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A Comparison of Physiological Variables between the Elliptical Bicycle and Run Training in Experienced Runners

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All research was conducted in the Ohio University Exercise Physiology Laboratory and at the Ohio University Outdoor Track

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ABSTRACT AND KEY WORDS

A novel outdoor elliptical bicycle has been designed to elicit running-similar physiological adaptations while reducing the impact forces that commonly lead to injury. Various cross-training methods have been utilized to reduce injury risk, restore or maintain fitness, and prevent detraining. The purpose of this study was to compare 4-weeks of elliptical bicycle-only training to run-only training on maximal oxygen consumption, ventilatory threshold, respiratory compensation point, running economy, and 5,000 m time trial times. Twelve experienced runners (age, 22.33 ± 3.33 y; running experience, 9.25 ± 4.53 y) completed 4-weeks of randomly assigned elliptical bicycle or run training. Physiological and performance testing procedures were repeated, and subjects then performed a second matched 4-week training period in a cross-over design. Ventilatory threshold was significantly greater following elliptical bicycle ($p < 0.05$; 41.60 ± 6.15 ml/kg/min) and run training ($p < 0.05$; 42.33 ± 6.96 ml/kg/min) compared to the initial time point (40.17 ± 6.47 ml/kg/min). There were no significant group differences ($p > 0.05$) for these variables at any time point. In conclusion, elliptical bicycle-only training yielded similar physiological and performance maintenance or improvements compared to run-only training. These results suggest that elliptical bicycle training can be an effective cross-training method to maintain and improve certain physiological and performance variables in experienced runners over a 4-week period.

Key Words: running, injury, cross-training, performance

INTRODUCTION

Running is a highly popular mode of exercise with over 19 million race finishers in 2013 (31). Despite these numbers, runners have seen injury rates up to 79% within a one year span (37). Most commonly experienced injuries for runners are overuse injuries (13), which have been linked to the repeated ground impact forces that occur during running (14). Overuse injuries force runners to partially or fully terminate their run training (RT) (21, 38). Detraining, or the reversal of physiological adaptations and performance abilities, can consequently occur (26). Runners seek non-impact cross-training methods that have the ability to produce running-similar movements and high intensity efforts in order to prevent decrements in fitness and performance, whenever detraining is likely to occur (26, 34).

To prevent detraining from occurring, non-impact cross-training methods are often utilized in hopes of maintaining fitness and performance levels without incurring further injury. For a runner, cross-training can encompass any alternative form of exercise implemented into a runner's training program apart from running, such as cycling, swimming, or using an elliptical trainer. Cycling and swimming have been unable to elicit maximal oxygen consumption (VO_2max) values similar to treadmill running in trained runners (34, 40) or provide adequate training adaptations to maintain ventilatory threshold (VT) (15, 34). Exercise using an elliptical trainer has been shown to improve physiological variables, such as VO_2max, in previously moderate-fit, untrained populations compared to treadmill running (9). This has also been seen in recently trained runners of 4-weeks (18). However, it is suggested that the elliptical trainer might not be effective in improving physiological variables or maintaining 3,000 m time trial times in long-term trained runners (16).

Other low impact cross-training methods have been designed to imitate similar running movements in an attempt to maintain physiological and performance variables in experienced runners. In a case study, the anti-gravity treadmill training (AGT), which used treadmill running at 50-95% body weight, suggested maintenance of performance abilities following a period of injury for one collegiate distance runner (35). Deep water running (DWR) was also performed in the athlete's training which may have contributed to the observed results. DWR has been seen to elicit similar muscle activity in deep water (22) compared to running. However, VO_2max, heart rate (HR), and ventilation (VE) values during DWR have been unable to reach levels seen during treadmill running in trained runners (8, 33). The oxygen consumption (VO_2) and HR at a runner's VT were also observed to be greater during treadmill running compared to DWR (12). Over a 6-week training period, DWR has been shown to maintain VO_2max, VT, running economy (RE), and run performance in trained male runners (38). Exercise with an outdoor, running-similar, low impact, and physiologically similar cross-training machine is ultimately desired.

The elliptical bicycle (EBIKE) is a new modality of non-impact cross-training which has been developed for runners to imitate outdoor running. The previously unresearched EBIKE is marketed as a non-impact and running-similar exercise modality (28). The EBIKE was engineered as a hybrid between an elliptical trainer and a bicycle with modifications intended to emulate the running motion in hopes of eliciting running-similar training adaptations. The EBIKE has four adjustable stride lengths, from 41 to 64 cm, which are similar or greater in length compared to various models of the stationary elliptical trainer (3, 28). Handlebar heights on the EBIKE also adjust from 127-147 cm to best fit a rider's height in order to imitate their preferred running body position. Another major difference between these modalities is the EBIKE includes a steeper pedal angle during the recovery phase that positions a riders' toe downward. This modification is designed to allow the rider's leg to recover from the most posterior position and travel into the most anterior knee drive position in a running-similar fashion. This is designed to facilitate greater knee flexion and ankle plantarflexion movements. Secondly, the absence of a fly wheel on the EBIKE prevents momentum from assisting the rider in propulsion of the EBIKE. Foot contact with foot pedals occurs at all times and riding can occur outdoors, as opposed to DWR or AGT. Proper EBIKE balance and steering are also necessary for riding, which aims to recruit weight-bearing stability musculature similar to those muscles used when running.

To date, the training effects of the EBIKE compared to running on physiological and performance variables have yet to be studied. This information would be of great importance and interest for injured runners who are unable to run and also for healthy runners who aim to attenuate losses in physiological and performance factors during scheduled non-running periods of recovery. The purpose of this study was to compare VO_2max, VT, respiratory compensation point (RCP), RE, and 5,000 m time trial (TT) times between 4-weeks of EBIKE-only and run-only training. It was hypothesized that these variables would not be different between groups.

METHODS

Experimental Approach to the Problem

In order to compare ET to RT, a randomized, cross-over, training study design using matched 4-week exercise training periods of ET and RT in experienced runners was implemented. Four-week training periods were chosen to reflect a length of time when detraining can occur for experienced runners (4, 26). VO_2max, VT, RE, RCP, and TT times were the measured variables at each testing point and were selected due to their high importance as fitness markers and predictors of running performance (24). The TT was used as a definite measure of running performance (27). Exercise training periods of either ET or RT were matched for frequency, duration, and relative intensity. Intensity was measured by use of HR zones, which included easy (HR range = HR below VT), medium (HR range = HR above VT to HR at RCP), and hard (HR range = HR above RCP to HRmax) as determined from each subjects's VO_2max test. Prescribed percentages of exercise training in these zones were 80%, 15%, and 5% for easy, medium, and hard, respectively, in accordance with typically prescribed, evidence based running programs that aim to improve aforementioned physiological and performance variables (10, 32).

Subjects

This study included twelve (N = 12) subjects including six males (n = 6) and six females (n = 6), ages 19-31 (average 22.33 ± 3.33 y). Subjects were healthy and experienced runners with an average Body Mass Index (BMI) of 21.54 ± 2.29, body fat percentage (BF%) of 10.68 ± 4.79 %, and running experience of 9.25 ± 4.53 y. Subjects averaged 4.46 ± 1.09 total runs per week (runs/wk) with an average of 37.74 ± 11.04 km/wk, and 2.17 ± 1.37 high intensity runs/wk in the 2 months before volunteering for this study. Table 1 displays subject characteristics and training history. A power analysis was conducted to calculate the proper sample size for this study using G*Power 3.1.2 (Germany). Using a power of 0.80 and α of 0.05, with an effect size of 0.20, the required number of subjects was 12 for significance. Smokers and those with diseases or injuries that limited their ability to perform vigorous exercise were excluded. Subjects were excluded if they had any orthopedic injuries in the 3 months prior to this study that prohibited them from running for more than 6 consecutive weeks during that time frame. No subjects had any previous EBIKE experience prior to this study. Previous recreational bicycling, elliptical riding, or swimming activities were reported by a total of seven subjects at a frequency of four or less times per month. This study was approved by the Institutional Review Board for Human Subjects. All subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Place Table 1 about here.

Exclusionary conditions included heart disease, pulmonary, metabolic, or other conditions that could influence the inflammation response, including Crohn's disease, severe arthritis, cancer, or a previous heart attack. Subjects that were pregnant were excluded from this study. Blood pressure equal to or greater than 140 mmHg systolic and 90 mmHg diastolic was considered high blood pressure (36) and warranted exclusion from this study. Those on blood pressure medications were also excluded from this study. Additionally, a subjects' BMI and BF% were used as methods for determining a healthy subject. Subjects were required to have a BF% within the 50^{th}-99^{th} percentile for their respective gender and age group (36). Subjects were included if their VO_2max values were equal to or greater than the 90^{th} percentile values for their gender and age group (36). Average VO_2max values were 57.92 ± 9.68 ml/kg/min.

Procedures

Physiological and performance assessments were completed over two testing sessions. Subjects were asked to avoid vigorous exercise and alcohol consumption 24 hours prior to these testing sessions as well as caffeine and food intake 3 hours before each testing session. Each subject underwent inclusionary and physiological assessments during an initial testing session, including a health history questionnaire (HHQ) and running history questionnaire (RHQ). Resting HR was measured using a HR monitor (Polar, Lake Success, NY) and was determined as the lowest HR seen after the subject rested in a seated position for 5 min. BP was determined using a sphygmomanometer and an appropriately sized BP cuff. Height was measured using a stadiometer and was measured to the nearest tenth of a centimeter. Weight was measured using an electronic scale in kilograms. Next, in the controlled exercise physiology laboratory, a body composition measurement was performed using Lange skin fold calipers (Beta Technology, Ann Arbor, MI) (30, 36). Body composition, via BF% measurement, was performed using a 7-site measurement protocol and included skin fold sites at the chest, triceps, subscapular, abdominals, thigh, and suprailliac. The same trained researcher performed this protocol on each subject throughout the study. BF% was calculated using a gender specific calculation (36).

During the same testing session, a graded VO_2max treadmill test (GXT), using a motorized treadmill (TMX-425, Full Vision Inc., Newton, KS) and calibrated metabolic cart (Truemax 2400 Metabolic Measurement System, ParvoMedics, Sandy, UT), was used to determine VO_2max, VT, RE, and RCP. Following a 5 min warm up period on the treadmill, subjects were fitted for headgear, a mouthpiece, and nose clip. All subjects were given instructions on the use of the 15-point (6-20) Rating of Perceived Exertion (RPE) scale (2). Subjects were also instructed to provide a maximal effort during this test and to straddle the sides of the treadmill when they decided to stop. The first and second stages were set at speeds of 2.68 m/s and 3.13 m/s, respectively, and a 1% incline. These treadmill speeds were chosen in order to ensure a steady state was reached below a subject's VT. Without knowledge of each subject's VT prior to the first GXT, two conservative speeds were chosen to ensure these steady state measurements could be taken. Each subject displayed VT measurements at speeds above these first two stages. The first two stages were 3 min in duration in order to ensure steady state values were obtained for calculation of RE. A subject's RE was defined as the milliliters of oxygen ventilated per kilogram of body weight for one kilometer (ml/kg/km) at a given running velocity. This measurement was averaged over the last 1 min of these 3 min stages after a steady state had been achieved. The remaining stages were 1 min in duration and individualized for each subject. These stages were gradually increased each stage no greater than 0.45 m/s and 2% incline until volitional exhaustion occurred. HR was monitored at all times and recorded every 30 s.

At the cessation of the GXT, the fitted headgear, mouthpiece, and nose clip were then removed, and subjects remained seated until a finger prick blood sample was taken. This sample was used to measure blood lactate concentration 5 min following the cessation of the treadmill test. Subjects were then able to perform a walking or running cool down. Immediately following the GXT, the subjects' RPE was recorded for the whole, upper, and lower body (2). A valid VO_2max test occurred when three out of the following five criteria were met: a plateau in VO_2 or increase less than or equal to 0.15 L/min with an increase in intensity, a respiratory exchange ratio (RER) > 1.1 or greater, a maximal HR within 10 bpm of predicted maximal HR, a blood lactate concentration ≥ 8 mmol/L, and an RPE of 18 or greater (17). Maximal heart rate was determined using the equation: 220-Age (23). At least 3 of the 5 criteria were met for all subjects and enabled researchers to record the VO_2max as the highest 30 s VO_2 measurement before volitional exhaustion and stoppage of the GXT occurred (20).

VT was determined following the GXT via the pattern recognition method as described in previous research (29). This method was accomplished by confirming several identifiers. The first identifier was observed where the workload or time point when Forced Expired Oxygen (FEO_2) values increased following a plateau period. Secondly, the FEO_2 increase was aligned with the workload when the ratio of VE/VO_2 increased without a subsequent increase in VE over ventilated carbon dioxide (VE/VCO_2) (5). A drastic increase in VE was also used to confirm that this workload was a true VT. RCP was determined as the second increase in VE and rise VE/VO_2 without an increase in VE/VCO_2 (29). One experienced researcher determined VT and RCP, and both were confirmed by another blinded, experienced researcher.

The TT took place on an outdoor standardized 400 m running track at least 24 but no more than 48 hours following the GXT. Subjects were given 10 min to perform a warm up and then were instructed to complete the 5,000 m distance in the fastest time possible. Times were recorded with a standard stopwatch (Accusplit AX602M500, West Warwick, RI). The RPE for a subject's whole, upper, and lower body were recorded immediately after the finish of the TT. A finger prick blood sample was taken 5 min after the subject completed the time trial, and procedures were identical to blood lactate sampling as described following the GXT.

After another 24-48 hour period, subjects were then randomly assigned to either ET or RT and provided all needed equipment including a HR watch (Garmin Forerunner 310XT, Olathe, KS), chest strap, and charger (Garmin, Olathe, KS). An EBIKE (ELLIPTIGO INC., Solana Beach, CA) was loaned to each subject for the ET period. A bicycle helmet was loaned to the subject, if needed. A training notebook was also provided which included all subjective measurements and training schedules. Each training period included 20 prescribed exercise sessions between 30 and 60 min in duration. Exercise training sessions were 30, 40, 42 and 60 min in duration for easy, medium, hard, and long sessions, respectively. The exercise training zone prescriptions, easy (HR range = HR below VT), medium (HR range = HR above VT to HR at RCP), and hard (HR range = HR above RCP to HRmax), for both training groups was based on each subject's HR achieved at VT, RCP, and maximal effort time points during the VO_2max test (10). Previous research (7) has shown HRmax to be similar between the treadmill and the elliptical. Prescribed percentages of exercise training in these zones were 80%, 15%, and 5% for easy, medium, and hard, respectively. These percentages reflect previously prescribed run training programs with the goal of improving physiological and performance variables measured in this study (10, 32).

Easy training sessions included 30 min at an easy intensity. The medium training session included 10 min at an easy intensity for a warm up, 20 min at a medium intensity, and then 10 min at an easy intensity for a cool down. The hard session involved similar warm up and cool down to the medium session but included 1 min hard intervals repeated eight times with 2 min of easy intensity exercise in between intervals. The long training session entailed 50 min at an easy intensity with an additional 10 min of medium intensity exercise to complete the session. Five training sessions were performed each week for the four week training period. All previously described exercise sessions were continuous and were performed once per week, except the easy sessions, which were completed twice per week.

A total of seven testing sessions were completed by each subject for this study including a familiarization session preceding ET. During the familiarization session each subject ensured he or she could safely and properly ride the EBIKE. Also at this time, handlebar height and stride length specifications were made to replicate the subject's preferred running position. Instructions were given to wear a helmet at all times while riding the EBIKE and to not cease leg movement at any time, while training. Subjects were also asked to refrain from any other exercise apart from the prescribed exercise program. Twenty-four to forty-eight hours following the completion of the final exercise session of the first 4-week training period, subjects returned to the laboratory for identical testing procedures to the initial session. Subjects were not required to complete additional HHQ and RHQ. A second training period, in a cross-over design, was then completed. Subjects that first completed the ET now began the RT and vice versa. Twenty-four to forty-eight hours following the second training period, subjects concluded their participation by performing a third testing session, identical to the previous two. Subjects were asked to be well hydrated and to not change their nutritional habits throughout the study and to consistently replicate their dietary intake prior to each testing session. Throughout the training period, subjects were contacted via email, telephone, or verbally in order to ensure adherence to the prescribed training program.

Statistical Analyses

A power analysis was conducted to calculate the proper sample size for this study using G*Power 3.1.2 (Germany). Using a power of 0.80 and α of 0.05, with an effect size of 0.20, the required number of subjects was 12 for significance. Predictive Analysis Software (PASW Inc., Chicago, IL) was used to analyze and report means and standard deviations (SD) for each variable. A randomized, cross-over design was chosen for this study. A 2 x 3 factorial repeated measures analysis of variance (RM-ANOVA) was used to determine if an order effect was present by comparing relative VT at 0, 4, and 8 week time points, regardless of training modality. A RM-ANOVA (within-ANOVA) test was used to compare VO_2max, VT, RCP, RE, and TT times across the three testing time points: initial, post-EBIKE, and post-run. Percent change values were computed and paired *t*-tests were used to compare these values. The significance level was set at alpha $\alpha \leq 0.05$. A Fisher's least significance difference (LSD) post hoc test was used to further analyze the significance between parametric variables (VO_2max, VT, RCP, RE, and TT). A Bonferroni correction factor of $p \leq 0.0125$ was used for paired *t*-test comparisons between ET and RT groups for the four heart rate intensities. Finally, training details, including exercise session frequency, duration, intensity, and total time, were compared between training modalities using paired *t*-tests.

RESULTS

The 2 (mode) x 3 (time) factorial RM-ANOVA performed to assess an order effect did not demonstrate a significant interaction ($p = 0.458$) or main effect ($p = 0.435$) for relative VT. However, there was a significant main effect for time ($p = 0.034$). A post-hoc analysis showed a significant difference between the initial time point and 4-weeks of training ($p = 0.025$), and the initial time point and 8 weeks of training ($p = 0.034$), regardless of what training modality was performed first. Since no order effect was determined, analyses proceeded without concern for which training modality was performed first. A RM-ANOVA was performed for all the descriptive variables (age, resting HR, resting BP, height, weight, BMI, and BF%). There were no significant differences ($p > 0.05$) for any of these variables over time. Paired *t*-tests were used to determine if the total training time or total number of training sessions differed between ET and RT. The average total time per session was not significantly different (41:03 min for ET versus 41:33 min for RT, $p = 0.658$), and the average number of training sessions was not significantly different (19.92 versus 19.50, respectively, $p = 0.210$).

Table 2 displays the physiological and performance variables at each time point. A RM-ANOVA displayed no statistically significant differences among time points for all physiological and performance variables (VO_2max, VT, RCP, RE, and TT times) except relative ($p = 0.024$) and absolute ($p = 0.010$) VT. A post hoc analysis revealed a significant difference between the relative VT values at the initial 40.17 ± 6.47 and post-ET 42.33 ± 6.96 ($p = 0.024$) and between the initial and post-run 41.60 ± 6.15 ($p = 0.035$) time points, but no significant difference between the modalities ($p > 0.05$). This was also seen for absolute VT values between the initial 2.54 ± 0.78 and post-EBIKE 2.68 ± 0.78 ($p = 0.020$) and initial and post-run 2.66 ± 0.80 ($p = 0.009$).

Place Table 2 about here.

The percent change between initial testing and each training modality was also evaluated using paired *t*-tests to better examine the degree of change in VO_2max, VT, RCP, RE and TT times. The only significant differences found were between the percent change values for RE and also TT times. RE improved by a significant amount post-run (-1.87 ± 5.06 %) as compared to post-EBIKE (0.86 ± 3.58 %) ($p = 0.027$). Also, TT times significantly improved post-run (-2.67 ± 2.95 %) as compared to post-EBIKE (-0.04 ± 4.31 %) ($p = 0.022$).

A 2 x 4 factorial RM-ANOVA was performed to determine if average maximal HRs for easy, medium, hard, and long intensity sessions differed between training modalities. Actual maximal intensities did display a significant interaction ($p = 0.015$) between ET and RT groups and a significant main effect ($p = 0.001$) among exercise intensities. A Bonferroni correction factor of $p \leq 0.0125$ was calculated for paired *t*-test comparisons between ET and RT groups for the four exercise intensities. For actual maximal HRs, only the easy intensity session was significantly different ($p = 0.011$) between modalities with the ET averaging 162.35 ± 12.30 bpm and the RT averaging 168.07 ± 10.29 bpm.

DISCUSSION

This study investigated the physiological responses to a 4-week training program using an EBIKE compared to a matched RT program in experienced runners. Inherent in the study design was analyzing the effectiveness of the EBIKE to maintain or improve cardiorespiratory fitness in experienced runners. Four weeks is a period of time that has been seen to produce short term detraining effects and has been used in previous cross-training research (4, 26). An analysis of measured physiological variables at 0, 4, and 8 weeks showed there was no order effect seen in this randomized, cross-over design study.

The results of this study support the hypothesis that there are no significant differences between ET and RT for VO_2max, VT, RCP, RE, and TT over a 4-week training period in experienced runners. Results indicate that both training modalities were effective in increasing VT and maintaining all other physiological and performance variables when compared to initial values. This was expected since researchers designed the training program to increase these physiological and performance variables in experienced runners over a 4-week training period based on previous research (25). The prescribed training intensities included 80% below VT levels, 15% of exercise within a range between VT and RCP, and 5% high intensity exercise above RCP. This training is representative of the exercise training an experienced endurance runner participates in (10, 32). This result was not hypothesized, but demonstrates that the novel EBIKE is an effective means for increasing VT with this training program.

These outcomes agree with previous research that have used similar training protocols to elicit physiological changes (25, 32) with elliptical exercise. This was also observed in a study researching the effects of a 3-week elliptical training period on recently trained runners (18). However, subjects were only recently trained runners with an experience level of 4-weeks. In contrast, this present study used experienced runners with an average of 9.25 ± 4.53 y running experience. Egana & Donne (9) observed maintenance of VO_2max and maximal ventilation using an elliptical trainer. In that study, only moderately trained non-runners were used, and testing was performed on a cycle ergometer and not on a treadmill. In this current study, a treadmill was used for GXTs and runners had an average VO_2max of 57.92 ± 9.68 ml/kg/min similar to previous research with experienced runners (1, 38).

Beyond VO_2max, no significant differences were observed for RE among the initial, post-EBIKE, or post-run time points at speeds of 2.68 m/s and 3.13 m/s. A possible trend (p = 0.063, η^2 = 0.222) was proposed for RE in that RE displayed a slight improvement, or lower VO_2 value, at 3.13 m/s following the RT period and only maintenance of RE following the ET period. RE has been found to be highly dependent on the neuromuscular capacity of a runner (27). This neuromuscular component of RE has been related to the ability to produce force or impact into the ground to propel oneself upwards and forward. The EBIKE might be limited in this capacity due to the non-impact, closed chain design that elliptical and EBIKE machines have compared to running. It is suggested that this difference in impact between elliptical exercise and running produces differences in muscular work required for riding the EBIKE and running (11). More research is needed to fully gauge the physiological efficacy of the EBIKE over longer periods of time compared to other cross-training modalities. Additionally, the length of 4-weeks might not have been long enough to see significant decreases in measured variables in some subjects.

The average TT time was 1303.00 ± 210.05 s, 1303.17 ± 224.13 s, and 1269.00 ± 188.62 s at the initial, post-ET, and post-RT time points, respectively. Researchers noted a possible practical improvement ($p = 0.051$, $\eta^2 = 0.237$) in TT times following 4-weeks of RT. On average runners were 34 s faster following RT. It is suggested that this improved performance is linked to the difference observed in impact forces during RT via improvements in RE. Subjects might have also been able to pace themselves during the TT having had knowledge throughout the RT period of their training paces and running distances.

Research investigating the stationary elliptical trainer has provided similar results. Over a 5-week period of elliptical training, trained high school runners were unable to maintain 3,000 m run performance when compared to run training (16). The elliptical trainer group became on average 47.70 ± 11.30 s slower and the run group became 9.40 ± 8.30 s faster. Honea (16) did not see any differences in VO_2max, similar to this study, or VT. The ET in this EBIKE study did not show the TT performance decrement seen by Honea post elliptical training, and that may be due to the differences in design between the EBIKE and the elliptical. The elliptical trainer has been seen to produce vertical pedal reaction forces similar to walking, below 100% body weight (6), and lower average percentage body weight values compared to running (19). This further suggests a difference in neuromuscular and muscular work between running and non-impact elliptical motion exercise. It is postulated that the EBIKE could allow for an increased training volume without an increase in injury risk due to its non-impact nature. Future studies should investigate increased training volume using an EBIKE, separate or with run training.

In the current study, the changes in 5,000 m TT performance from initial testing were similar between EBIKE and RT. However, Honea (16) showed decrements in 3,000 m TT performance following stationary elliptical training compared to running in trained high school cross country runners. In both the current study and the study of Honea (16), easy, medium, and hard intensity sessions with similar number of sessions per week (i.e. 5 to 6) and similar ranges of session duration (i.e. 30 to 70 min) were used. The findings from both studies suggest that the EBIKE might be better at maintaining endurance running performance compared to stationary elliptical training in experienced runners.

Possible reasons for these improvements could be related to the running-similar recovery foot motion, lack of a fly wheel, and increased instability when riding the EBIKE compared to a stationary elliptical. The need to balance the EBIKE while riding may lead to increased recruitment of stabilizer muscles as compared to the stationary elliptical. The necessity to support one’s weight, balance, and steer the EBIKE over ground, while in motion, could produce increased physiological demand as compared to running at a similar intensity. More research is needed to determine the impact of instability on the metabolic demands when riding the EBIKE.

Additional research should also investigate important physiological, performance, and subjective variables such as running economy, 5,000 m performance, and muscle soreness in the weeks following a period of ET when RT is reintroduced into one's training program, in order to examine the effects of ET during the "return to run" training period. In summary, ET was not significantly different than RT for VO_2max, RCP, RE, and TT times following 4-weeks of matched exercise training. An increase in VT was observed following either training period. Despite these findings, there were practical differences in the TT times and RE between training modalities.

PRACTICAL APPLICATION

The results of this study suggest the use of the EBIKE as an effective cross-training method for experienced runners to maintain aerobic fitness and 5,000 m performance over a 4-week period. EBIKE-only training yielded similar physiological and performance maintenance or improvements compared to run-only training. The EBIKE not only is a non-impact modality, but also is a training modality that can elicit similar physiological and performance improvements to run training. This has special implication for coaches and clinicians aiming to improve physiological and performance variables in experienced runners without incurring an injury, in injured runners going through an injury recovery period, and the running population at large. Healthy runners wishing to recover from high impact run training could utilize the EBIKE to maintain or possibly improve fitness during cross-training periods.

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TABLE 1. Subject Characteristics and Training History (mean ± SD)

	Both (N = 12)	Males (n = 6)	Females (n = 6)
Age (y)	22.83 ± 3.33	23.00 ± 4.29	22.67 ± 2.42
Body Mass Index	21.54 ± 2.29	21.65 ± 2.50	20.38 ± 1.60
Body Fat (%)	10.68 ± 4.79	6.50 ± 1.25	14.85 ± 2.67
VO_2max (ml/kg/min)	57.92 ± 9.68	64.17 ± 10.20	51.67 ± 2.86
Running Experience (y)	9.25 ± 4.73	10.17 ± 5.74	8.33 ± 3.78
Average weekly runs (runs/wk)	4.46 ± 1.09	5.00 ± 1.05	3.92 ± 1.02
Average weekly total distance (km/wk)	37.74 ± 11.04	45.54 ± 18.25	28.32 ± 15.71
Average high intensity (runs/wk)	2.17 ± 1.37	2.75 ± 1.86	1.58 ± 0.49

TABLE 2: Physiological and performance variables at initial, post-ET, and post-RT testing (mean ± SD)

	INITIAL		POST EBIKE		POST RUN	
	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD
VO_2max						
	(ml/kg/min)	(L/min)	(ml/kg/min)	(L/min)	(ml/kg/min)	(L/min)
Group 1	56.73 ± 11.97	3.30 ± 1.12	57.09 ± 11.05	3.33 ± 1.03	57.62 ± 10.31	3.38 ± 1.04
Group 2	59.58 ± 6.07	4.17 ± 0.99	61.41 ± 8.15	4.33 ± 1.17	60.96 ± 8.87	4.32 ± 1.21
Total	57.92 ± 9.68	3.66 ± 1.11	58.89 ± 9.78	3.75 ± 1.16	59.01 ± 9.46	3.77 ± 1.17
Ventilatory Threshold						
	(ml/kg/min)	(L/min)	(ml/kg/min)	(L/min)	(ml/kg/min)	(L/min)
Group 1	39.20 ± 8.12	2.28 ± 0.76	40.88 ± 8.12	2.38 ± 0.74	40.16 ± 7.16	2.36 ± 0.74
Group 2	41.52 ± 3.48	2.91 ± 0.73	44.35 ± 5.04	3.10 ± 0.70	43.61 ± 4.30	3.07 ± 0.75
Total	40.17 ± 6.47	2.54 ± 0.78	42.33 ± 6.96*	2.68 ± 0.78*	41.60 ± 6.15*	2.66 ± 0.80*
Respiratory Compensation Point						
	(ml/kg/min)	(L/min)	(ml/kg/min)	(L/min)	(ml/kg/min)	(L/min)
Group 1	50.99 ± 11.77	2.98 ± 1.06	50.67 ± 11.19	2.96 ± 0.99	50.52 ± 10.60	2.97 ± 1.00
Group 2	52.21 ± 6.21	3.65 ± 0.88	55.81 ± 5.70	3.92 ± 0.97	54.79 ± 8.39	3.89 ± 1.13
Total	51.50 ± 9.49	3.25 ± 1.01	52.81 ± 9.33	3.36 ± 1.06	52.30 ± 9.58	3.35 ± 1.11
Running Economy						
	(2.68 m/s) (ml/kg/km)	(3.13 m/s) (ml/kg/km)	(2.68 m/s) (ml/kg/km)	(3.13 m/s) (ml/kg/km)	(2.68 m/s) (ml/kg/km)	(3.13 m/s) (ml/kg/km)
Group 1	211.30 ± 14.48	210.24 ± 9.92	211.36 ± 12.87	211.93 ± 6.60**	208.26 ± 12.07	203.28 ± 7.06**
Group 2	195.42 ± 18.36	191.42 ± 19.11	191.15 ± 13.50	192.46 ± 15.00	189.53 ± 13.37	190.54 ± 10.62
Total	204.69 ± 17.43	202.40 ± 16.74	202.94 ± 16.28	203.82 ± 14.36	200.46 ± 15.41	197.98 ± 10.55
5,000 m Time Trial Time						
	(s)		(s)		(s)	
Group 1	1360.14 ± 210.98		1374.71 ± 233.81		1329.57 ± 195.20	
Group 2	1223.00 ± 202.16		1184.20 ± 158.98		1203.00 ± 186.12	
Total	1303.00 ± 210.05		1303.17 ± 224.13		1269.00 ± 188.62	

Note. * Indicates a significant increase ($p \leq 0.05$) compared with the initial time point. ** Indicates a significant difference between time points.
Group 1 (n = 7) – ET training period first, RT training period second
Group 2 (n = 5) – RT training period first, ET training period second
Total (N = 12) – Combined Group 1 and Group 2