 degrees (5%), 8.77 degrees (10%), and 6.04 degrees (15%). There was a significant difference across all groups, and a statistically significant reduction of the mean foot inclination

Table 2. Comparisons of the angle of foot inclination are shown.

Factor	Foot Inclination	p-values		vs. Preferred		vs. 5%		vs. 10%	
	Mean (95% CI)	Overall	Trend	Mean (95% CI)	p-value	Mean (95% CI)	p-value	Mean (95% CI)	p-value
Condition		<0.001	<0.001						
Preferred	13.6 (11.6, 15.6)								
5%	10.3 (8.23, 12.3)			-3.34 (-4.72, -1.96)	<0.001				
10%	8.77 (6.74, 10.8)			-4.83 (-6.67, -2.99)	<0.001	-1.49 (-2.88, -0.11)	0.035		
15%	6.04 (4.01, 8.07)			-7.56 (-9.69, -5.44)	<0.001	-4.22 (-6.06, -2.38)	<0.001	-2.73 (-4.12, -1.35)	<0.001

Table 3. Comparisons of the step rate are shown.

Factor	Step Rate	p-values		vs. Preferred		vs. 5%		vs. 10%	
	Mean (95% CI)	Overall	Trend	Mean (95% CI)	p-value	Mean (95% CI)	p-value	Mean (95% CI)	p-value
Condition		<0.001	<0.001						
Preferred	165 (161, 168)								
5%	173 (170, 176)			8.22 (8.03, 8.42)	<0.001				
10%	181 (178, 184)			16.4 (16.2, 16.6)	<0.001	8.20 (8.00, 8.39)	<0.001		
15%	189 (186, 192)			24.7 (24.4, 25.0)	<0.001	16.5 (16.2, 16.7)	<0.001	8.28 (8.08, 8.47)	<0.001

Table 4. Comparisons of the foot strike pattern are shown.

Factor	Pattern			p-values				
	Heel (N=137)	Mid-foot (N=15)	Fore-foot (N=8)	Overall	Trend	vs. Preferred	vs. 5%	vs. 10%
Condition				<0.001	<0.001			
Preferred	40 (100.0)	0 (0.0)	0 (0.0)					
5%	36 (90.0)	3 (7.5)	1 (2.5)			0.059		
10%	33 (82.5)	5 (12.5)	2 (5.0)			0.013	0.10	
15%	28 (70.0)	7 (17.5)	5 (12.5)			0.001	0.005	0.021

angle as step rate increased (both $p < 0.001$). The 5% condition had a 3.34 point smaller angle on average than the preferred step rate. The angle in the preferred rate was significantly greater than all other conditions ($p < 0.001$), while the 15% condition had an angle that was significantly smaller than all other conditions ($p < 0.001$). No significant difference between 5% and 10% was observed.

Table 3 shows a similar comparison of the recorded step rates. Mean step rates of the subjects were (reported as steps per minute): 165 (preferred), 173 (5%), 181 (10%), and 189 (15%). As expected, the step rates all were significantly different at each level and step rates showed a statistically significant increase as the step rate percentage increased.

Table 4 and Table 5 compare the foot strike pattern. Table 4 compares all three foot strike patterns at the

different step rates, while Table 5 shows the heel strike versus not. Results of the two tables are similar. The percentage of non-heel strikers increases from 0% at the preferred rate to 10% at preferred rate + 5%, 17.5% at the preferred rate + 10%, and 30% at the preferred rate + 15%. There was an overall difference and a significant increasing number of non-heel strikers as the step rate increased. The preferred rate + 15% had significantly more non-heel strikers than the preferred rate and preferred rate + 5% conditions. When combining mid-foot and fore-foot strike versus heel strike (Table 5), the preferred rate + 10% condition had significantly more non-heel strikers than the preferred rate.

In summary, in both the foot inclination angle and foot strike pattern analysis, significant changes were observed with increases in step rate conditions. For

Table 5. Comparisons of the heel strike are shown.

Factor	Pattern		Overall	Trend	p-values		
	Heel (N=137)	Mid/Fore (N=23)			vs. Preferred	vs. 5%	vs. 10%
Condition			<0.001	<0.001			
• Preferred	40 (100.0)	0 (0.0)					
• 5%	36 (90.0)	4 (10.0)			0.046		
• 10%	33 (82.5)	7 (17.5)			0.0082	0.083	
• 15%	28 (70.0)	12 (30.0)			<0.001	0.005	0.025

foot inclination angle, significant decreases in the angle were observed with even 5% increases in step rate, while for the foot strike pattern, increases of at least 10% in the step rate were needed to show a significant increase in the number of non-heel strikers.

Discussion

The intent of this study was to determine whether step rate manipulation alone was enough to change foot strike pattern in shod recreational distance runners. The results of this study show that there is a statistically significant change in foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern at both 10% and 15% step rates above preferred. Increasing step rate above preferred by 10% was successful in changing foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern in 17.5% of the runners while increasing step rate by 15% changed foot strike pattern in 30% of the runners in our study. These results suggest that step rate manipulation alone may be an effective way to change foot strike pattern in a small percentage of shod distance runners.

Step rate manipulation was chosen as a method to attempt to change foot strike pattern in distance runners wearing traditional running shoes. Step rate manipulation has been shown in the literature to be an effective means to reduce impact loading variables by changing sagittal plane variables such as stride length, center of mass vertical excursion, knee flexion angle at initial contact, and foot inclination angle.^{6, 28,29} Hafer et al.³⁰ found that runners were able to adopt a new running style at a step rate 10% above preferred after a six week cadence retrain-

ing program and showed carryover of decreased stride length, hip adduction angle and hip abductor moment. In addition to the beneficial effect of step rate manipulation on sagittal plane running biomechanics, it is also very easy to implement in the clinical rehabilitation setting. For rehabilitation professionals seeking to reduce impact forces and rehabilitate or prevent running related injuries, manipulating step rate can be done quickly with a simple metronome either on a treadmill or while running over ground.

Increasing subjects' step rate by 15% over their preferred step rate was effective at changing 30% of the subjects to a mid-foot or forefoot strike pattern. While this is a statistically significant change it does represent a relatively small percentage of the overall subject population. The majority of the runners in this study continued to run with a heel strike pattern at all step rate conditions. This would suggest that step rate manipulation may be helpful to change foot strike pattern in a small percentage of shod recreational runners, but that if the intent is to change foot strike pattern that other methods may be more effective to accomplish this. One observation that was made by the researchers, although not statistically studied, was that many runners who changed foot strike pattern had a very small foot inclination angle at initial contact at their preferred step rate. This would appear to facilitate an easier transition to a mid-foot or forefoot strike pattern with an increased step rate.

What is probably the more significant finding of this study is that there was a strong trend toward a reduction in the foot inclination angle as step rates

were increased. Heiderscheidt et al.⁶ documented in their research that foot inclination angles are reduced at higher step rates. The results of the current study support that change and found a significant reduction in the foot inclination angle even at a 5% increase above preferred. Wille et al.²⁹ has previously shown that there is a correlation between a reduction in the foot inclination angle and reduced ground reaction forces and knee joint loads at initial contact. It may be concluded that a reduction of foot inclination angle through increasing step rate above preferred by at least 5% may have beneficial effects on reducing impact forces and potentially reducing injury risk. The current study also showed that the foot inclination angle progressively decreased as step rate was increased at 5%, 10%, and 15% above preferred, therefore, it might be that increasing step rate by 10% or 15% may have a greater effect on the reduction of impact forces. Rehabilitation professionals can utilize step rate manipulation above preferred to potentially change foot strike pattern, but more likely to reduce the foot inclination angle or the severity of the heel strike in hopes of reducing impact forces and having a positive effect on injury rehabilitation or prevention.

This study did have some limitations. The current study utilized 2D video analysis and a camera filming at 60fps. This may have reduced the sensitivity of the measurements of foot inclination angle compared to what might be possible with a camera filming at greater than 100fps. It was the researcher's experience, however, that an individual video frame where that initial foot contact was taking place was able to be identified with good certainty to both determine the foot strike pattern as well as to measure foot inclination angle. Foot strike pattern was identified by one researcher and then verified by a second researcher for all conditions. The methodology also attempted to reduce the variability of observations by measuring foot inclination angle for each subject at three random foot strikes during the 30 second video footage and then taking the mean of the three angles to represent the subject's foot inclination angle at each condition. Damstead et al.³¹ determined that the reliability of determining foot strike pattern using 2D video analysis was acceptable in the clinical setting and showed very

good intra-rater reliability for within day observations. Bertelsen et al.¹³ also reported that visual analysis of 2D video was a feasible and practical way of identifying foot strike pattern in novice runners and found good reliability of this method. The camera and video analysis software utilized in this study are very commonly used in many clinical settings. The results of this study show that clinicians with similar equipment can effectively film and analyze the foot strike pattern and foot inclination angle of runners and observe relevant and meaningful measures consistent with results found in laboratory studies such as Heiderscheidt et al.⁶

A second limitation to the current study was that subjects were filmed running on a treadmill rather than over ground. Observation of runners on the treadmill provides obvious convenience for conducting this type of research through the ability to observe a runner on a continuous basis over an extended period of time. It also allows for the standardization of camera and observation set-up which is important to the consistency and quality of observations. Riley et al.³² found that running mechanics of treadmill running can be generalized to over ground running as kinetics and kinematics of running on a treadmill are comparable, but not directly equivalent to running over ground. For the purpose of this study to merely identify foot strike pattern this similarity was determined to be sufficient.

A final limitation was that subjects were being observed running at each condition (step rates above preferred) while never having had the opportunity to practice running at these step rates prior to the study observation. It could be a valid discussion as to whether subjects were running naturally or just finding a movement strategy to effectively match their foot strikes to the metronome. The study methodology, however, was similar to several other step rate manipulation studies that have studied biomechanics of runners in a similar manner.^{27,6,7,22,24,33} Every effort was made to film the runner at each condition only after they had been able to successfully match the metronome beat and maintain that step rate while running for at least one minute. It was noted that the 5% and 10% above preferred conditions were typically very easy for the subjects to match and that only the 15% above preferred

condition was a challenge initially for some of the subjects. We agree with Heiderscheidt et al⁶ that the perceived increase in effort of subjects, especially at the +15% condition, was more to do with attentional focus to achieve a novel task rather than a true increase in metabolic cost.^{34,35,36} This would suggest that while increasing step rate above one's preferred, especially at rates as high as +15%, may seem challenging at first, that practice would reduce the attentional focus and perceived exertion. Allowing step rate increases to be phased in gradually in the clinical environment would potentially help to reduce this change in perceived exertion for the runner.

CONCLUSION

Step rate manipulation may be effective in changing the foot strike pattern of recreational runners wearing traditional running shoes from a heel-strike pattern to a mid-foot or forefoot strike pattern in 17.5% of runners at 10% above preferred and 30% of runners at 15% above their preferred step rate. If changing foot strike pattern is the primary goal other methods may be needed to make a change from a heel strike pattern to a non-heel strike pattern. Step rate manipulation above preferred does show a progressive reduction of the foot inclination angle at 5%, 10%, and 15% above preferred which represents a reduction in the severity of the heel strike angle at initial ground contact. Reduction of foot inclination angle may represent the primary benefit of step rate manipulation on foot position at initial contact rather than a change in the actual foot strike pattern. Step rate manipulation of at least +10% above preferred may be an effective running gait retraining method for clinicians to decrease the severity of heel strike and possibly assist a runner to change to a non-heel strike pattern. Further research is needed to investigate the effect of step rate manipulation on injury prevention in runners.

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