Effects of an Orthotics Intervention on Running Economy

INTRODUCTION

Measurements of movement economy during physical activity may reflect improvements in neuromuscular efficiency with an optimal orthotic intervention[1-3]. Running economy is defined as the steady-state oxygen consumption for a given running velocity. Subject specific changes in steady-state oxygen consumption occurred as a function of the heel material characteristics of the running shoes; however, the maximal change for any one subject was 2%[4]. Approximately a 1% improvement in steady-state oxygen consumption occurred by increasing midsole longitudinal bending stiffness, with 11 of the 13 subjects showing this experimental effect[5].

These subtle, but consistent changes in running economy as a function of shoe material characteristics provide an experimental model to identify systematic changes in neuromuscular efficiency with orthotic interventions. Measurements of oxygen consumption at several moderate exercise intensities generates an individual's economy-of-running line[6-9]. An individual's economy-of-running line is an index of neuromuscular efficiency[10;11]. Using linear extrapolation of an individual's economy-of-running line to VO_{2max}, predicted velocity at VO_{2max} (vVO_{2max}) is a primary predictor of endurance performance [6-9;11;12]. Physiologic adaptations to high-intensity and aerobic interval training programs substantiate a relationship among running economy, vVO_{2max} and middle- and long-distance running performances[13-16].

Research Objective: The objective of this research was to determine the effects of an orthotics intervention on running economy.

It was hypothesized that the orthotics intervention would improve running economy and endurance performance as stated in the below two hypotheses, respectively.

Hypothesis 1*:* Submaximal VO_2 at the five different running velocities would be less for the orthotic intervention as compared to the normal running shoe condition.

Hypothesis 2*:* vVO_{2max} would be greater for the orthotic intervention as compared to the normal running shoe condition.

METHODS

Study Population: The subjects were three endurance-trained males and three endurance-trained females. All subjects wore their orthotic intervention for at least a period of one month and perceived the orthotic intervention as more comfortable than normal athletic footwear according to the methodology of

Mundermann et al.[17]. The orthotic intervention was the flexible, custom-made orthotics by Foot Levelers, Inc. (Roanoke, VA). For males and females respectively, the subject's self-reported ability to sustain a mile pace of at least 7:00 minutes or 8:00 minutes for a duration of 30 minutes was the training criterion. For each subject, running economy and lower extremity muscle activity and kinematics during human gait were measured for the orthotic intervention and the normal running shoe condition. Only the running economy methodologies and data outcomes are provided in this report. The institutional ethics committee approved all testing procedures. The subjects provided written informed consent.

Study Design: The subjects reported to the Biomechanics Laboratory on two separate occasions with one week in between visits. The laboratory visits for the two footwear conditions were random among the subjects. The subjects reported to the Biomechanics Laboratory for a third testing session, if $VO2_{max}$ deviated by more 2% between their first and second graded exercise run to volitional exhaustion. A 2% deviation in the repeated measurements of $VO2_{max}$ is the measurement error of metabolic cart (V_{max29}, SensorMedics Corporation, Yorba Linda, CA) and $VO2_{max}$ deviations greater than 2% were deemed accommodation effects.

In each of the testing sessions, steady-state oxygen consumption was measured during submaximal treadmill running. Each testing session also included the measurement of VO_{2max} during a graded exercise run to volitional exhaustion.

Submaximal Treadmill Running: The five minute submaximal treadmill stages for males began with a warm-up stage at a 9:00 (min-sec) mile pace and then preceded in increments of 30 seconds from the first stage at 8:30 (min-sec) mile pace until the fifth stage at 6:30 (min-sec) mile pace. The five minute submaximal treadmill stages for females began with a warm-up stage at a 10:00 (min-sec) mile pace and then treadmill speed was increased to correspond to mile pace increments of 30 seconds from the first stage at 9:30 (min-sec) mile pace until the fifth stage at 7:30 (min-sec) mile pace. After a 15 minute rest period, the subjects performed a graded exercise test to volitional exhaustion.

Graded Exercise Run to Volitional Exhaustion: The males began at 0% treadmill evaluation and 9:30 (min-sec) mile pace and treadmill speed was increased every minute to correspond to mile pace increments of 30 seconds until completing 7:00 (min-sec) mile pace at 0% treadmill evaluation; thereafter, the mile pace was maintained with increasing treadmill evaluations of 2% per stage until volitional exhaustion. Similarly for females, the beginning stage was 9:30 (min-sec) mile pace at 0% treadmill evaluation until completing an 8:00 (min-sec) mile pace at 0% treadmill evaluation; thereafter, the mile pace was maintained with increasing treadmill evaluations of 2% per stage until volitional exhaustion

Measurement of Oxygen Consumption During Submaximal (VO_2) and Maximal (VO_{2max})Treadmill Runs. The subjects were weighted before each testing session. Cardiorespiratory-metabolic variables were measured using the V_{max29} automated metabolic cart. The metabolic cart was calibrated before each submaximal and maximal test within each testing session according to the manufacturer's instructions. VO_2 was measured continuously, breath-by-breath method. VO_2 and the respiratory exchange ratio (RER) were calculated over 15 second intervals. Steady-state values of VO_2 for each of the five stages of the submaximal treadmill run were calculated by averaging the 15 second interval measurements during the final two minutes of each stage.

Following the 15 minute rest period, the subjects performed a graded exercise run to volitional exhaustion to determine VO_{2max}. The highest 15 second interval value for VO_2 was recorded as VO_{2max}. Criteria for attainment of VO_{2max} included two of the following as observed during the graded exercise run: a plateau in VO_{2max} despite an increase in workload, a RER value greater than 1.15, or volitional exhaustion. The subjects received feedback related to each of the criteria in a normal tone of voice by the principle investigator.

Calculation of Predicted Velocity at VO_{2max}. Using linear extrapolation of an individual's economy-of-running line to VO_{2max}, vVO_{2max} were calculated for each of the laboratory visits[6;7;9].

Data Analysis: The main outcome variables were VO_2 during each treadmill stage of the submaximal run, VO_{2max}, and vVO_{2max}. A Footwear Condition x Treadmill Stage repeated measures ANOVA model was used to reveal differences in VO_2 during the submaximal treadmill runs. A significant Footwear Condition main effect will indicate that the orthotic intervention affects running economy. A significant paired sample t-test result for vVO_{2max} between the orthotic intervention and the normal running shoe condition will indicate that the orthotic intervention affects endurance performance. A non-significant paired sample t-test result for VO_{2max} between the orthotic intervention and the normal running shoe condition will imply that maximum performance, volitional effort and physiological steady-state were similar between the testing sessions of the two footwear conditions.

RESULTS:

Testing Order Effects: With the exception of two female subjects, the four remaining subjects needed to repeat the testing of the footwear condition assigned in Session 1. The resultant order of testing the footwear conditions were two subjects being tested with orthotics in Session 1 and four subjects being tested in their normal shoe condition in Session 1. $V0_2$ measurements during each treadmill stage of the submaximal runs were not significantly different between Session 1 and Session 2 [$F(1, 5)_{Session} = 0.13$; $p > .05$; Figure 1a]. VO_{2max} values were not significantly different between Session 1 (53.1 ±

6.41 ml/kg-min) and Session 2 (53.6 ± 6.29 ml/kg-min) [$t_5 = 2.10$; $p = .09$; Figure 1b]. More importantly, the repeated measurements of VO_{2max} on two different days were within 2% deviations for all of the subjects. vVO_{2max} values were not significantly different between Session 1 (10.25 ± 0.764 mph) and Session 2 (10.50 ± 1.223 mph) [$t_5 = 0.43$; $p < .05$; Figure 1b].

Orthotic Intervention: The orthotic intervention improved running economy as indicated by a significant main effect of Footwear Condition across the five treadmill stages [$F(1, 5)_{\text{Footwear Condition}} = 10.37$; $p < .05$; Figure 2a]. Footwear Condition by Treadmill Stage interaction term was also significant [$F(1, 5)_{\text{Footwear Condition xTreadmill Stage}} = 10.37$; $p < .05$]. The orthotic intervention improved endurance performance as indicated by the significantly greater vVO_{2max} for the orthotic intervention (10.94 ± 0.636 mph) as compared to normal shoe condition (9.81 ± 0.977 mph) [$t_5 = 4.20$; $p < .05$; Figure 2b]. VO_{2max} values were similar for both footwear conditions [$t_5 = 0.05$; $p < .05$; Figure 2b], which indicated that maximum performance, volitional effort and physiological steady-state were similar during each test of the footwear conditions. The VO_{2max} values were 53.3 ± 6.57 ml/kg-min and 53.3 ± 6.14 ml/kg-min for the orthotic intervention and normal shoe condition respectively.

DISCUSSION

The orthotics intervention improved movement economy and endurance performance during treadmill running. Approximately 8% improvements in steady-state oxygen consumption occurred with the orthotic intervention during submaximal treadmill running, with a range of between 3% and 23%. Approximately 10% improvements in vVO_{2max} occurred with the orthotic intervention, with a range between 3% and 20%. The data substantiated that the measurements of an individual's economy-of-running line at several moderate exercise intensities and the calculation of vVO_{2max} may be a more robust experimental protocol than steady-state runs at approximately aerobic threshold[4;5] to determine the beneficial effects of orthotic interventions on improving neuromuscular efficiency during physical activities.

All subjects perceived the orthotic intervention as more comfortable than normal athletic footwear. In accordance with neuromuscular concepts underlying the benefits of orthotics, it would be expected that that the orthotic intervention would enhance neuromuscular efficiency by supporting the preferred movement pattern of the individual[1-3]. Thus, the results may only be generalized to individuals who perceive the orthotic intervention as more comfortable than normal athletic footwear. Ratings of comfort perceptions between the footwear conditions were markedly difference between the subject with the smallest experimental effect and the subject with the largest experimental effect. In addition, the subject with the largest experimental effect used the Brooks running shoe with and without the customized pre-fitted orthotic intervention, rather than their normal athletic shoe.

The results are consistent with the effects of shoe material characteristics of increasing midsole longitudinal bending stiffness and subject-specific preferences for either elastic or viscous heel properties[4;5]. Heel cushioning with the orthotic intervention was perceived as more comfortable by all of the subjects than their normal athletic footwear; whereas, the inherent characteristics of the orthotic intervention may be assumed to have increased midsole longitudinal bending stiffness. Mechanisms by which shoe material characteristics improve neuromuscular efficiency remain to be elucidated[4;5].

The other limitation was that the test-retest reliability of measuring running economy was not determined. The study did control for extrinsic factors such as time of day of testing, 24 hour pre-test diet, and workload – same VO_{2max} performance. Another confounding variable is footwear, which was the independent variable in the current investigation. Well-controlled reliability studies indicate that coefficient of variation (CV) is 2.0% for moderately trained individuals with intra-individual variations ranging between 1.5% and 5%[11]. Given that the current study manipulated footwear condition, our CVs for running economy varied between 2% for the smallest experimental effect and 15% for the largest experimental effect, and there were no testing order effects, it may be concluded that between sessions variations were consistent with well-controlled reliability studies of running economy in the literature and that intra-individual variations were a function of footwear condition.

The physical demands of the testing protocol, although more robust than steady-state runs at approximately aerobic threshold[4;5] were problematic in recruiting endurance trained individuals whose preferred footwear was the orthotic intervention and who would perform the testing protocol on multiple days to allow for the assessment of reliability. Future research will extend the experimental protocol to a walking regimen across five treadmill stages, which will allow us to determine test-retest reliability within a testing session and between testing sessions. An individual's economy-of-walking line will be the primary outcome measure with heart rate monitoring and Borg's ratings of perceived exertion being the controls for workload.

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