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Measurement of Exchanging Oxygen and Carbon Dioxide and Subsequent Use of Respiratory Exchange Ratio During Exercise do not Mimic Macronutrient Contribution to Overall Energy Expenditure: Cross-Sectional Study

Egzersiz Esnasındaki Oksijen-Karbondioksit Değişiminin ve Solunum Değişim Oranının Ölçülmesi Makro-Besin Ögelerinin Toplam Enerji Tüketimine Katkısını Yansıtmamaktadır: Kesitsel Çalışma

Uğur CAN[a], Nasuh Evrim ACAR[b], Yağmur ARINLI[c]

[a]Mersin University Institute of Education Sciences, Mersin, TURKEY
[b]Mersin University Faculty of Sports Science, Mersin, TURKEY
[c]Mersin University State Conservatory, Mersin, TURKEY

ABSTRACT Objective: Physical exercise and neuromuscular characteristics are essential modulators of total energy expenditure (TEE), and oxygen and carbon dioxide gas exchange measurements and subsequent use of the respiratory exchange ratio do not fully mirror macronutrient contribution to TEE. The rationales of the study were to compare oxidative, anaerobic glycolytic, excess post-exercise oxygen consumption (EPOC), and TEE between equivalent bouts of uphill treadmill running and non-steady-state cycling using an alternative method, and to determine the relative contribution of lower extremity muscles on TEE. **Material and Methods:** Twenty male participants completed cardiorespiratory and isokinetic measurements over a one-week interval. Anaerobic energy expenditure was estimated from blood lactate. **Results:** Perceived exertion for cycling was greater than running (p=0.005). However, respiratory exchange ratio (p=0.005), heart rate (p=0.005), EPOC (p=0.001), oxidative energy expenditure (p=0.001) and TEE (p=0.001) were greater for uphill running compared to cycling. **Conclusion:** Due to the variations in the metabolic components, i.e., oxidative, EPOC, total energy expenditure calculated using the equations to equate work output between non-steady cycling and uphill running revealed discrepancies. Additionally, this study also revealed that compared to knee extensor and flexor muscles, hip muscles had a greater contribution to overall energy expenditure during cycling and uphill treadmill running which also enabled the participants to generate less energy cost. Per the results of the current study, it would be more accurate to use the anaerobic glycolytic energy expenditure data rather than oxygen only measures in the assessment of energy expenditure between these equivalent exercise modalities.

Keywords: Energy expenditure; oxygen consumption; blood lactate; excess post-exercise oxygen consumption; training load

ÖZET Amaç: Fiziksel egzersiz ve nöromusküler özellikler, toplam enerji tüketiminin (TET) temel modülatörleridir ve oksijen-karbondioksit değişiminin ölçülmesi ve ardından belirlenen solunum değişim oranının kullanılması, makro besinlerin TET'e olan katkısını tam olarak yansıtmamaktadır. Bu çalışmanın amacı, iş yükleri eşitleştirilmiş, hızı ve eğimi kademeli olarak artış gösteren bir koşu bandı ve bisiklet test protokolü esnasında oluşan oksidatif, anaerobik glikolitik, egzersiz sonrası artan oksijen tüketimi [excess post-exercise oxygen consumption (EPOC)] ve TET değerlerinin alternatif bir yöntem kullanarak karşılaştırılması ve alt ekstremite kaslarının TET'e olan katkısını belirlemektir. **Gereç ve Yöntemler:** Yirmi erkek katılımcı birer hafta arayla kardiyorespiratuar ve izokinetik ölçümlere tabi tutuldu. Anaerobik enerji harcaması kan laktatı ölçümüyle belirlendi. **Bulgular:** Bisiklet testi esnasındaki algılanan zorluk derecesi düzeyi, koşu protokolüne göre daha yüksek bulundu (p=0,005). Ancak koşu protokolü esnasındaki solunum değişim oranı (p=0,005), kalp atış hızı (p=0,005), EPOC (p=0,001), oksidatif enerji tüketimi (p=0,001) ve TET (p=0,001) yokuş bisiklet testine göre daha yüksek bulundu. **Sonuç:** Metabolik bileşenlerdeki varyasyonlar, yani oksidatif, EPOC, sabit olmayan döngü ve yokuş yukarı koşu arasındaki iş çıktısını eşitlemek için denklemler kullanılarak hesaplanan toplam enerji harcaması tutarsızlıkları ortaya çıkardı. Ek olarak bu çalışma, ayrıca diz ekstansör ve fleksör kaslarıyla karşılaştırıldığında, kalça kaslarının bisiklet ve eğimli koşu bandı testi sırasında toplam enerji harcamasına daha fazla katkı sağladığını ve bunun da katılımcıların daha az enerji maliyeti üretmesini sağladığını ortaya koydu. Mevcut çalışmanın sonuçlarına göre bu eş değer egzersiz modaliteleri arasındaki enerji harcamasının değerlendirilmesinde, sadece oksijen ölçümlerinden ziyade anaerobik glikolitik enerji harcama verilerinin kullanılması daha doğru olacaktır.

Anahtar Kelimeler: Enerji harcaması; oksijen tüketimi; kan laktat; egzersiz sonrası artan oksijen tüketimi; egzersiz şiddeti

Correspondence: Nasuh Evrim ACAR
Mersin University Faculty of Sports Science, Mersin, TURKEY/TÜRKİYE
E-mail: nasuhacar@mersin.edu.tr

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During physical activities such as cycling and running, exercising muscles require energy to function and increase the demand for the total energetic cost both in an acute and chronic manner.[1] Numerous interventions to date have been developed for the quantification of energy expenditure with different levels of precision including the measurements of heart rate (HR) and oxygen uptake since these two determinants have a strong relationship during these testing modalities. However, during these research modalities, the relationship between the energy consumption and HR is linear only within a small range of just about 90-150 beats.[2] In addition, measurements of carbon dioxide (CO_2) and oxygen (O_2) gas exchange and following use of the respiratory exchange ratio (RER) during both cycling and running efficiency have shown that the contribution of essential nutrients to total energy expenditure (TEE) is underestimated.[3] Additionally, although aerobic energy metabolism constitutes the greatest part of cycling and running performance due to the predominant activation of the lower extremity muscles, the disparity between their patterns of muscle mobilization facilitates various anaerobic and aerobic contributions to total energy consumption for exercise.[4] Physiological factors, such as motor unit recruitment patterns during maximal and submaximal intensities, relative adjustment of cardiac output to maximum oxygen consumption (VO_{2max}), muscle mass recruitment in conjunction with oxidative capacity, central fatigue, and reduction of maximum strength in addition to HR and oxygen consumption have been reported to affect cycling and running energy expenditure.[5]

Excess post-exercise oxygen consumption (EPOC), which is used to determine the rate of oxygen intake following strenuous activity, is defined as the disturbance of the body's homeostasis related to exercise. After a prolonged or brief bout of exercise, EPOC can be divided into two stages: 1) rapid phase EPOC (within the first minutes of exercise completion) and 2) prolonged EPOC-lasting multiple hours after exercise.[6] During the rapid phase following an exercise, increases in VO_{2max} promote to increase energy expenditure and EPOC serves to restore homeostasis at this stage. However, EPOC may not mimic the contribution of rapid glycolytic adenosine triphosphate (ATP)-resynthesis during intense exercise.[7] However, the magnitude of EPOC not only relies on increased O_2 uptake, but the intensity of the exercise is also a major component, which is followed by the duration of exercise, but to a lesser extent.[8] Thus, the higher the intensity of exercise the more disrupts our homeostasis, and exercise intensity is suggested to be the main contributor to EPOC. However, energy expenditure could not be accurately determined using oxygen only measures since performance information during the brief report would have the potential to underestimate real energy expenditure. We hypothesized that due to the repeated and rhythmic recruitment patterns of hip and knee muscles during cycling and running, the metabolic energy systems are contributing a short bout of cycling and running uphill at equivalent power outputs would reveal similar results, and the muscle strength balance between these muscle groups would also affect TEE. Due to the inconsistent evaluation of energy expenditure using oxygen only measures the current study aimed: (a) to compare the interactions of skeletal muscle metabolic energy systems during a short bout of cycling and running uphill at equivalent power outputs using an alternative method to evaluate energy expenditure and, (b) to verify the relationships of lower extremity muscle characteristics on these interactions during these testing modalities.

MATERIAL AND METHODS

STUDY PARTICIPANTS

Twenty healthy male participants (volunteers) between the ages of 18 to 26 (21.20±2.17) years old who maintain regular physical activity and enroll in the physical education and sports department were recruited for this study. The anthropometric parameters of participants were (height: 176.35±5.28 cm, weight: 75.99±8.05 kg, lean body mass: 65.35±4.81 kg, fat mass: 14.04±4.93 %), respectively. Prior to participating in the study approved by the Mersin University Institutional Review Board, all participants issued written informed consent in accordance with the ethical requirements of the Helsinki Declaration (Protocol number: 78017789/050.01.04; 2017/92, date of approval: 04.13.2017).

INSTRUMENTATION AND PROCEDURES

Participants were told about equipment prior to all study sessions and familiarized with the experimental procedures. Using bioelectric impedance analysis (Japan, 418-MA Tanita) before isokinetic strength, cycling, and uphill treadmill running test sessions, anthropometric parameters (body fat mass, lean body weight, weight) were evaluated. With a stadiometer, height was measured in the standing position (U.K., Holtain Ltd.).

ASSESSMENT OF MAXIMUM OXYGEN CONSUMPTION PARAMETERS USING CYCLE ERGOMETER AND TREADMİLL

All participants performed incremental treadmill and cycling tests over a one-week interval with two separate visits to the laboratory. In the oxygen kinetics evaluation, the participants randomly performed two maximum exercise measures on different days for fatigue. A standard Bruce protocol to volitional exhaustion (CareFusion MasterScreen™ CPX, Germany) was used to determine VO_{2max} of each participant using a treadmill. This test was also adapted to determine VO_{2max} during cycling using an Ergoline Ergoselect 100/200 cycle ergometer. The test started with a load of 50 Watts and then continued with a load of 50 Watts increasing every 2 minutes. Upon completing 250 Watts, the load was increased by 25 Watts at every 2-minutes for all participants. Exchange of gas was measured at 10-second exemplification times during the VO_{2max} and 1 minute exercise tests using the MasterscreenTM CPX metabolic cart. Concentrations of blood lactate were determined using samples taken in duplicate from the earlobe at rest and 2 minutes after a seated recovery (Japan, Kyoto, Lactate Pro 2 LT-1730, Arkray, Inc.). It was suggested that blood lactate reached a peak concentration at 2-minutes post-exercise.[9] Also, HR was monitored and recorded using 12-lead electrocardiography during treadmill and cycling testing sessions.

ISOKINETIC MUSCLE STRENGTH ASSESSMENT

In the assessment of isokinetic knee peak moments, the participants were seated on the Humac Norm Cybex CSMI chair in an upright position. The hips and thighs of the participants were stabilized at an angle of 90° by pelvic and thigh straps during the test session prior to the isokinetic test session. They initially performed a warm-up test at 60°/s angular velocity and then accomplished five maximum stress contractions at a similar velocity to determine isokinetic peak torque strength parameters. Participants were instructed to work on all contractions as hard and as quickly as possible. The rest of the time between each contraction was 10 seconds. The hamstrings-to-quadriceps strength ratios (H*ecc*/Qcon) calculated as the peak moment of the hamstrings divided by the peak moment of the quadriceps within the same limb.

During the fourth visit to the laboratory, the participants placed supine on the isokinetic chair with the chair back fully flattened to measure isokinetic hip flexion and extension peak moment strength at an angular velocity of 60°/s. The being tested of the hip was 0° bending at 90° bending of the knee and secured to the brace. At the level of the femur, the test thigh was attached to the dynamometer pad. The untested thigh was fastened at 0° of hip flexion on the isokinetic chair. The range-of-motion restrictions were fixed starting from the hip that was neutrally extended to the hip that was maximally flexed on the table. The trunk and pelvis were strapped to the isokinetic chair to prevent undesirable movements throughout the test. Gravitational corrections were made prior to all test sessions to avoid the effect of limb weight on moment production.

ISOKINETIC FATIGUE TESTING PROTOCOL

To determine the quotient of hamstring and quadriceps muscles under fatigued conditions, the participants underwent an isokinetic fatigue testing. Participants performed 50 maximal bilateral knee flexion and extension repetitions at 180°/s angular speed to observe extension and flexion changes under fatigued conditions. The participants were asked to perform as quickly as possible and to grasp the handles at the sides of the chair throughout the warm-up and the test. The knee moment of the limbs was measured through a range of motion from 90^{o} (knee flexion) to 0^{o} (full knee extension). Gravity correction was made before isokinetic test protocol sessions. The participants underwent the same protocol for both of their legs during all isokinetic testing sessions. The percent decline from the former to the latter repetitions was calculated to determine hamstring:quadriceps (H:Q) fatigue rate during isokinetic testing was calculated as follows.[10]

(Maximum moment of the first 5 knee bends-maximum moment of the last 5 knee bends)/maximum moment of the first 5 knee bends x100.

THE ASSESSMENT OF TOTAL ENERGY EXPENDITURE

All participants were recruited in the test sessions twice on separate occasions and reported having refrained from vigorous physical activity, at least 3-hour postprandial, randomly assigned to either a short run or cycle protocol. Resting oxygen uptake was recorded for 5-minutes in standing on the treadmill or sitting mode on the bike prior to the test session. Resting energy consumption was calculated on the basis of the RER principle and was removed from all EPOC and oxygen uptake exercises.

The power generated by the participants during the bike test was calculated in watts. In the treadmill test, their vertical work, body weight, and running speed were taken into account for the estimation of power. During cycling and uphill running all participants performed a 1 minute bout of exercise at a work rate equivalent to 250 Watts following a 5 min resting oxygen uptake measurement and all participants were asked to pedal at 60 rpm along with a 1 minute bout of cycling exercise.

THE ASSESSMENT OF OXIDATIVE ENERGY METABOLISM

In the assessment of kcal consumed per liter of oxygen expended (kcal per LO_2), the RER measurements registered every minute during the periods corresponded to the table "Thermal oxygen parities about non-protein respiratory quotient" which allows the estimation of the percentage of kilocalories (kcals) derived from carbohydrate and fat.[11] The kcals cost during that minute of exercise was determined on the basis of the multiplying of Net VO_{2max} by kcals per L of O_2. During all the testing sessions, a metabolic cart was used to predict the oxidative addition to the total energy consumption. As a result, each participant was to comply with the metabolic cart to measure RER, gross VO_{2max} (L/min), and collected VO_{2max} (L/min). The exact VO_{2max}, which is the oxygen exhausted during training (i.e., oxygen exhausted over rest due to exercise), has been calculated for each minute of the protocol. Total fat and carbohydrate oxidation rates were calculated based on the "Thermal equivalents of oxygen for the nonprotein respiratory quotient" table. RER, which is a surrogate of substrate utilization, was used to determine the rate of lipid oxidation.[12]

The participants performed a run to exhaustion at a 10% stage with a pace that revealed 250 Watts and the power output during treadmill running was attempted to equate based on the formula shown below: $\text{meters}\cdot\text{min}^{-1} = [(0.1)^{-1} (\text{body weight in kg})^{-1} (1{,}530\ \text{kg-m}\cdot\text{min}^{-1})]$

DETERMINATION OF EXCESS POST-EXERCISE OXYGEN CONSUMPTION

Subsequently, the participants sat in a chair next to the bike or treadmill after a 1 min working period, and EPOC was enrolled till it fell below the 5 min remaining O_2 uptake measurement. The contribution of oxidative energy metabolism EPOC to over-all performance was determined by converting glucose oxidation to heat as 1 liter of O_2=21.1 kJ to complete glucose oxidation and converting fats to heat as 1 liter of O_2=19.6 kJ during cycling and uphill running for further calculations.

THE ASSESSMENT OF GLYCOLYTIC ADENOSINE TRIPHOSPHATE RE-SYNTHESIS DURING EXERCISE

After the exercise tests, concentrations of blood lactate were gathered twice from the earlobe at rest and 2 min into a seated recovery (Japan, Kyoto, Lactate Pro 2 LT-1730, Arkray, Inc.) to estimate the contribution of anaerobic glycolytic energy expenditure. Blood lactate concentrations of the participants were achieved by subtracting resting from reach the high point of blood lactate levels. In the estimation of anaerobic glycolytic component, only measurements of blood lactate levels (mmoles) were transformed to oxygen parity rates as 3 ml $O_2\cdot kg^{-1}$ body weight per mmol of Δblood lactate. The concentration of blood lactate during testing was used to estimate glycolytic contribution to overall energy expenditure. It was reported that each 1 mmol rising in blood lactate upon resting conditions was close to 3.0 mL of O_2 oxygen expenditure per kilogram of body weight.[13] The equivalent of O_2 was turned into 1 L of O_2=21.1 kJ to estimate the contribution of complete glucose oxidation to overall energy expenditure.

STATISTICAL ANALYSIS

Descriptive data are presented as means and standard deviation, except where otherwise indicated. A paired-samples t-test was conducted to compare knee and hip isokinetic strength characteristics, consumption of aerobic energy, consumption of anaerobic energy, and consumption of acute recovery energy between brief bouts of cycling and uphill running protocols. The correlations between energy expenditure components and lower extremity muscle strength characteristics were tested using a Pearson product-moment correlation coefficient. The level of statistical significance was set at $p<0.05$ and $p<0.001$ for all comparisons. The statistical analysis was carried out in version 20.0 of the SPSS. (SPSS Inc., Chicago, Illinois, United States). GraphPad Software GraphPad Prism 6 was used for graphical expression.

RESULTS

Data of neuromuscular characteristics of participants are shown as mean±standard deviation in Table 1. Paired-sample t-test analysis revealed significant differences between the dominant and non-dominant knee extension peak moments (273.00±39.69 vs. 234.65±52.96; t (19)=4.92, p=0.000); and, the dominant and non-dominant knee flexion peak moments (151.40±25.33 vs. 135.40±31.27; t (19)=3.22, p=0.000), respectively.

THE COMPARISON OF PHYSIOLOGICAL VARIABLES BETWEEN UPHILL RUNNING AND CYCLING

Data on the physiological characteristics of participants are shown as mean±standard deviation in Table 2. The results of the paired-sample t-test analysis displayed significant differences between treadmill and cycling VO_{2max} (41.48±5.28 vs. 48.84±5.00; t (19)= -10.09, p=0.001); VO_{2max} relative to fat free mass (56.50±4.26 vs. 47.83±5.42; t (19)=-9.73, p=0.001); RER (1.31±0.08 vs. 1.27±0.07; t (19)=-2.87, p=0.005). Rate of perceived exertion was found significantly higher during uphill running compared to cycling (14.75±1.52 vs. 15.40±1.67; t (19)=2.37, p=0.005). HR also found higher during uphill running than those during cycling (180.30±9.36 vs. 187.25±13.33; t (19)= -2.36, p=0.005). Despite equivalent power outputs, EPOC (73.12±23.42 vs. 94.95±14.62; t (19)=-3.87, p=0.001); oxidative energy expenditure (100.86±16.01 vs. 77.19±24.50; t (19)=-3.97, p=0.001); TEE (248.55±32.30 vs. 202.04±50.55; t (19)=-3.42, p=0.001) was found significantly higher during uphill running compared to cycling, respectively.

CORRELATIONS BETWEEN MUSCULAR STRENGTH CHARACTERISTICS AND ENERGY EXPENDITURE

The correlations between energy expenditure components and lower extremity muscle strength characteristics were tested using the Pearson product-moment correlation coefficient. The results of the analysis showed that H:Q fatigue index of both dominant (r=0.54, p<0.05), and non-dominant limb (r=0.45, p<0.05) was positively correlated with cycling VO_{2max}. Similarly, H:Q fatigue index of both dominant (r=0.50, p<0.05), and non-dominant limb

TABLE 1: Neuromuscular strength characteristics of participants.

Variable	Dominant	Non-dominant	t value	Sig. (p value)
Hip extension (Nm)	323.80±73.26	312.10±64.18	0.911	NS
Hip flexion (Nm)	187.20±28.92	180.85±32.16	1.20	NS
Knee extension (Nm)	273.00±39.69	234.65±52.96	4.92	0.000**
Knee flexion (Nm)	151.40±25.33	135.40±31.27	3.22	0.005**
H:Q fatigue rate (%)	43.85±12.12	41.11±15.12	0.754	NS

**p<0.001; NS: Not significant; H:Q: Hamstrings quadriceps.

TABLE 2: Physiological characteristics of participants (mean±standard deviation).

Variable	Cycling	Running	t value	Sig. (p value)
VO_{2max} (mL.kg.min-1)	41.48±5.28	48.84±5.00	-10.09	0.001**
VO_{2max} FFM (mL.kg.min-1)	47.83±5.42	56.50±4.26	-9.73	0.001**
RER	1.27±0.07	1.31±0.08	-2.87	0.005**
RPE	15.40±1.67	14.75±1.52	2.37	0.005**
HR (beat/min)	180.30±9.36	187.25±13.33	-2.36	0.005**
Blood lactate concentration (mM)	10.73±3.20	11.01±3.24	-0.317	NS
EPOC (kj)	73.12±23.42	94.95±14.62	-3.87	0.001**
Oxidative (kj)	77.19±24.50	100.86±16.01	-3.97	0.001**
Glycolytic (kj)	51.73±16.42	52.74±16.71	-0.234	NS
Total energy expenditure (kj)	202.04±50.55	248.55±32.30	-3.42	0.001**
Glycolytic/oxidative ratio (%)	1.66±0.79	2.11±0.76	-2.77	0.012*

*p<0.05; **p<0.001; VO_{2max}: Maximum oxygen consumption; VO_{2max} FFM: Maximum oxygen consumption relative to fat free mass; RER: Respiratory exchange ratio; RPE: Rate of perceived exertion; HR: Heart rate; EPOC: Excess post-exercise oxygen consumption; NS: Not significant.

(r=0.47, p<0.05) was positively correlated with treadmill VO_{2max}. On the other hand, hip flexion muscle strength were found to be negatively significantly correlated with EPOC (r=-0.47, p<0.05) and oxidative energy expenditure (r=-0.47, p<0.05) during cycling (Figure 1a, Figure 1b).

Also, glycolytic energy expenditure was found negatively correlated with glycolytic/oxidative ratio both during uphill running (r=-0.856, p=0.000) and (r=-0.685, p=0.001) during cycling (Figure 2a, Figure 2b).

DISCUSSION

Specifically, with higher intensity and/or longer duration of exercise EPOC gets higher.[14] We found in the current study that the ratio of glycolytic/oxidative ratio was higher during uphill running compared to cycling (Figure 2a, Figure 2b). The recruitment of large muscle mass during uphill running might have resulted in an imbalance of oxygen usage and oxygen delivery because of anaerobic glycolysis, which leads to lactate accumulation, inefficient glucose usage and subsequently to inadequate ATP production.

As demonstrated by previous research, it has been reported that the estimation of the total energy expenditure by the exchange of pulmonary gas alone may not be the most reliable method due to the alleged glycolytic contribution when the exercise modality consists of high-intensity work.[15] However, the estimation of EPOC during or after an exercise generally relies on the measurement of oxygen uptake and consequently glycolytic ATP re-synthesis is often neglected when calculating the total energy expenditure.[16] Similarly, the results of the current study revealed that glycolytic ATP re-synthesis accounts for 25.60% of TEE during cycling, and 21.21% during uphill running. These results were consistent with previous data that reported that the expenditure of total energy included a fast glycolytic ATP re-synthesis component of 28 percent for cycling and 17 percent for running.[7] However, they found no significant differences in TEE during these testing modalities while the aforementioned data were found significantly higher during uphill running compared to cycling in the current study. Thus, despite higher blood lactate concentrations following uphill running in our study, the reason as to why glycolytic ATP re-synthesis signify a bigger addition to TEE for cycling in proportion to uphill running is may be due to the quotient of glycolytic ATP re-synthesis to the TEE for uphill running. Also, the level of blood lactate concentration after a high intensity cycling exercise in the current study was found in accordance with the previous data.[17] Additionally, the use of neither oxygen data nor respiratory quotient derived using the same exercise modalities showed significant differences between the components.

Besides being one of the most important factors in successful sports performance, muscle strength is

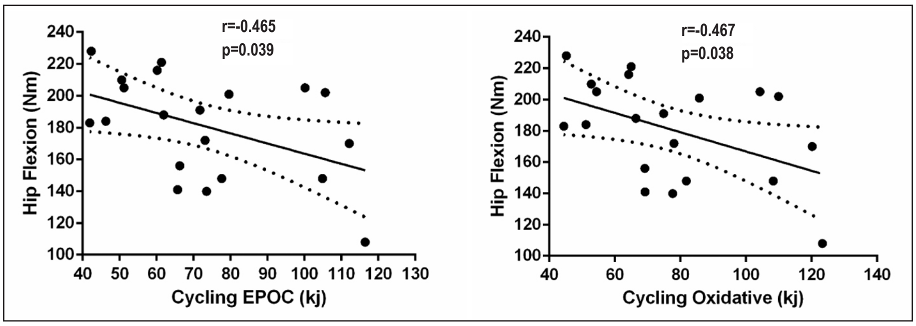

FIGURE 1: The relationships between hip flexion muscle strength and (a) cycling excess post-exercise oxygen consumption and (b) cycling oxidative component.

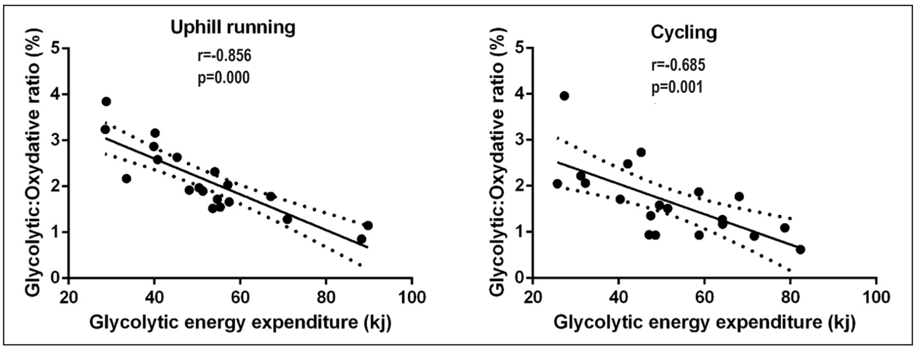

FIGURE 2: The relationships between glycolytic energy expenditure and glycolytic/oxidative ratio during (a) uphill running, and (b) cycling.

an important indicator of effective muscular performance.[18] On the other hand, the ratio of H:Q muscle fatigue rate both in the preponderant and non-preponderant member was positively correlated with cycle and treadmill VO_{2max}. Similar results were reported between H:Q muscle strength ratio and VO_{2max} parameters.[19] Despite significant correlations, the strength characteristics of knee flexor and extensor muscles between the dominant and non-dominant limbs were also found significantly different while the participants had similar hip muscle strength. Additionally, hip flexion muscle strength was found to be negatively correlated with EPOC and oxidative energy expenditure during cycling (Figure 1a, Figure 1b). Previous data argued that the muscular strength balance of the hip is correlated with running economy of endurance athletes while it was also noted that uphill running comes about a tiny swing stage and a larger rate of the streak cycle spent in the position.[20,21] Previously, it has been reported that if the normal flexibility of the connective tissue around the joint is not maintained, a decrease in the range of motion may occur over a period of time.[22] As a result of these mechanical differences, the lower limb muscles perform higher net mechanical work checked to ground-level running, and the increased work requirements of the hip muscles, in particular, are met.[23] This accounts for the assumption that due to the differences in muscle mass involved during uphill running, TEE might have been greater compared to cycling even during equivalent bouts of exercises. However, as Table 2 shows, oxygen uptake is not the only way to measure energy consumption. In other words, the reason why energy expenditure was found to be lower during cycling can be due to the recruitment of distinct muscle mass as compared to running, which can lead to accelerated lactate glycogenolysis, which plays a significant role in overall ATP re-synthesis. Additionally, strength asymmetries that occurred in the knee extensor and flexor muscles might also have caused a greater energy expenditure during running. The difference in energy expenditure between similar cycles and uphill runs may be due to the content of transfer which aerobic and anaerobic energy during these trainings, rather than to training and overall energy consumption.

CONCLUSION

Due to the variations in the metabolic components, i.e., oxidative, EPOC, TEE calculated using the equations to equate work output between non-steady cycling and uphill running revealed discrepancies. Nevertheless, the data concerning the glycolytic component and blood lactate concentrations derived using the same protocol did not demonstrate any inconsistency, although blood lactate is a dynamic metabolite during exercise. Additionally, this study also revealed that compared to knee extensor and flexor muscles, hip muscles had a greater contribution to TEE during cycling and uphill treadmill running which also enabled the participants to generate less energy cost. Per the results of the current study, it would be more accurate to use the anaerobic glycolytic energy expenditure data rather than oxygen only measures in the assessment of energy expenditure between these equivalent exercise modalities. Optimizing symmetrical hip, knee extensor, and flexor muscle strength appear to play a significant role to maintain optimal running and cycling biomechanics, thus generating less energy cost during these activities.

Disclaimers

The results of the current study do not constitute an endorsement of the product by the authors or the journal.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Uğur Can, Nasuh Evrim Acar;* ***Design:*** *Uğur Can, Nasuh Evrim Acar;* ***Control/Supervision:*** *Yağmur Arınlı;* ***Data Collection and/or Processing:*** *Uğur Can, Nasuh Evrim Acar, Yağmur Arınlı;* ***Analysis and/or Interpretation:*** *Nasuh Evrim Acar;* ***Literature Review:*** *Uğur Can, Yağmur Arınlı;* ***Writing the Article:*** *Nasuh Evrim Acar;* ***Critical Review:*** *Uğur Can, Yağmur Arınlı;* ***References and Fundings:*** *Uğur Can;* ***Materials:*** *Uğur Can.*

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