Mechanisms for Improved Running Economy in Beginner Runners

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ABSTRACT

MOORE, I. S., A. M. JONES, and S. J. DIXON. Mechanisms for Improved Running Economy in Beginner Runners. Med. Sci. Sports Exerc., Vol. 44, No. 9, pp. 1756–1763, 2012. Controversy surrounds whether running mechanics make good predictors of running economy (RE) with little known about the development of an economical running gait. Purpose: The aim of this study was to identify if mechanical or physiological variables changed during 10 wk of running in beginners and whether these changes could account for any change in RE. Methods: A 10-wk running program (10wkRP) was completed by 10 female beginner runners. A bilateral three-dimensional kinematic and kinetic analysis, in addition to RE and lower body flexibility measurements, was performed before and after the 10wkRP. The Balke–Ware graded walking exercise test was performed before and after the 10wkRP to determine VO2max.

Results: Seven kinematic and kinetic variables significantly changed from before to after training, in addition to a significant decrease in calf flexibility (27.3° ± 6.3° vs 23.9° ± 5.6°, P < 0.05). A significant improvement was seen in RE (224 ± 24 vs 205 ± 27 mL·kg⁻¹·min⁻¹, P < 0.05) and treadmill time to exhaustion (16.4 ± 3.2 vs 17.3 ± 2.8 min, P < 0.05); however, VO2max remained unchanged from before to after training (34.7 ± 5.1 vs 34.3 ± 5.6 mL·kg⁻¹·min⁻¹). Stepwise regression analysis showed three kinematic variables to explain 94.3% of the variance in change in RE. Conclusions: These results show that beginner runners naturally developed their running gait as they became more economical runners. Key Words: OXYGEN CONSUMPTION, RUNNING MECHANICS, KINEMATIC, KINETIC, FLEXIBILITY

R
unning economy (RE), the rate of oxygen an individual consumes at a given speed, is reported to be a good predictor of running performance (9). Saunders et al. (35) and Jones and Carter (20) identified a consensus in the literature that trained runners exhibit a better RE than untrained runners. Running training can lead to improvements in RE (16,21), although the evidence regarding the relationship between running training and RE improvements is equivocal (12). A contributory factor to these inconsistencies is the initial training status of the participants, with enhancements to RE more likely to occur in untrained individuals than in trained runners (35).

Evidence shows that trained runners can use a lower percentage of their maximal oxygen consumption (% VO2max) at a given submaximal running speed than untrained runners. The better RE in trained runners is associated with a lower percentage of HRmax (%HRmax) and with lower minute ventilation (Ve) (7,32). It has been reported that decreases in Ve can account for 70% of the improvements in RE (16). However, determinants of RE are not just limited to physiological factors; anthropometric, environmental, and biomechanical factors may also be important (35).

The biomechanical factors potentially influencing RE encompass kinematics, kinetics, flexibility, and elastic energy storage in the stretch–shortening cycle (SSC) (35). Running mechanics, specifically the kinematic variables of shank angle at touchdown (TD) and plantarflexion at toe off (TO) in addition to net positive power, have been reported to explain 54% of the variance in RE (41). These mechanics are believed to have developed through a process of self-optimization (41) because individuals adopt a running gait that is most economical for them (8). Cross-sectional studies have identified various other kinematic, kinetic, and flexibility variables to be associated with better RE (18,23,37,41,42), such as knee extension at TO, vertical impulse, and lower back and hamstring flexibility. Yet, there are appreciable interindividual differences (9), and evidence is often inconsistent between studies. For example, Kyröläinen et al. (23) argue that running mechanics are poor predictors of RE,
contradicting Williams and Cavanagh (41). Furthermore, Kyröläinen et al. (23) identified the braking kinetic force as the main factor explaining RE and not kinematics variables.

Currently, little is actually known about the development of an economical running gait, primarily because research has focused on trained runners. A limited number of studies have examined how individuals develop their gait (25,31) with only a shortening of stride length being observed (31). Gait manipulation research suggests that self-selected traits are near optimal for oxygen consumption (VO2), and manipulations to stride length and vertical oscillation away from these self-selected parameters can decrease economy (8,15,38). Although informative, these studies only demonstrate the outcome of adjustments to running mechanics and do not consider the underlying changes in kinematics and/or kinetics that may cause them. In addition, by studying runners who already exhibit their optimal running gait to examine RE associations, it is difficult to discern whether the biomechanical traits are inherent in those runners or a feature of gait development with training.

The purpose of this study was, therefore, to explore the effect of a 10-wk running program on the running mechanics and RE of beginner runners. The aim of this study was to identify if mechanical or physiological variables changed during 10-wk of running in beginners and whether these changes could account for any change in RE.

METHODS

Participants. Fourteen female beginner runners (age = 34.1 ± 8.8 yr, height = 1.64 ± 0.09 m, body mass = 69.1 ± 10.8 kg) volunteered for the study through a 10-wk beginners’ running program (10wkRP). Fourteen was calculated as an appropriate sample size to provide 80% power to detect changes in kinematics on the basis of magnitudes found in previous gait training studies (30,38). A beginner runner was defined as an individual having had no prior running training and not being involved in regular sporting activities. All participants were free from injury before data collection and did not sustain any injury to the lower extremities during the 10wkRP. They were also free from cardiac abnormalities and provided written informed consent and a medical and athletic history, which covered previous injuries and sports involvement. Ethical approval was given by the University of Exeter Sport and Health Sciences Ethics Committee.

Procedure. Data collection occurred during four laboratory visits: session 1 occurred before initiating the 10wkRP, session 2 occurred 3 wk after beginning the 10wkRP, and sessions 3 and 4 took place at least 2 d apart, after completion of the 10wkRP. Sessions 1 and 3 consisted of a gait analysis, flexibility assessment, a graded exercise test (GXT), and body mass (Seca, Hamburg, Germany) and stature measurements; RE was assessed during sessions 2 and 4. For both the GXT and RE measurements, the same motorized treadmill (PPS 55 sport slat-belt treadmill; Woodway, Weil am Rhein, Germany) was used. HR was measured via a wireless chest strap telemetry system (Polar Electro T31; Kempele, Finland), and respiratory gas exchange was measured every 10 s using an automated gas analysis system (Cortex Metalyzer II; Cortex Biophysik, Leipzig, Germany).

Gait analysis. Gait analysis sessions involved the simultaneous collection of kinematic and force plate data during running. A three-dimensional bilateral kinematic analysis was performed using an eight-camera motion capture system (Vicon Peak, 120 Hz, automatic, optoelectronic system; Peak Performance Technologies, Inc., Englewood, CO), with cameras positioned in an oval shape around a single floor-mounted force platform (960 Hz; Advanced Mechanical Technology, Inc., Watertown, MA) located halfway down a 12-m runway. Synchronization of the force and kinematic data occurred within the Vicon software using the initial foot contact as automatic event detection (vertical force > 10 N). A fifth-order quintic spline filter was applied to the raw kinematic data within the Vicon system. Kinetic calculations were conducted on the raw force plate data.

Participants were issued with a standardized Adidas neutral cushioning shoe (14) of appropriate size and then performed a 5-min warm-up to become accustomed to the footwear and the data collection environment. Eleven reflective markers were attached to the following anatomical positions to denote the anatomical position of the thigh, shank, and foot using a modified model of Soutas-Little et al. (36): the proximal greater trochanter (hip), the medial and lateral condyles (knee), the musculotendinous junction where the medial and lateral belly of the gastrocnemius meet the Achilles tendon, the mid tibia below the belly of the tibialis anterior, the lateral malleolus (ankle), the superior and inferior calcaneus, the third proximal head of the third metatarsal, and the distal head of the fifth metatarsal joint. A 12th reflective marker was placed on the inferior calcaneus of the opposite foot to allow for the calculation of step length. The 12 markers were affixed for the data capture of one leg and then removed and attached to the opposite leg to record the next set of data because data for each leg were collected separately using a block randomized order to reduce potential familiarization effects.

Angles were normalized to standing by the collection of a single standing trial on the force plate, in the anatomic position. The resulting standing joint angles were subtracted from angles gathered during the dynamic movement, with this adjustment providing anatomically meaningful values. Familiarization trials were performed until participants were deemed to be comfortable at the required running velocity of 2.53 m s−1 (±5%). The velocity was monitored by two sets of timing gates; each set was positioned on either side of the force plate. Ten successful trials were recorded per leg, and a total of 36 biomechanical variables were collected for each leg (Table 1). The time of occurrence for each peak value was reported as a percentage of stance time. The force conventions used were medial–lateral (FML), anterior–posterior (FAP), and vertical (FV).
A familiarization run on the treadmill was performed before the RE assessment. A minimum of 6 min was used during the familiarization to enable a natural running style to be achieved as is required when comparing treadmill and overground running (26). This period served as the participants’ warm-up. RE was measured on a level treadmill over three test speeds in the following order: 2.08, 2.31, and 2.53 m s⁻¹. These speeds were chosen following the recommendations that test speeds should be representative of training speeds for RE assessment (11, 20). Although not a randomized protocol, fatigue effects were minimized by progressing from the slowest to the fastest speed. Each speed was sustained for 6 min, with 9-min rest periods between consecutive running bouts. \( \text{VO}_2 \) was measured during the final 2 min of each bout of running, and the mean \( \text{VO}_2 \) was calculated. All three \( \text{VO}_2 \) values were used to calculate RE. In addition, HR was determined by averaging the final 2 min of each test, and then, the mean HR was calculated from the combination of all three velocities.

**10wkRP.** The 10wkRP used a combination of walking and running to gradually build up an individual’s constant running time (see Table, Supplemental Digital Content 1, http://links.lww.com/MSS/A166, which outlines a typical 10wkRP).
and were performed within a 3.2 min (towards the right (17.3 T 0.036* 9.8 cm, j j n 10.1 61.5 T 41.5 T 15.3 89.1 T 0.07 1.01 T T j 5.2 T ntly slower after the 10wkRP T j j T 28.2 T T T 30.7* was similar between the two measurements (34.7 0.05). Seven biomechanical vari-
ables that show similar trends to the significant result observed in the opposite leg.
Variables that significantly change over time to identify which variables significantly contributed
to any change in RE. Data analysis was conducted using PASW (Predictive Analytics Software) Statistics version 18 (SPSS Inc., Chicago, IL). Statistical significance was defined as \( P \leq 0.05 \).

RESULTS

On the basis of the logbook records, all weekly sessions and “homework” sessions were completed by everyone except two participants. These two individuals were unable to attend one running session each. A total of four participants withdrew from the 10wkRP because of being unable to commit to the weekly sessions; therefore, after data could not be collected for these individuals after 10wkRP.

Physiological variables. RE was found to signifi-
cantly improve between before and after measurements (Table 2). This was true even if data from only the final minutes continuously by the end of the program.

Statistical analysis. Means, SD, and 95% confidence intervals were calculated for all test variables, for both before and after measurements. The Kolomogorov–Smirnov test was performed on all measured variables to determine their distribution. All the variables were normally distribut-
ed, and consequently, paired-samples t-tests were performed (before vs after 10wkRP). Stepwise regression was performed on those variables found to significantly change over time to identify which variables significantly contributed to any change in RE. Data analysis was conducted using PASW (Predictive Analytics Software) Statistics version 18 (SPSS Inc., Chicago, IL). Statistical significance was defined as \( P \leq 0.05 \).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before (n = 14)</th>
<th>After (n = 10)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE (mL·kg⁻¹·km⁻¹)</td>
<td>224 ± 24</td>
<td>205 ± 27*</td>
<td>1.86 to 27.7</td>
</tr>
<tr>
<td>%VO₂max</td>
<td>89.1 ± 21.1</td>
<td>90.0 ± 15.8</td>
<td>-15.8 to 8.41</td>
</tr>
<tr>
<td>HR (beats·min⁻¹)</td>
<td>168 ± 15.8</td>
<td>166 ± 15.3</td>
<td>-1.99 to 6.77</td>
</tr>
<tr>
<td>V̇O₂ (L·min⁻¹)</td>
<td>62.8 ± 10.1</td>
<td>61.5 ± 13.1</td>
<td>-4.09 to 5.03</td>
</tr>
<tr>
<td>RER</td>
<td>0.97 ± 0.07</td>
<td>1.01 ± 0.08</td>
<td>-0.13 to 0.01</td>
</tr>
</tbody>
</table>

* Significantly different between before and after (\( P \leq 0.05 \)).

Sessions were for women only and were performed within a group setting once a week led by qualified leaders. The leaders set weekly “homework,” which was to be performed in the individual’s own time. Women were encouraged to run at their own pace throughout the 10wkRP, aiming to be able to run for 30 min continuously by the end of the program.

Flexibility. The SRT scores were similar between the two sets of measurements (13.2 ± 9.9 and 13.6 ± 9.8 cm, before and after, respectively). The left leg calf flexibility significantly decreased from before (27.3° ± 6.3°) to after (23.9° ± 5.6°). In the right leg, a similar trend was observed, but this was not statistically significant (28.6° ± 5.2° and 24.6° ± 7.6°, before and after, respectively).

Biomechanical variables. Seven biomechanical vari-
ables were found to significantly change from before to after (Table 3). Kinematic analysis revealed that the knee was significantly less extended and the ankle was significantly less plantar flexed at TO after the 10wkRP compared with baseline. Peak dorsiflexion of the right leg occurred earlier in stance after running compared with baseline. At TD, both the ankle plantarflexion velocity and ankle eversion velocity of the right leg became significantly slower after the 10wkRP compared with baseline. Peak eversion velocity became significantly lower for the right leg with more running experience.

Two individuals were identified as being midfoot strikers because of an indistinguishable initial \( F_T \) peak and were excluded from the analysis of this variable. Peak propulsive force significantly increased from baseline to after 10wkRP in the right leg and was the only kinetic variable to significantly change over time.

Regression analysis. Regression analysis was performed on all the variables that were found to significantly change. Previous research has considered trends within groups when investigating RE and running mechanics because of the large variance found (41). Therefore, from the lower extremity variables that had significantly changed, if

TABLE 2. Means ± SD and 95% confidence intervals (CI) for the submaximal physiological measurements.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before</th>
<th>After</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TO knee extension (°)</td>
<td>164.2 ± 4.6</td>
<td>159.4 ± 8.6*</td>
<td>-2.74 to 12.5</td>
</tr>
<tr>
<td>TO plantarflexion (°)</td>
<td>-21.3 ± 11.2</td>
<td>-19.8 ± 5.5*</td>
<td>-7.60 to 4.67</td>
</tr>
<tr>
<td>TD plantarflexion velocity (°·s⁻¹)</td>
<td>-194.5 ± 81.8</td>
<td>-94.3 ± 26.1*</td>
<td>-151.4 to -49.1</td>
</tr>
<tr>
<td>TD eversion velocity (°·s⁻¹)</td>
<td>-100.0 ± 35.0</td>
<td>-59.2 ± 30.2*</td>
<td>-65.5 to -17.4</td>
</tr>
<tr>
<td>Peak eversion velocity (°·s⁻¹)</td>
<td>-110.1 ± 47.1</td>
<td>-77.1 ± 27.1*</td>
<td>-61.8 to -4.18</td>
</tr>
<tr>
<td>Timing of peak dorsiflexion (%)</td>
<td>49.6 ± 6.9</td>
<td>56.2 ± 2.5*</td>
<td>-12.11 to -1.06</td>
</tr>
<tr>
<td>Peak propulsive force (BW)</td>
<td>0.193 ± 0.040</td>
<td>0.225 ± 0.036*</td>
<td>-0.054 to -0.011</td>
</tr>
</tbody>
</table>

* Variables that show similar trends to the significant result observed in the opposite leg.
* Significantly different between before and after (\( P \leq 0.05 \)).

TABLE 3. Means ± SD and 95% CI for the right and left legs, before and after the 10wkRP for the biomechanical variables that significantly changed over time.

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<th>After</th>
<th>95% CI</th>
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* Significantly different between before and after (\( P \leq 0.05 \)).

BW, bodyweights.
TABLE 4. Predictive model for changes in RE in beginner runners.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unstandardized Coefficients</th>
<th>SE</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timing of peak dorsiflexion(a)</td>
<td>-3.054</td>
<td>0.388</td>
<td>-7.738</td>
<td>0.001</td>
</tr>
<tr>
<td>TD knee extension(b)</td>
<td>-1.209</td>
<td>0.207</td>
<td>-5.945</td>
<td>0.004</td>
</tr>
<tr>
<td>TD eversion velocity(c)</td>
<td>-0.189</td>
<td>0.064</td>
<td>-2.928</td>
<td>0.042</td>
</tr>
<tr>
<td>Constant</td>
<td>5.731</td>
<td>0.968</td>
<td>(0.943)</td>
<td>0.176</td>
</tr>
</tbody>
</table>

\(a\) Left-leg variable.
\(b\) Right-leg variable.

both legs exhibited a similar trend, they were both entered into the regression analysis. The results revealed that a significantly less extended knee at TO, peak dorsiflexion occurring significantly later in stance, and a slower eversion velocity at TD explained 94.3% of the variance in the change in RE (Table 4).

DISCUSSION

The aim of this study was to identify if mechanical or physiological variables changed during 10 wk of running in beginners and whether these changes could account for any change in RE. The results revealed that seven biomechanical variables, calf flexibility, and time to exhaustion significantly changed with an increase in running experience. Of these, eversion velocity at TD, timing of peak dorsiflexion, and knee extension at TO contributed significantly to the change in RE, collectively accounting for 94.3% of the variance.

Changes in running mechanics. Research suggests that visual and verbal feedback of running gait can help an individual alter how he or she runs (10,30) but that completing a running program does not necessitate a change in running mechanics (25). To our knowledge, the current study is the first to use a detailed kinematic and kinetic analysis to observe individuals using a self-optimizing process to develop their running gait with increased running. It seems that during 10 wk of running, individuals begin to adapt their running style, producing a gait that is more economical than their initial gait. Previously, this was a theoretical concept (41) lacking empirical evidence.

The values obtained at baseline for peak eversion velocity are comparable to those reported previously for female recreational runners (4), although others have found much higher values (223°·s\(^{-1}\)) (29). The slower peak eversion velocities observed for beginner runners after 10 wk of running may have developed as a protective mechanism to reduce the strain on the musculoskeletal system, which could otherwise lead to overuse injuries (40). Such low eversion velocities found in the post-10wkRP data are, however, unsupported by previous research. It is likely that the slow running velocity (2.53 m·s\(^{-1}\)) and low mean peak eversion angles (−3.38° and −3.35°, right and left, respectively) contributed to this finding. This contrasts with previous running literature that reports peak eversion angles between −9° and −16° for test velocities ranging from 3.1 to 4.0 m·s\(^{-1}\) (13,17,29).

Kinetically, it seems that with increased running experience, beginner runners can generate greater propulsive forces without compromising upward force or affecting sideways adjustments because both the peak \(F_p\) and \(F_{ML}\) forces remained unchanged. A mechanism that may have accounted for some of the change in peak propulsive force may be the ankle angle differences at TO. The ankle was more flexed at TO after the 10wkRP, possibly as a result of peak dorsiflexion occurring later during stance. It is suggested that at TO, more force could be generated in the direction of the run. A similar difference in plantarflexion at TO has been observed in runners with better RE (41). Taken together, this suggests that the positioning of the foot leaving the ground can be modified, affecting other mechanical variables and influencing VO\(_2\). However, a greater understanding of the interactions between mechanical variables and their resultant effect upon RE is needed before firm conclusions can be reached.

Relationship between running mechanics and RE. The results revealed that biomechanical variables can explain 94.3% of the variance in RE when both legs are considered. This supports the findings of Williams and Cavanagh (41), who reported that 54% of the variance in RE can be accounted for by the shank angle with the vertical at TD, maximal plantarflexion angle (which occurred at TO), and net positive power. Contrary to these results, Lake and Cavanagh (25) found that after 6 wk of running training, there were no gait adaptations and no relationship between RE and running mechanics. Together, these results suggest that adaptations may occur between 6 and 10 wk. However, Lake and Cavanagh (25) only used six biomechanical variables based on previous evidence obtained using trained runners, and, therefore, they may have missed any changes specific to a novice gait.

The significant contribution of knee extension at TO to the variance in RE change suggests that reduced knee extension at TO is a feature of economical female running gait. Although there have been discrepancies reported regarding variations in knee kinematics with gait manipulations and/or altered RE (30,41,42), this finding is consistent with observations of elite female runners (42). Thus, reduced knee extension at TO is a quality found both in elite female runners, with an established gait pattern, and in beginner female runners developing their gait.

The observed change in both the knee and ankle extension at TO means a less extended leg is generated (Fig. 1), but the mechanism through which this translates to better RE has yet to be explained. Given that extension of the lower extremities helps to propel the body vertically upward, facilitating the support leg’s clearance of the ground during its swing phase, some extension is necessary. However, it is possible that the leg is in a better position for the swing phase, when less extended, meaning less energy is expended in flexing the leg during swing.

By increasing the length of time spent dorsiflexing, beginner runners spent longer in the eccentric phase of the SSC.
after training, facilitating elastic energy storage during the absorption phase of ground contact (27). The results suggest that prolonging dorsiflexion, toward the higher end of the expected occurrence time of 50%–60% of stance (34), is more economical than a shorter dorsiflexion time. This is because runners will be able to enhance the performance of the propulsive concentric phase of the SSC because of an improved eccentric phase (22). The calf muscles became 3.4° and 4° (left and right legs, respectively) less flexible after training, suggesting increased calf muscle stiffness, which could also have implications for the SSC. Increasing the stiffness of calf muscle–tendon units contributes to improving RE (24) potentially via reducing muscle activation. Further research incorporating joint and muscle moment data in addition to the kinematics and SSC is necessary to fully understand the biomechanical relationship with the SSC. The change in TD eversion velocity coupled with a change in TD plantarflexion velocity suggests that approach kinematics, and possibly muscular activity, were altered with an increase in running experience. This observation is consistent with the suggestion of Williams and Cavanagh (41) that changes to approach kinematics can contribute to VO$_{2\text{max}}$ differences. Bonacci et al. (6) found that seven of eight triathletes who showed a change in muscular activity also altered their running mechanics after a cycle–run transition compared with a control run. Their results suggested that 73% of the variance in RE can be explained by changes to sagittal plane knee and ankle TD angles. However, swing kinematics and EMG data were not analyzed in the current study, so changes before TD can only be speculated upon.

The beginner runners became 8.4% more economical. Physiologically, only time to exhaustion, improved, and thus, only biomechanical factors could account for the variance in RE change. This contrasts with previous research that suggests that physiological differences predominantly explain changes in RE with training (16,25). Some studies of recreational athletes or runners have failed to find alterations to running mechanics (16,25). This highlights the importance of using beginner runners with limited prior running experience to improve understanding of RE development. Furthermore, as symmetry was not assumed in the current study, the right and left legs were comprehensively analyzed meaning trends between both legs could be observed.

It is important to note that although biomechanical rather than physiological changes were clearly responsible for the improved RE in beginner runners after short-term training, physiological changes (perhaps in addition to further biomechanical changes) might contribute to continued improvements in RE in elite athletes or after long-term training (19). These changes might include a lower oxygen cost of cardiac or respiratory work, changes in muscle stiffness, or transformation of fiber types from Type II to Type I (35).

It is unclear why there were no improvements in VO$_{2\text{max}}$ given the initially low fitness levels and improvement in treadmill time to exhaustion. One possibility is the motivational aspect of completing a GXT to volitional exhaustion. Beginner runners may lack the desire to push themselves to volitional exhaustion. Conversely, the improvement found in RE would have enabled participants to perform for longer before reaching the same VO$_{2\text{max}}$, meaning that although the participants increased their time to exhaustion, they may have still terminated the test at a similar maximal-effort level. Because of the protocol used for the GXT, fitter individuals may terminate exercise because of discomfort to their lower back and calf regions rather than volitional exhaustion. However, it was deemed the most appropriate procedure because it can elicit true VO$_{2\text{max}}$ values for individuals with low fitness levels (28). In addition, it must be noted that the first RE measurement occurred 3 wk after the initial gait analysis because of these low fitness levels and lack of prior running training experience. The delay was necessary for participants to be able to fulfill the requirement of sustaining 6 min of running at three different speeds.

Caution must be taken in generalizing these results because within-group differences were often large in many of the biomechanical variables. In addition, as Williams and Cavanagh (41) have suggested, the combined effect of the change in running mechanics should perhaps be used to understand why the runners became more economical rather than the single set of variables forming the regression equation. This notion may explain why two of the variables found to significantly explain the variance in this change in RE were only included in the analysis as a result of exhibiting a similar trend to the opposite leg rather than a significant change. Therefore, if only one side of the body had been analyzed, trends would have been missed, and they would not have been considered. Their inclusion demonstrates that gait adaptations occur in both sides of the lower extremities but to differing degrees and that, perhaps, it is not the magnitude of change but the effect that the change has on other mechanical variables that is important for developing an economical gait. Exploring ways of understanding the interaction of biomechanical variables and their effect on economy is encouraged as opposed to studying variables in isolation.

FIGURE 1—Differences in knee angle and ankle angle at TO between before and after measurements.
Although the test speeds used for the RE assessment were relatively slow compared with previous studies, the %VO_{2\text{max}} elicited during the RE assessments was high yet below the 90% VO_{2\text{max}} outlined by Daniels and Daniels (11). Biomechanical comparisons with the literature were, however, limited by using a slow velocity because kinematics and kinetics change as a result of velocity. There were also two different procedures used for the RE and running gait assessments: treadmill and overground, respectively. Although both modes of running have been used in previous studies examining running mechanics and RE (18,41) and can produce similar values for submaximal VO_{2} (2), kinematic differences have been observed (39), especially in the knee (33). Generally, however, it is considered that treadmill running provides a good representation of overground running (33). In addition, adequate familiarization to treadmill running was given to each participant, an important prerequisite when using both modes of running (26). A pilot study from our laboratory also demonstrated that running with a respiratory apparatus does not alter running kinematics, suggesting that the instrumentation required to measure gas exchange during treadmill running had no bearing on the results.

CONCLUSIONS

This study has demonstrated that beginner runners use a self-optimization process to develop their running gait with training. This natural modification to running gait explained 94.3% of the variance in the change in RE that was observed.

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REFERENCES