

INCREASING RUNNING STRIDE FREQUENCY: CAN IT BE TRAINED AND DOES IT IMPROVE ECONOMY?

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RUNNING HEAD: Running stride frequency training

ABSTRACT

Numerous websites, popular literature, and coaches recommend a stride frequency (SF) of 180 steps per min (spm) as optimal for running economy and that most novice runners have lower spontaneous SF (SSF). The implication is that these runners should train to increase SSF. However, the literature to support these suggestions is inconclusive. The purpose of this study is to re-assess whether SSF can be increased through a training program and if so, does the increase in SF result in improved running economy? Using a metronome to increase SF and heart rate (VO_2 was also measured in 2014) as a measure of running economy at constant speed, treatment subjects were trained for 10 min/week over 9 weeks in 2013 and 2014 and for 10 min 3x/week over 5 weeks in 2015. Treatment subjects showed a significant increase in SSF ($P=0.001$, $F=9.686$, $N=16$) and running economy ($P=0.013$, $F=5.036$, $N=16$) in 2013, no significant changes in 2014, and only a significant increase in SSF ($P=0.002$, $t=-5.175$, $N=7$) in 2015. No significant changes were found for any of the control groups. These findings indicate some merit in increasing SF, but the inconsistencies highlight the need for additional studies including more frequent training sessions and focusing on new, but habitual runners with uneconomical SSF.

KEY WORDS: kinematics, fatigue, optimization, locomotion, step rate, running costs

INTRODUCTION

Numerous websites and popular literature recommend a stride frequency (SF) of 180 steps per min (spm) to optimize running economy (energy demand per submaximal running speed) and that most novice runners have naturally chosen or spontaneous SFs (SSF) that are lower than optimal SFs (OSF), the SF at which metabolic cost is lowest for a given pace. The implication is that runners should attempt to increase their SF to improve running economy as is often advised by coaches (4). However, it is difficult to

find consistent, supporting evidence within the scientific literature for these recommendations. This is due to multiple factors affecting running economy including running experience, fatigue, and kinematic characteristics especially stride length (SL) and SF (4, 7), the frequency and duration of training (7, 12), and inter-individual differences for all the above (4, 7). Furthermore, OSF is not static and can change with fatigue and speed (7, 8). To assess these recommendations two basic questions must be answered for most runners: 1) is SSF different than OSF, typically lower, and 2) if so, can SSF be

altered, typically increased, through some sort of training program? A related and implied question is, if SSF can be altered, typically increased, does this result in improved running economy?

The literature on this is very mixed. Several studies conclude that SSF is similar to OSF and when runners are forced to alter SF, a U-shaped relationship for SF vs. running economy (usually VO_2 per distance) is observed (2, 3, 7, 11, 12). However, some of these studies and others suggest that some runners, especially novice runners, had different, typically slower, SSF than OSF (3, 4, 11). These inconsistent findings were also observed for the effects of training where some studies found that training did alter SF (5, 6, 12), while others did not (14). Similar inconsistencies were found for running economy where some studies showed that increasing SF through training resulted in improved economy (12), while others did not (9, 10, 14).

Because of the inconsistent results in the scientific literature and yet the somewhat definitive recommendations in the popular literature, the purpose of this study is simply to re-assess whether SSF can be increased through a training program and if so, does the increase in SF result in improved running economy? Based on the varied results mentioned above it is difficult to formulate a definitive hypothesis. However, as the whole point of a training program is an alteration resulting in improved performance, we hypothesize that higher SSF can be trained and that higher SSF (nearing

180) result in improved running economy.

MATERIALS & METHODS

Participants

The protocol for this study was approved by the SUNY Potsdam institutional review board for human participants in research. Subjects for this study were recruited over a three-year (2013-2015) period from the undergraduate population of SUNY Potsdam, New York. Subjects were required to be over 18 years of age and be able to maintain a constant running pace for 12 minutes. All subjects read and signed a consent form describing the experiment, benefits and risks, that participation was voluntary and subjects could withdraw at any time, and that all published data would be anonymous. Additionally, all subjects filled out a physical activity ready questionnaire (PAR-Q) and answered "no" to all the questions indicating there were no health concerns and that they were physically ready to participate in the study. For 2013 and 2014, subjects were primarily recruited from an Anatomy and Physiology class (Biol 403). A small number of subjects were also recruited from Human Biology class (Biol 107). Because of the slow average pace for 2013 and 2014, in 2015 an attempt was made to recruit from a population of more experienced runners. Opportunistically, subjects were recruited from the SUNY Potsdam men's NCAA Division III soccer team. Subjects were randomly put into a treatment and control group by flipping a coin, heads=control and tails=treatment. The number of subjects

participating each year are shown in Table 1.

Table 1. Number of subjects participating and completing (in parentheses) the study each year.

Year	Control n	Treatment n	Total n
2013	17 (11)	21 (16)	38 (27)
2014	18 (15)	18 (11)	36 (26)
2015	4 (3)	7	11 (10)

Protocol

In 2013 and 2014 evaluation and training occurred over a nine-week period from September to November and in 2015 evaluation and training occurred over a five-week period from November to December. Height, weight, and chosen pace were recorded at the first session. Room temperature was measured each session. Subjects completed a 30-min session the same day and time each week. Each session started with subjects completing a five-min warm up on the treadmill (NordicTrack C 900) before recording and ended with a five-min cool. At the five-min mark, subjects began running at their preferred pace (based on their first session) for 10-min. This pace stayed constant each week for a given subject. At the end of each minute, heart rate was recorded using a polar chest strap T31 (Model: Beat) and receiver watch (Polar Electro Oy CEo537, Kempele, Finland). Stride frequency was recorded for 20-sec each minute, by counting the number of right foot strikes. This number was multiplied by six to get the SF for each minute. Subjects in the 2014 study also had VO_2 recorded while running for an additional two-min on the treadmill at the end of the 10-min period and before the cool down. This was measured using a Biopac MP35 data acquisition

unit, GASSYS2-EA gas analysis system, and an SS11LA flow sensor calibrated with an AFT26 two-liter syringe. Subjects breathed through a Biopac AFT1 mouthpiece connected to Han Rudolf 2700 Series Large Two-Way T-Shape Valve. A Biopac AFT3 nose clip ensured breathing only through the mouth.

In non-training sessions (week 1, 5, and 9 for 2013 and 2014 and week 1 and 5 for 2015), subjects ran at their chosen running pace and SSF for the 10-min recording period (12-min for 2014). For week 2-4 and 6-8 in 2013 and 2014 and weeks 2-4 for 2015, control participants ran at preferred pace and SSF for the 10-min recording period. The treatment participants had the addition of SF training where they were asked to match their footfalls to the beat of a metronome set above their SSF. In 2013 and 2014 most participants were novice runners and had difficulty maintaining higher SFs. Therefore, training SF was set at 6 beats higher than their SSF (according to the previous week). The first minute, they ran at their SSF ("natural" min) and for the second minute ("training" min) they ran to the metronome. This sequence was repeated for 10-min. If subjects were able to comfortably maintain the higher SF the previous week, the metronome was increased 6 additional beats each successive training week. For 2015, most participants were experienced runners and were therefore challenged to increase their SF to 180 bpm during training minutes. If this value was reached easily, five more beats were added the subsequent week. Additionally, in 2015, subjects also

performed independent training on treadmills at the SUNY Potsdam fitness center two days a week in between supervised sessions. All subjects (both control and treatment) were given a log with the specified SF (treatment group only), pace, and instructions to record the time and date of their independent sessions. The protocol for these independent sessions was the same as in supervised sessions except that SF and HR were not recorded and the treatment subjects were responsible for controlling the metronome via a phone app (ProMetronome App for iPhone and Android).

Statistical Analysis

In 2013 and 2014, repeated measures analysis of variance (ANOVA) was used for analysis (General Linear Models, Repeated Measures, SPSS, Version 20). Treatment and control HR and SF were compared separately for weeks 1, 5, and 9. For 2014, treatment and control normalized VO_2 were compared separately for weeks 1, 5, and 9. For significant ANOVAs, Tukey's HSD post hoc tests were performed by hand. For 2015, a paired t-test (SPSS, Version 20) was used to compare the non-training sessions for week 1 and 5. Significance level was set at $\alpha = 0.05$.

RESULTS

The average pace for each year and treatment are shown in Table 2.

Table 2. Average speed for each year and treatment.

Year	Average speed (min mile ⁻¹ , mph, mps)		
	Control	Treatment	Total
2013	10:04, 5.96, 2.66	10:47, 5.56, 2.49	10:28, 5.73, 2.56
2014	11:18, 5.31, 2.37	12:07, 4.95, 2.21	11:42, 5.13, 2.29
2015	8:34, 7.01, 3.13	7:40, 7.83, 3.50	7:54, 7.60, 3.40

In 2013, SSF increased significantly for the treatment group ($P=0.001$, $F=9.686$, $N=16$, $\eta_p^2=0.392$), but not for the control group ($P=0.136$, $F=2.269$, $N=9$, $\eta_p^2=0.221$) (Figure 1). Heart rate for the treatment group decreased significantly from week 1 to week 5, but did not differ between week 5 and week 9 ($P=0.013$, $F=5.036$, $N=16$, $\eta_p^2=0.251$) (Figure 2). Heart rate for the control group did not decrease significantly ($P=0.091$, $F=2.795$, $N=9$, $\eta_p^2=0.259$) (Figure 2).

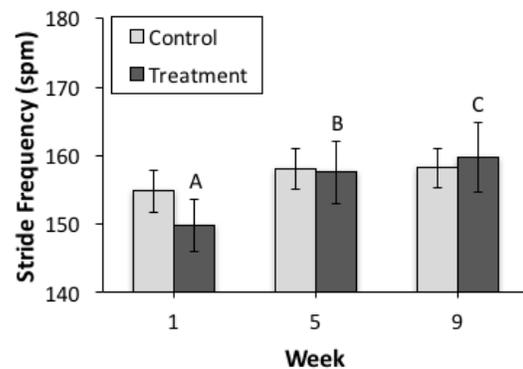


Figure 1. Average \pm SE spontaneous stride frequencies (spm) for subjects in 2013 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. On weeks 1, 5, and 9, no stride frequency training occurred even for the treatment group. Different letters denote significant differences (Repeated measures ANOVA with Tukey Post-hoc test).

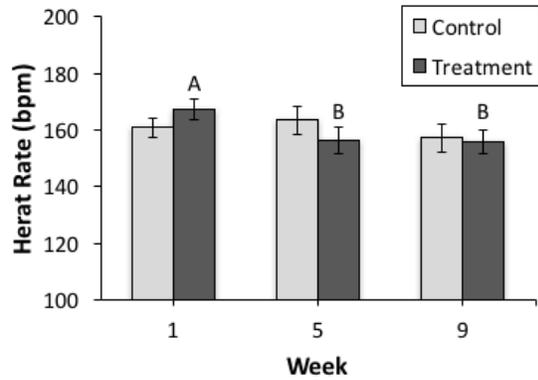


Figure 2. Average±SE heart rate (bpm) for subjects in 2013 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. On weeks 1, 5, and 9, no stride frequency training occurred even for the treatment group. Different letters denote significant differences (Repeated measures ANOVA with Tukey Post-hoc test).

In 2014, SSF did not increase significantly for the treatment group ($P=0.279$, $F=1.36$, $N=11$, $\eta_p^2=0.210$) or the control group ($P=0.251$, $F=1.454$, $N=15$, $\eta_p^2=0.090$) (Figure 3). Heart rate did not decrease significantly for the treatment group ($P=0.113$, $F=2.439$, $N=11$, $\eta_p^2=0.196$) or the control group ($P=0.189$, $F=1.771$, $N=15$, $\eta_p^2=0.112$) (Figure 4). Normalized VO_2 did not decrease significantly for treatment group ($P=0.72$, $F=3.005$, $N=11$, $\eta_p^2=0.231$) or the control group ($P=0.059$, $F=3.13$, $N=15$, $\eta_p^2=0.183$) (Figure 5).

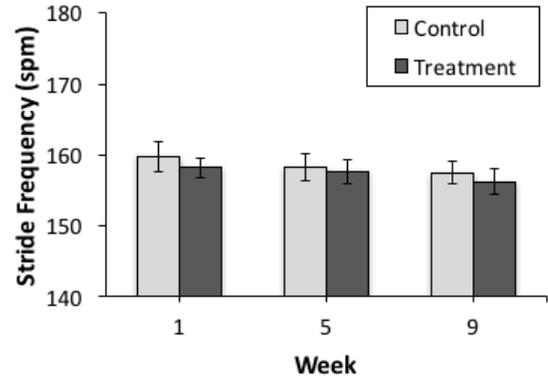


Figure 3. Average±SE spontaneous stride frequencies (spm) for subjects in 2014 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. On weeks 1, 5, and 9, no stride frequency training occurred even for the treatment group. Different letters denote significant differences (Repeated measures ANOVA with Tukey Post-hoc test).

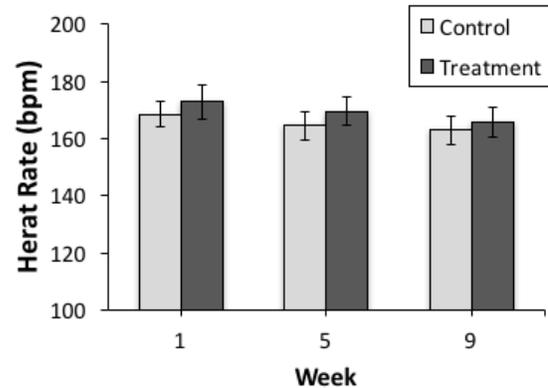


Figure 4. Average±SE heart rate (bpm) for subjects in 2014 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. On weeks 1, 5, and 9, no stride frequency training occurred even for the treatment group. Different letters denote significant differences (Repeated measures ANOVA with Tukey Post-hoc test).

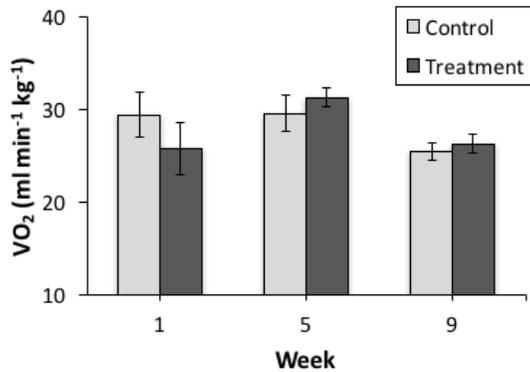


Figure 5. Average \pm SE normalized VO₂ (ml min⁻¹ kg⁻¹) for subjects in 2014 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. On weeks 1, 5, and 9, no stride frequency training occurred even for the treatment group. VO₂ was measured for two min immediately following the 10 min session while subjects continued to run at the same pace. Different letters denote significant differences (Repeated measures ANOVA with Tukey Post-hoc test).

In 2015, SSF increased significantly for the treatment group ($P=0.002$, $t=-5.175$, $N=7$, Cohen's $d = 1.956$), but not the control group ($P=0.580$, $t=0.655$, $N=3$, Cohen's $d = 0.378$) (Figure 6). Heart rate did not decrease significantly for the treatment group ($P=0.313$, $t=-1.102$, $N=7$, Cohen's $d = 0.416$) or the control group ($P=0.227$, $t=-1.725$, $N=3$, Cohen's $d = 0.996$) (Figure 7).

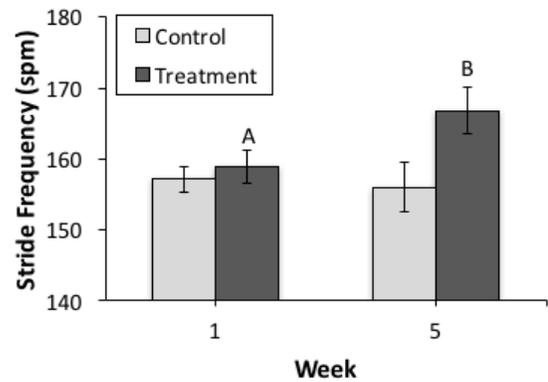


Figure 6. Average \pm SE spontaneous stride frequencies (spm) for subjects in 2015 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. Independent training was also done twice a week in between lab sessions. On weeks 1 and 5 no stride frequency training occurred in the lab session even for the treatment group. Different letters denote significant differences (Paired t-test).

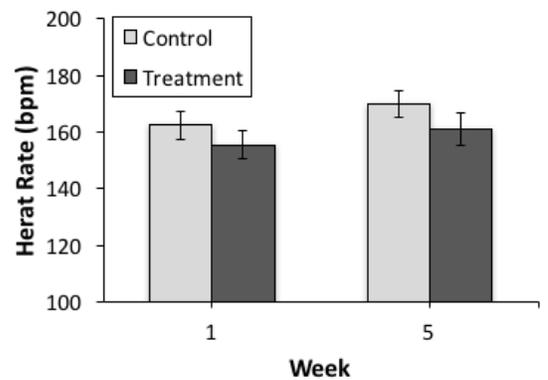


Figure 7. Average \pm SE heart rate (bpm) for subjects in 2015 trained for higher stride frequencies (treatment) vs control (no training). All subjects, following a five-min warm-up, ran for 10-min at a comfortable pace chosen by the subject in week 1. Training involved matching foot-strikes to a metronome set to a pace higher than preferred. Independent training was also done twice a week in between lab sessions. On weeks 1 and 5 no stride frequency training occurred in the lab session even for the treatment group. Different letters denote significant differences (Paired t-test).

DISCUSSION

Not unlike the inconsistent findings in the scientific literature, our results varied from year to year. In 2013, both hypotheses were accepted in that SSF increased significantly from week 1 to week 5 to week 9 and running economy (as measured by a decrease in HR) increased although not significantly from week 5 to 9. Conversely, in 2014, not only were there no significant changes in SSF and running economy, SSF actually decreased. In 2015, with more experienced runners, SSF did increase significantly, but surprisingly running economy decreased, although non-significantly. The explanation for 2015 is perhaps the most straightforward. Due to time requirements and demands of the soccer season, subjects were only available to begin the training protocol immediately following the end of the soccer season. Consequently, the subjects' level of exercise intensity and duration decreased drastically at the outset of our study and this lower level of activity continued throughout the study. Therefore, there was likely a de-training effect which can result in significant decreases in aerobic capacity in as short as two weeks (13). Consequently, even though SSF was increasing and perhaps so was running economy, the subjects' overall aerobic fitness was decreasing a greater amount. Additionally, maintaining the necessary leg stiffness for higher SF may have resulted in recruitment of more fast-twitch fibers and a decrease in leg stiffness from fatigue may have resulted in decreased elastic energy, both of

which would decrease running economy (7).

The 2013 results were generally as expected and suggested that most of the benefits of stride frequency training can be realized in as few as three weeks of training. However, considering the inconsistent result from other years, clearly this conclusion is not definitive. In 2014, we were perhaps working with subjects with relatively poor aerobic capacity as indicated by the slow average running pace and relatively high HR averaging approximately 170 bpm (greater than 80% of max HR) for both treatment and control groups. In fact, several subjects showed considerable difficulty in maintaining their pace over the 10-min session. As fatigue set in, and perhaps to a greater extent than in other years, SSF would naturally decrease (7), negating any changes due to SF training.

Another possible explanation for the inconclusive results was that SSF was well below 180 for all years even after training. In 2013 and 2014, the highest average SSF for any group or session was 160 spm. Even in 2015 with more experienced runners, the highest average SSF for the treatment group after training was 167 spm. Considering the U-shaped relationship for SF vs. running economy (usually VO_2 per distance) (3, 7, 12) and assuming an OSF is in the 170-180 spm range (7), many of our subjects may have had SSF so far below optimal that any benefits from increased SSF would be less clear.

Lastly, limitations in our study protocol likely contributed to the inconsistent

results. First, we did not determine the OSF for each runner. While novice runners on average have a greater SSF-OSF difference than experienced runners, many have smaller differences similar to experienced runners (4). Therefore, first quantifying and then focusing on subjects with the largest SSF-OSF difference or the most metabolically uneconomical SSF (12) would likely provide more consistent and definitive results. Second, the duration of our training and testing sessions may have been too short and infrequent. Morgan et al. (12) trained runners with uneconomical SSF for 30 min sessions, five days a week for three weeks and showed significant increases in SSF (measured as a decrease in stride length) and an increase in running economy (a reduction in SSF $\dot{V}O_2$). Third, motivation may have been a factor in that most participants were not habitual runners, were not interested in becoming habitual runners, and were not focused on improving their running performance (1). Even in 2015, when subjects were recruited from the men's soccer team and were clearly more experienced runners as indicated by much higher average running speed, these subjects were recovering from the demands of the soccer season and not focused on improving running performance. Lastly, as mentioned above, the characteristics of each of our subject pools may not have lent themselves to finding significant results. Unmotivated and or de-training subjects likely created considerable noise in the data that not only masked potential trends, but may have countered them (e.g. de-training). For future studies it would be best to focus on new runners

already committed to a habitual running program and motivated for improvement.

In conclusion, the goal of this study was to find consistent results on whether SSF can be increased through a training program and if so, does the increase in SF result in improved running economy? Unfortunately, our results over three years were as inconsistent as those found in the scientific literature. Although only significant in two of the three years, it appears that SSF can be increased through training, but clearly more work is needed to confirm this including longer and more frequent training sessions and assessing SSF-OSF differences to specifically test subjects with uneconomical SSF. Improvement in running economy following increases in SSF is more questionable as this was only observed in one of the three years. This may have been due to poor aerobic capacity and the resultant fatigue during testing for some subjects or a de-training effect in other subjects. Future subject pools should include new, but habitual runners so that changes in running economy would be mostly due to altered running kinematics.

REFERENCES

1. Blegen MD, Stenson MR, Micek DM, Matthews TD. Motivational differences for participation among championship and non-championship caliber NCAA division III football teams. *J Strength Cond Res* 26(11): 2924-2928, 2012.
2. Cavagna GA, Mantovani M, Willems PA, Musch G. The resonant step frequency in human running. *Eur J Sport Sci* 434(6): 678-684, 1997.
3. Cavanagh PR, Williams KR. The Effect of Stride Length Variation on Oxygen Uptake

during Distance Running. *Med Sci Sports Exercise* 14(1): 30-35, 1982.

4. de Ruiter CJ, Verdijk PWL, Werker W, Zuidema MJ, de Haan A. Stride frequency in relation to oxygen consumption in experienced and novice runners. *Eur J Sport Sci* 14(3):251-8, 2014.

5. Dallam GM, Wilber RL, Jadelis K, Fletcher G, Romanov N. Effect of global alteration of running technique on kinematics and economy. *J Sports Sci* 23(7): 757-764, 2005.

6. Hafer JF, Brown AM, Demille P, Hillstrom HJ, Garber CE. The Effect of a Cadence Retraining Protocol on Running Biomechanics and Efficiency: A Pilot Study. *J Sports Sci* 33(7): 724-31, 2014.

7. Hunter I, and Smith GA. Preferred and optimal stride frequency, stiffness and economy: changes with fatigue during a 1-h high-intensity run. *Eur J Appl Physiol* 100: 653-661, 2007.

8. Mercer J, Dolgan J, Griffin J, and Bestwick A. The physiological importance of preferred stride frequency during running at different speeds. *J Exercise Phys online* 11(3): 26-32, 2008.

9. Messier SP, Cirillo KJ. Effects of a verbal and visual feedback system on running technique, perceived exertion and running economy in female novice runners. *J Sports Sci* 7(2): 113-126, 1989.

10. Miller T, Milliron M, Cavanagh P. The effect of running mechanics feedback training on running economy. *Med Sci Sports Exercise* 22 Suppl: S17, 1990.

11. Morgan D, Martin P. Effects of stride length alteration on racewalking economy. *Can J Appl Sport Sci* 11: 211-217, 1986.

12. Morgan D, Martin P, Craib M, Caruso C, Clifton R, Hopewell R. Effect of step length optimization on the aerobic demand of running. *J Appl Physiol* 77(1): 245-251, 1994.

13. Neuffer PD. The effect of detraining and reduced training on the physiological

adaptations to aerobic exercise training. *Sports Med.* 8(5): 302-20, 1989.

14. Petray C, Krahenbuhl G. Running training, instruction on running technique, and running economy in 10-year-old males. *Res Q Exercise Sport* 56: 251-255, 1985.