Chronic stretching and running economy

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Research demonstrates an inverse relationship between the range of motion of selected joint movements (flexibility) and running economy. Since stretching exercises have been shown to increase joint range of motion, stretching exercises may be contraindicated for endurance running performance. Hence, this study investigated the influence of a 10-week program of stretching exercises on the oxygen costs of a 10 min sub-maximal (approx. 70% peak VO₂) treadmill run. Thirty-two (16 female, 16 male) physically active, treadmill accommodated, college students participated in the study. All participants maintained their current activity level, with half the participants (8 female, 8 male) adding a 40 min, 3 days per week session of thigh and calf muscle stretching exercises. After 10 weeks, the stretching group (STR) exhibited a significant (P<0.05) increase (3.1±2.2 cm) in the sit-and-reach, while the non-stretching group (CON) experienced no significant (P>0.05) change (0.0±0.4 cm). However, neither the STR nor the CON exhibited a significant (P>0.05) change in the O₂ cost for the submaximal run. It is concluded, therefore, that a chronic stretching program does not necessarily negatively influence running economy.

Flexibility (joint range of motion) has been long recognized as an important component of physical fitness. It is widely conjectured that increasing flexibility will promote better performances and reduce the incidence of injury (for a review see Shellock & Prentice, 1985; Smith, 1994). Consequently, stretching exercises designed to enhance flexibility are regularly included in both the training programs and the pre-event warm-up activities of most athletes.

Notwithstanding the widespread acceptance and use of stretching exercises as a major component of training programs, the findings of two investigations into the relationship between running economy and flexibility (Gleim, Stachenfeld, Nicholas, 1990; Craib, Mitchell, Fields, Cooper, Hopewell, Morgan, 1996) could be interpreted by some individuals as a recommendation or caution against improving flexibility. Based on the premise that less flexible joints improve running economy because increased stiffness allows for a greater return of the stored elastic energy built up during the repetitive stretch-shortening cycles, Gleim et al. (1990) and Craib et al. (1996) correlated different joint flexibilities with running economy. Gleim et al. (1990) used a “tightness” score based on the sum of 11 different trunk and lower limb flexibility measures to compare individual’s economy of walking and running on a treadmill. These researchers concluded that non-pathological musculoskeletal tightness was associated with increased economy or lowered oxygen consumption. Similarly, Craib et al. (1996) associated nine measures of trunk and limb flexibility with oxygen costs of treadmill running at two different speeds. Their study supported the work of Gleim et al. (1990) by also showing that runners who had lower body flexibility (during dorsiflexion and hip rotation) were more economical. Moreover, support in general terms for the findings of Gleim et al. (1990) and Craib et al. (1996) can be seen in inter-gender comparisons. Also as pointed out by Craib et al. (1996), it has been shown that females on average have greater flexibility than males (Bell, 1981), but males run more economically than females (Daniels & Daniels, 1992).

Given that running economy can influence success in an endurance race, these correlations between joint flexibility and running economy seem to contraindicate the established athletic practice of including stretching exercises as part of the normal workout regimen. Thus, it would appear that endurance runners must make a difficult decision: Do they include flexibility exercises in their regular training programs and risk becoming uneconomical, or do they drop the flexibility exercises and increase the risk of injury? This dilemma is further confused by several con-
found many factors. First, since the two aforementioned studies were correlative studies, they do not imply that alterations in flexibility will result in altered running economies. Second, there is a lack of evidence showing a coupling between increased injury risk and a long distance runner’s level of flexibility. Finally, the premise of the Gleim et al. (1990) and Craib et al. (1996) studies (i.e. flexible joints result in decreased running economy because a more compliant musculotendinous unit reduces the return of the stored elastic energy built up during the repetitive stretch-shortening cycles) is based on faulty logic: namely, joint flexibility and musculotendinous stiffness are not synonymous terms. In his review of stretching and the passive properties of muscle, Magnusson (1998) points out that there is a lack of evidence linking long-term changes in flexibility to changes in the passive properties of the musculotendinous unit. In fact, Magnusson, Simonsen, Aagaard, Sorensen and Kjaer (1996) found that increases in joint range of motion following a 3-week stretch training program were due to increased stretch tolerance rather than a change in the viscoelastic properties of the muscle.

The aforementioned work of Magnusson et al. (1996) suggests that endurance runners could employ stretches as part of their training program without compromising running economy. In addition, it questions whether the relationship between joint flexibility and running economy is due to the supposed changes in the musculotendinous unit (i.e. flexible joints result in decreased running economy because a more compliant musculotendinous unit reduces the return of the stored elastic energy built up during the repetitive stretch-shortening cycles) or some other mechanism. Clearly, more information related to this topic is warranted. Moreover, since there are no studies which have looked directly at flexibility training and running economy, this area needs particular attention. Therefore, the purpose of this study was to determine whether performing a stretch training program for 10 weeks would result in a reduction of a person’s running economy.

Material and methods
Participants
Thirty-two (10 female, 16 male) college aged students participated in the study. It was determined that a reduction in running economy would be more manifest in individuals with a high economy as opposed to a low economy. Therefore, it was decided that trained individuals would be a better research model than untrained. Moreover, research (Caird, McKenzie, Sleivert, 1999; Foster, Hector, Welsh, Schrager, Green, Snyder, 1995; Williams, Krahenbuhl, Morgan, 1991) indicates that training induced changes in running economy are less likely to occur in individuals whose VO2peak is no longer increasing, and whose workout loads have been constant for several weeks. Therefore, only individuals who had been participating for at least the last six months in 30 min of vigorous running (>70% maximum heart rate) 3–5 days per week, who had not altered their training program during that time and who were willing to continue to maintain present levels, and who were not performing any regular stretching program were selected for participation. In addition to the above criteria, all individuals had to be accustomed to running on a treadmill prior to their participation in the study. The study was approved by the appropriate institutional review board, and each participant gave both written and oral consent before engaging in the experiment.

Experimental design
First, each person’s VO2peak was measured using a running graded exercise test protocol. The initial workload was 6% grade at either 6 mph (males) or 5 mph (females). The grade was then increased by 2% every 2 min until the subject could no longer keep pace with the treadmill. Expired gases and minute ventilation were monitored continuously with a SensorMedics series 2500 analyzer. Oxygen consumption was measured breath-by-breath, and was averaged and outputted at 20 s intervals. VO2peak was defined as the highest 20 s average obtained during the last 4 min of the test.

On a subsequent day, each person performed a running economy test. Running economy was determined by averaging all of the VO2 readings obtained during the last 5 min of a 10 min sub-maximal run. The desired intensity of the running economy test was 70% of VO2peak; however, with the intra-runner peak VO2peak being similar for all participants it was decided that the same, albeit gender-specific, workload would be used. The workload was 6 mph at 2% grade for the males, and 5 mph at 2% grade for the females.

Upon entering the laboratory on the day of the running economy test, each person sat in a chair for 10 min. This was followed by the person performing a sit-and-reach test (without any warm-up) on an Acuflex I sit-and-reach box to assess pre-run flexibility. The individual was then connected to the SensorMedics 2500 analyzer, and sat in a chair on the treadmill for 2 min. Following the seated rest, the subject walked for 1 min on the treadmill at 3 mph and 0% grade. At the end of the 1 min walk, the treadmill speed and grade were advanced to the gender-specific workload, and the participants ran for 10 min, after which the running economy test was terminated. During the rest, walk and run periods, the oxygen consumption was calculated and printed at 20 s intervals.

Following the running economy test, the participants were randomly assigned to either a stretching (STR) or non-stretching group (CON), with each group comprising eight females and eight males. Both groups maintained their current running/exercise habits; however, the CON group was asked to refrain from performing any stretching exercises, while the STR group added a stretching program to their usual activities. Each individual’s diligence in maintaining a minimum running program was monitored by weekly reports, with the pre- and post VO2peak test serving as back-up verification.

The STR and CON programs were performed for 10 weeks. At the end of the 10-week period, each subject’s VO2peak, sit-and-reach, and running economy were again tested following the exact procedures outlined above.

Stretching program
The STR stretching program consisted of 15 different static stretches designed to stretch all of the major lower extremities muscles which were included in the Gleim et al. (1990) overall flexibility score. A 10-week training program duration was chosen. This particular stretching program was chosen because it was longer than the 3-week Magnusson et al. (1996) program. In addition, previous research (Kokkonen, Eldredge, Nelson, 1997) had shown that a 10-week stretch training pro-
gram using the same stretching activities had elicited a significant change in not only flexibility (joint range of motion), but also performance of selected sport skills. Each of the subjects actively performed (i.e. unassisted stretching) the 15 exercises, and 12 of the 15 exercises were also performed passively (i.e. assisted stretching). The passive stretching was done by members of the research team. This allowed for both compliance monitoring as well as daily assessment of changes in flexibility. The order in which the exercises were performed was left up to the individual. For each stretch, the muscle was held in the stretched position for 15 s, and this was repeated three times (both unassisted and assisted). A 15 s rest period was implemented between trials, and a minimum period of 1 min separated the different exercises. Each stretching session lasted approximately 40 min, and was performed 3 days each week for the entire 10 weeks.

Four of the 15 exercises were variations of the sit-and-reach. These were performed assisted and unassisted by sitting on the floor with the legs in one of four different positions: legs parallel, legs in the lotus position, legs abducted 45° apart, or legs abducted as far as possible. Once in position, the subject would bend forward at the waist as far as possible.

In another five exercises, the head was lowered towards the knee (both assisted and unassisted) when at least one leg was straight, but placed in different positions relative to the body. The first position was sitting on the floor with the legs ab ducted as far as possible. From here, the head was lowered to each knee three times, alternating between knees. The second position was sitting on the floor with one leg placed straight out in front (0° abduction), and the other leg in the lotus position. While in this position, the head was lowered to the knee of the straight leg three times before leg positions were swapped. The third and fourth positions were performed while standing erect with one leg resting upon a table (90° hip flexion). From this position, the participants’ heads were lowered three times to the knee of the supported leg (third position), and then the participants would externally rotate the erect leg 90° and bend down three times to the knee of the erect leg (fourth position). After performing these exercises, the erect leg and supporting leg were switched, and the exercises repeated. The fifth position was standing erect with one hip flexed (>120° hip flexion) as much as possible with the corresponding foot resting upon a beam at eye level or above. Once in position, the participants’ heads were lowered three times to the knee of the supported leg, and then the position of the legs was swapped.

The next group of exercises used the standing half lotus position. Two exercises were performed, and both were done assisted and unassisted. While standing with one foot flat on the floor, the participants placed the opposite leg in a lotus position upon a table (90° hip flexion). The participants would then alternate lowering their head toward either the foot (first exercise) or the knee (second exercise) of the leg resting upon the table. Each exercise was performed three times before the leg positions were changed.

Two other activities consisted of quadriceps stretching with one of the activities being done unassisted only. The unassisted only activity required the participants to stand up straight and balance on one leg. The non-weight bearing leg was flexed at the knee, and using the corresponding hand, the heel was held as close as possible to the buttocks. For the quadriceps stretch, which was done both assisted and unassisted, the participants stood with their back to a pommel horse, and then placed the superior side of one foot on the pommel horse by flexing at the knee joint. From this position, the participants would lean (or when assisted, the corresponding knee and shoulder were pushed) backwards.

The other two unassisted stretches involved the calf muscles. To do one of the calf stretches, the participants first stood with one foot flat on the floor and the other foot placed on a block so that the ball of the foot was approximately 10 cm above the heel. The participants would then lean forward until maximum dorsiflexion was achieved and noticeable tension was felt in the calf. The other calf stretch was the classic “wall push”. Here the participants stood with one leg 15-30 cm away from a wall with the other foot placed even further away from the wall so that the ankle was dorsiflexed. The participants would then lean towards the wall, keeping the heel of the dorsiflexed foot in contact with the floor. Both the height of the block and the distance from the wall were increased over the duration of the program to compensate for increases in flexibility.

**Statistical analysis**

A two-way (treatment×time) repeated measures ANOVA was used for data analysis. Significance was set at *P*<0.05. Initial statistical tests revealed no gender based differences in response to the treatments. Therefore, data for the males and females were combined. Post-hoc ANOVA analysis involved, where appropriate, the use of Tukey's protected *t*-test. The dependent variables analyzed were sit-and-reach scores, VO₂peak, and average VO₂ during the last 5 min of the running economy test.

**Results**

The influence of the STR and CON programs upon sit-and-reach scores are shown in Fig. 1. The main effect for treatment was not significant. Both the main effect for time (*F*(1,30)=28.6, *P*<0.05) and the interaction between treatment and time (*F*(1,30)=29.7, *P*<0.05), however, were significant. Post hoc analysis showed that the significance was due to the STR group having a significant 9% gain in their sit-and-reach score, while the CON group had no change.

The initial VO₂peak for STR was 47.2±11.4 mL·kg⁻¹·min⁻¹, and at the end of the 10 weeks it was 47.6±12.1 mL·kg⁻¹·min⁻¹. For CON, the initial VO₂peak was 47.1±7.0 mL·kg⁻¹·min⁻¹, and the post-treatment VO₂peak was 47.8±6.6 mL·kg⁻¹·min⁻¹.

![Fig. 1. The mean (±standard deviation) sit-and-reach scores. The sit-and-reach was measured before (pretreatment) and after (post-treatment) the two treatments. * indicates a post-test sit-and-reach score which is significantly greater (*P*<0.05) than the respective pretest sit-and-reach score.](image-url)
Neither the treatment main effect ($F(1,30)=0.07, P>0.05$), nor the time main effect ($F(1,30)=1.52, P>0.05$), nor their interaction ($F(1,30)=0.33, P>0.05$) were significant.

The cost of the treadmill running task (average VO$_2$ costs) is presented in Fig. 2. As with the peak VO$_2$ values, there were no significant differences found for the oxygen cost of running (treatment = $F(1,30)=0.01, P>0.05$; time = $F(1,30)=0.10, P>0.05$; interaction = $F(1,30)=0.26, P>0.05$).

**Discussion**

This study was designed to determine whether running economy could be reduced by adding 10 weeks of stretching exercises to a training program. The impetus behind the study came from the work of Gleim et al. (1990), Craib et al. (1996), and Magnusson et al. (1996). Cross-sectional studies by Gleim et al. (1990) and Craib et al. (1996) presented the possibility that stretching exercises may be contraindicated for endurance running performance by finding an inverse relationship between the flexibility of selected movements and running economy. The underlying reason for this inverse relationship was postulated to be that the decreased flexibility causes decreased running economy because a more compliant muscle yields a lower stored elastic energy. Research by Magnusson et al. (1996), however, suggested that increases in flexibility following stretch training do not coincide with alterations in the stiffness in the stretched musculotendinous unit. The findings of this current study most closely follow the findings of Magnusson et al. (1996). After 10 weeks of stretching, an increase in flexibility was seen in the STR group, but this had no apparent influence upon running economy. Therefore, it would appear that the inclusion of stretching into an individual's training program may not necessarily result in impaired running performance.

Nevertheless, these results should be viewed with caution. Even though the stretching exercises targeted all of the movements included in the flexibility score used by Gleim et al. (1990), only the sit-and-reach score was used as statistical evidence of improved flexibility. Moreover, this study did not exclusively target the exact joint actions (dorsiflexion and standing hip rotation) which Craib et al. (1996) showed to have the highest correlation with running economy. Thus, it is possible that flexibility was increased only at the measured site and not at any other site. Notwithstanding this lack of statistical verification, empirical evidence suggests that increased flexibility occurred for all of the joint angles in question. Similar to the muscle groups involved in the sit-and-reach, all of the other muscle groups in question were stretched several times during each of the stretching sessions with the assistance of a member of the research team. Over the 10-week period, an increase in flexibility (or more precisely an increased difficulty in stretching the particular muscle group) was noted for each exercise. Hence, even though the exact magnitude of the overall flexibility increase is not known, it is not unreasonable to claim that a stretching regimen such as that used in this study (or intuitively one that involves fewer flexibility exercises) does not result in reduced running economy.

Before any final conclusions are made, it is important to remember that no definitive model of running economy has yet been established. This is because there are many factors that can contribute to the fluctuations in energy expenditure (for review see Morgan, Martin, Krahenbuhl, 1989). A multidisciplinary approach shows the aerobic demand to be affected by physiological (Conley & Krahenbuhl, 1980), environmental (MacDougall, Reddan, Layton, Dempsey, 1974), psychological (Crews, 1992), and biomechanical variables (Williams & Cavanagh, 1987). Moreover, within each discipline contributions to economy come from many areas. For example, biomechanical research has shown body mass, body mass distribution, stride length/rate, mechanical energy transfer between segments, ground reaction forces, flexibility and kinematic measures are all related to running economy (Martin & Morgan, 1992; Williams & Cavanagh, 1987). Therefore, caution must be exercised in analyzing the alteration effects of a single factor upon economy.

This does not suggest, however, that further studies upon the influence of changing joint range upon running economy should not be done. In particular, an attempt to establish a dose–response relationship should be made. It is possible that either some thresh-
old flexibility or percent change in flexibility must be achieved before a reduced running economy is noted. In addition, a link between reduced running economy and altered flexibility may require a longer time period to be manifested than the 10 weeks of our study. Unfortunately, Gleim et al. (1990) did not report the training status of their subjects and Craib et al. (1996) did not report if there were any differences in the years of training among their sub-elite athletes, and so neither study helps to resolve this question. It should be pointed out, however, that the stretching program used in this study was more extensive than that which is normally used by endurance athletes. Therefore, while it may be possible to find a large enough alteration in joint range of motion to induce a lower running economy, the level of effort required would make it of little practical concern for most endurance athletes.

Finally, it should be reiterated that the relationship between flexibility and running economy reported by Gleim et al. (1990) and Craib et al. (1996) is correlative and, as such, does not imply cause-and-effect nor does it establish any mechanisms of action. Moreover, the work of Magnusson et al. (1996) demonstrates that there can be a lack of connection between joint range of motion and passive stiffness. Interestingly, Alexander and Bennet-Clark (1977) have shown that the capacity of elastic energy storage is greater in muscles with long tendons and short muscle fibers. Since muscle with long tendons and short muscle fibers are more likely to lead to a smaller joint range of motion than vice versa, it is possible that the joint stiffness reported by Gleim et al. (1990) and Craib et al. (1996) was due more to differences in muscle tendon ratios and not passive stiffness. Unfortunately, the ability of flexibility exercises to alter the ratio of muscle length to tendon length is unknown. Finally, one could question whether passive stiffness and/or joint range of motion are accurate predictors of the dynamic stiffness of muscles and joints during activity. In fact, Cornwell & Nelson (1997) have reported that changing the joint range of motion by performing stretching exercises just prior to an activity did not change the dynamic stiffness of the musculotendinous unit during the activity.

**Perspective**

This study shows that an increase in joint range of motion does not necessarily cause a reduction in running economy. This implies that the relationship seen between running economy and the range of motion of certain joints may be more complex than the simple assumption that a stiffer joint allows for a greater elastic energy return. This does not imply that a stiffer joint and/or musculotendinous unit does not return more elastic energy for a given length change, but rather it implies that flexibility exercises do not alter stiffness. Unfortunately, the lack of stiffness measurements means this point must be examined further. Finally, given that the stretching program used in this study was more extensive than that which is normally used by endurance athletes, this study also suggests that the current stretching practices of most endurance athletes need not be completely discontinued in order to prevent reductions in running economy.

**Key words**: submaximal aerobic demand; flexibility; joint range of motion.

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**References**


