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RESEARCH ARTICLE

Women, Men, and Thermal Response: An Entropic Account of Gender Differences in Breathing During Exercise

Jale ÇATAK[1,*] ELİF DEVELİ[2] Serkan BAYRAM[3]

[1] *Istanbul Sabahattin Zaim University, Faculty of Health Sciences, Department of Nutrition and Dietetics, Istanbul, Turkiye*
[2] *Yeditepe University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Turkiye*
[3] *Sureyyapasa Chest Diseases and Thoracic Surgery Training and Research Hospital, Department of Thoracic Surgery, Istanbul, Turkiye*

** Corresponding author E-mail: jalecatak@gmail.com*

HIGHLIGHTS

> Thermal responses of men and women during physical activity were obtained and compared through energy and exergy analyses, as per the first and second laws of thermodynamics, applied to the respiratory muscles.
> The effects of exercise were investigated to determine and compare differences between men and women from the thermodynamic point of view.
> The entropy generation and exergy destruction is shown to be an indicator of performance and women was shown to have had higher entropy generation and exergy destruction than men during physical activities.

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ABSTRACT

This study aimed to determine differences in the thermal response of the respiratory muscle between healthy men and women during exercise. We analyzed the lungs of eight men and eight women thermodynamically. Previous work of breathing data of 16 endurance-trained healthy subjects undergoing a progressive cycle exercise test to exhaustion was used for calculations. During exercise, glucose absorbed from the blood flow was 2.12 mmol/L for men and 4.1 mmol/L for women. Glucose consumed for respiration was found as 10.6 and 20.49 mmol/min in men and women, respectively. Exergy destruction in the respiratory muscles of men and women was 0.41 and 0.79 kJ/min, respectively. Entropy generation rates for men and women were calculated as 1.38×10^{-3} and 2.66×10^{-3} (kJ/K)/min, respectively. Women were generated entropy remarkably higher than men and consumed more glucose than men during exercise for breathing due to their less efficient ventilatory response to exercise. In conclusion, gender-based alterations in lung and airway dimensions result in higher work of breathing and therefore glucose cost of respiration, higher exergy destroyed, and higher entropy generated in women during exercise for given exercise intensity.

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1. Introduction

Many studies aiming to characterize the respiratory response of healthy women to exercising have gender-based alterations in pulmonary gas exchange [1] and respiratory mechanics [2]. These investigations suggest that younger women without respiratory disorders may be more susceptible to lung restrictions in physical training, possibly

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related to women having smaller lungs and airways than men of the same height [3].

Women may have higher work of breathing (WOB) during physical training than men. However, which factors cause the higher WOB through physical training in women is unclear in the literature. Although smaller lungs of the women may the one of the contributing factors for this difference, data are very limited in the literature. Thermodynamic analysis tests the performance of the system. Entropy, also known as the systems' energy losses, can be calculated by the second law of thermodynamics.

In fact, identifying gender dissimilarities in respiratory mechanics is a major challenge due to the intrinsic complications of comparing males and females and the known distinctions in body dimension, and poor knowledge of the most relevant allometric scaling factor to use. The 2nd law of thermodynamics establishes that there must be some effect on the surroundings wherever there is an energy transference with a disequilibrium. However, this imbalance ensures vitality. Moreover, all biologicals maintain entropy at the maximum level when they come to death. Prigogine and Wiame (1946) proved that all alive are inclined to a minimum entropy generation [4].

Exergy analyses are involved in the human body and metabolism to assess the quality of the energy conversion process in the human body and muscle cells throughout specific activities. They aim to understand muscle efficiency better using the 2nd law of thermodynamics. In recent years, various exergy analyses have been applied and studied [5–12]. Recently, in a study by Spanghero et al. (2018), two kinds of exercises were assessed to calculate the quality of the energy conversion process in humans, bicycle, and weight lifting, and the authors concluded that the bicycle test was more efficient than weight lifting [13].

Although entropy generation and exergy destruction for the whole body [13–15], heart [16, 17], and lung [18–21] during physical activities have already been calculated, the thermal response of women and men to exercise has not yet been discussed. This study aimed to determine differences in the thermal response of the respiratory muscle between healthy men and women during exercise.

2. Material and Methods

We analyzed the lungs of eight men and eight women thermodynamically. Previous WOB data of 16 endurance-trained healthy subjects undergoing a progressive cycle exercise test to exhaustion were used for calculations [22]. The participants were healthy non-smokers and had no previous history of the cardiopulmonary disorder.

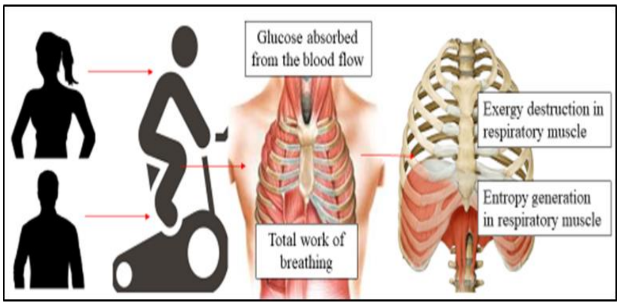

Figure 1 Flow chart of the study

A human breathing process was analyzed for men and women during exercising. Thermodynamic analyses were performed using the method described by [23]. The 1st and 2nd laws of thermodynamics were applied to assess the respiratory muscles of the subjects. The equations used in the analyses are taken from Çatak et al. [23]. Glucose consumed (**$m_{glucose}$**), entropy generated (s_{gen}), and exergy destroyed (**$Ex_{destroyed}$**) rates were determined by applying energy, exergy, and entropy balances to respiratory muscles as a function of 2nd law efficiency (η_{II}). According to the 1st law of thermodynamics, the mass balance equation was implemented to calculate glucose absorbed by respiratory muscles. The entropy generation was calculated by applying the 2nd law of thermodynamics, which let us measure the energy losses. The flow chart of the study is shown in Figure 1.

Total WOB was $1.64x10^{-1}$ kJ/min for males and was $3.17x10^{-1}$ kJ/min for females (Figure 2). The glucose consumed, entropy generated, and exergy destroyed, rates for males and females were calculated with the 2nd law efficiency of 0.30. In the study, the body temperature was taken as 37 °C and the environment air condition as 25 °C. This research is limited to the absorption of glucose to make ATP in the muscle cells of the respiratory system.

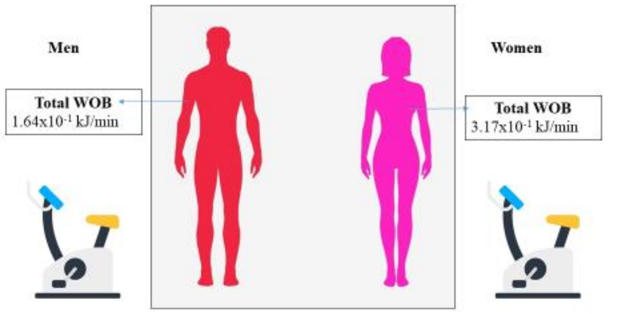

Figure 2 Total work of breathing (WOB) values in exercising men and women.

3. Results and Discussion

The calculated amounts of glucose consumption, entropy generation, and exergy destruction in the respiratory muscles by men and women during exercise were given in Table 1. During exercise, glucose absorbed from the blood flow was 2.12 mmol/L for men and 4.1 mmol/L for women. Glucose consumed for respiration was found as 10.6 and 20.49 mmol/min in men and women, respectively. Exergy destruction in the respiratory muscles of men and women was 0.41 and 0.79 kJ/min, respectively. Entropy generation rates for men and women were calculated as $1.38x10^{-3}$ and $2.66x10^{-3}$ (kJ/K)/min, respectively.

In the current research, we have done several unique thermodynamical comparisons. We implemented an inclusive thermal analysis using previous data belonging to 16 endurance-trained healthy people (eight male and eight female) that experienced a progressive cycle exercise test to exhaustion. This study suggests that the higher entropy generation in females during active exercise is due to a significantly larger total WOB. And this is probably because women's airways are smaller than men's and have a breathing pattern that supports a higher respiratory frequency. Glucose mass consumed in respiratory muscles was calculated using

WOB values by mass balance. It was determined that glucose consumption in women was remarkably higher than that of men.

Table 1 Calculated quantities of glucose consumed, exergy destroyed, and entropy generated during exercise in the respiratory muscles of women and men.

Thermal response	Women	Men
ηII	0.3	0.3
Mglucose (mmol/min)	20.49	10.6
Glucose absorption in blood (mmol/L)	4.1	2.12
Exdestroyed (kJ/min)	0.79	0.41
Sgen (kJ/K)/min	$2.66x10^{-3}$	$1.38x10^{-3}$

η_{II}, 2nd law efficiency; $m_{glucose}$, mass of glucose; $Ex_{destroyed}$, exergy destroyed; S_{gen}, entropy generated.

In the current research, we have done several unique thermodynamic comparisons. We implemented an inclusive thermal analysis using previous data belonging to 16 endurance-trained healthy people (eight male and eight female) that experienced a progressive cycle exercise test to exhaustion. This study suggests that the higher entropy generation in females during active exercise is due to a significantly larger total WOB. And this is probably because women's airways are smaller than men's and have a breathing pattern that supports a higher respiratory frequency. Glucose mass consumed in respiratory muscles was calculated using WOB values by mass balance. It was determined that glucose consumption in women was remarkably higher than that of men.

Men and women share the same physiological transport systems and phenomenological mechanism for exchanging heat and mass with the surroundings. However, it is reported in the literature that men and women have significantly different anatomies, metabolic rates, and hormonal cycles that affect individual comfort conditions. Increased entropy generation in females is probably because of their decreased ventilatory capacity, relatively more ventilatory restrictions, increased resistive WOB, and lesser efficient ventilatory response to exercise.

In this study, we analyzed the aerobic reactions in the muscle cells, aiming to predict muscle performance during exercise. As earlier proves in the publications, the rate of destroyed exergy increases as a function of speed [17, 24, 25]. The energy balance allows the exergy variation of the respiratory system to be resolved through analysis. Therefore, it is achievable to compute the exergy destruction by the exergy study. Exergy rates depend on the level of exercise and the human metabolism. The present study indicates that the relationship between exergy destruction and metabolism greatly depends on the subject's gender.

The 1st law is a conservation law that states energy can alter, despite the fact that the sum is all the time conserved. The 2nd law is a dissipation law that states an amount, entropy, which we usually characterize with the disorder [26]. The 2nd law further states that entropy must rise in any real irreversible process; equilibrium is not expected. Entropy can, in fact, be recognized by irreversibility. It is essential to know that the 2nd law forces biochemical reactions. The 1st law reveals that the total energy expended on work, heat, and changes in biochemical components will stand constant. It does not give information about whether such a reaction will occur, or if it will, what the relative distributions of energy forms will be. We have to use the 2nd law that tells the entropy must rise to see the propensity of the response to be [27]. The human body can be thought of as a thermodynamic device that can exchange heat or work with its surroundings, or both. Biological systems use air, which includes O_2, essential for reaction with carbohydrates, fat, and protein. These reactions generate heat and work to perform the vital actions of biological systems. Work is generated in the body and kept in ATP molecules. The reaction of glucose with oxygen generates heat. Since heat production is irreversible, it always occurs together with entropy production [28, 29].

Dissipative systems, such as living cells, are open systems. It is also essential to understand that living organisms are open systems, meaning they intake nutrients and oxygen and remove CO_2, H_2O, urea, and other waste products along with heat [27]. The earlier theories present essential interactions between life, energy, and thermodynamics. An important feature of biological systems is that they flourish on irreversibility. Therefore, they are not in thermal, chemical, and mechanical balance with their surroundings. To maintain life, living beings expend high-energy nutrients irreversibly, producing heat and entropy. Entropy is similarly moved to the environment through several waste-streams, namely advection containing perspiration and heat transference via the skin so that the living organism can maintain a stable thermal state [30].

Biological systems, like humans and other animals, continually require consuming energy to do physical work, sustain body temperature in the existence of heat transfer to the atmosphere, and generate, transfer, and substitute molecules that are their components. This energy is supplied by the oxidation of biological materials, namely carbohydrates, fats, and amino acids, mainly presented to the system by foods. Contrasting conventional heat motors where the chemical energy is initially transformed into thermal energy and then into mechanical work, biological systems can convert a fraction of nutrients' chemical energy directly into work. This is likely because the oxidation of nutrients within systems known as metabolism continues through numerous stages, allowing some of the energy in an intermediate chemical to be captured almost exclusively from ATP, which is used by biological systems for direct conversion to mechanical energy, as well as to support various biological reactions [9, 30].

To our knowledge, there are no investigations that have investigated the influence of exercise on the respiratory thermal response of men and women. However, in this study, entropy generated and exergy destroyed in women were significantly higher than in men. In addition, women consumed more glucose than men during exercise for breathing due to their less efficient ventilatory response to exercise.

Compared to men, women have smaller lungs and airways, expanded operating lung volumes, increased work and O_2 cost of breathing, lesser diaphragmatic fatigue, greater accessory inspiratory muscle recruitment [31]. Therefore, with the work done as input in the exergy analysis, the men and women were evaluated and compared during the exercise.

In this study, the thermal behavior of the body was evaluated and used as a basis for applying the exergy analysis. The 1st and 2nd laws of thermodynamics were implemented to the respiratory muscles to assess the quality of the energy conversion during muscular activity. The results show that the exergy destroyed may be an indicator of performance. This application represents an essential topic in the exergy analysis of humans because the literature contains difficulties assessing the work done in some activities.

4. Conclusions

Respiratory muscles of the men and women during exercising were evaluated thermodynamically, and the glucose consumption, exergy destruction, and entropy generation by the respiratory muscles were calculated. The higher entropy generation in females during exercise is owing to a considerably higher work of breathing. And this is probably because women's airways are smaller than men's and have a breathing pattern that supports a higher respiratory frequency. Women were generated entropy remarkably higher than men and consumed more glucose than men during exercise for breathing due to their less efficient ventilatory response to exercise. In conclusion, gender-based alterations in lung and airway dimensions result in higher work of breathing and therefore glucose cost of respiration, higher exergy destroyed, and higher entropy generated in women during exercise for given exercise intensity.

Declaration of Conflict of Interest

Authors declare that they have no conflict of interest with any person, institution, or company.

References

[1] Richards JC, Mckenzıe DC, Warburton, Darren E. R., Road JD, Sheel AW. Prevalence of Exercise-Induced Arterial Hypoxemia in Healthy Women. *Medicine & Science in Sports & Exercise* (2004) **36**(9):1514–1521. doi:10.1249/01.MSS.0000139898.30804.60.

[2] Guenette JA, Witt JD, McKenzie DC, Road JD, Sheel AW. Respiratory mechanics during exercise in endurance-trained men and women. *The Journal of Physiology* (2007) **581**(3):1309–1322. doi:10.1113/jphysiol.2006.126466.

[3] Mead J. Dysanapsis in normal lungs assessed by the relationship between maximal flow, static recoil, and vital capacity. *The American review of respiratory disease* (1980) **121**(2):339–342. doi:10.1164/ARRD.1980.121.2.339.

[4] Prigogine I, Wiame J. Biologie Et Thermodynamique Des Phénomènes Irréversibles [Biology and thermodynamics of irreversible phenomena]. *Experientia* (1946) **2**:451–453.

[5] Öngel ME, Yildiz C, Yilmaz B, Özilgen M. Nutrition and disease-related entropy generation in cancer. *International Journal of Exergy* (2021) **34**(4):411–423. doi:10.1504/IJEX.2021.114091.

[6] Öngel ME, Yıldız C, Akpınaroğlu C, Yilmaz B, Özilgen M. Why women may live longer than men do? A telomere-length regulated and diet-based entropic assessment. *Clinical Nutrition* (2021) **40**(3):1186–1191. doi:10.1016/j.clnu.2020.07.030.

[7] Dutta A, Chattopadhyay H. A Brief on Biological Thermodynamics for Human Physiology. *Journal of Biomechanical Engineering* (2021) **143**(7). doi:10.1115/1.4050458.

[8] Martinez Garcia M, Une R, Oliveira Junior S de, Keutenedjian Mady C. Exergy Analysis and Human Body Thermal Comfort Conditions: Evaluation of Different Body Compositions. *Entropy* (2018) **20**(4):265. doi:10.3390/e20040265.

[9] Özilgen M, Sorgüven Öner E. *Biothermodynamics Principles and applications, 1st ed. CRC Press* (2016). 411-411.

[10] Henriques IB, Mady CEK, Albuquerque Neto C, Yanagihara JI, Oliveira Junior S. The effect of altitude and intensity of physical activity on the exergy efficiency of respiratory system. *International Journal of Thermodynamics* (2014) **17**(4):265. doi:10.5541/ijot.550.

[11] Yildiz C, Öngel ME, Yilmaz B, Özilgen M. Diet-dependent entropic assessment of athletes' lifespan. *Journal of Nutritional Science* (2021) **10**:e83-e83. doi:10.1017/jns.2021.78.

[12] Semerciöz AS, Yılmaz B, Özilgen M. Thermodynamic assessment of allocation of energy and exergy of the nutrients for the life processes during pregnancy. *British Journal of Nutrition* (2020) **124**(7):742–753. doi:10.1017/S0007114520001646.

[13] Spanghero G, Albuquerque C, Lazzaretti Fernandes T, Hernandez A, Keutenedjian Mady C. Exergy Analysis of the Musculoskeletal System Efficiency during Aerobic and Anaerobic Activities. *Entropy* (2018) **20**(2):119. doi:10.3390/e20020119.

[14] Mady CEK, Albuquerque C, Fernandes TL, Hernandez AJ, Saldiva PHN, Yanagihara JI, et al. Exergy performance of human body under physical activities. *Energy* (2013) **62**:370–378. doi:10.1016/j.energy.2013.09.050.

[15] Çatak J, Develi AÇ, Sorguven E, Özilgen M, Inal HS. Lifespan entropy generated by the masseter muscles during chewing: An indicator of the life expectancy? *International Journal of Exergy* (2015) **18**(1):46–67. doi:10.1504/IJEX.2015.072056.

[16] Dutta A, Chattopadhyay H. Thermodynamic effect of RNA virus infection on the human cardiovascular system. *Journal of thermal biology* (2021) **100**:103039. doi:10.1016/j.jtherbio.2021.103039.

[17] Çatak J, Özilgen M, Olcay AB, Yılmaz B. Assessment of the work efficiency with exergy method in ageing muscles and healthy and enlarged hearts. *International Journal of Exergy* (2018) **25**(1):1. doi:10.1504/IJEX.2018.088885.

[18] Dutta A, Chattopadhyay H. Exergetic analysis of human respiratory system including effect of age and gender. *International Journal of Exergy* (2020) **31**(4):370–385. doi:10.1504/IJEX.2020.107194.

[19] Dutta A, Chattopadhyay H. Performance analysis of human respiratory system based on the second law of thermodynamics. *Journal of thermal biology* (2021) **96**. doi:10.1016/J.JTHERBIO.2021.102862.

[20] Dutta A, Chattopadhyay H, Yasmin H, Rahimi-Gorji M. Entropy generation in the human lung due to effect of psychrometric condition and friction in the respiratory tract. *Computer Methods and Programs in Biomedicine* (2019) **180**:105010. doi:10.1016/j.cmpb.2019.105010.

[21] Çatak A, Develi J, Bayram E. Entropy Generation and Exergy Destruction During and After Weaning from Mechanical Ventilation in Patients with Respiratory Failure. *Avrupa Bilim ve Teknoloji Dergisi* (2020)(18):283–289. doi:10.31590/EJOSAT.690568.

[22] Guenette JA, Querido JS, Eves ND, Chua R, William Sheel A. Sex differences in the resistive and elastic work of breathing during exercise in endurance-trained athletes. *American journal of physiology. Regulatory, integrative and comparative physiology* (2009) **297**(1). doi:10.1152/AJPREGU.00078.2009.

[23] Çatak J, Develi E, Bayram S. How does obesity affect bioenergetics in human respiratory muscles? *Human Nutrition & Metabolism* (2021) **26**:200136. doi:10.1016/j.hnm.2021.200136.

[24] Çatak J, Develi E, Bayram S. Entropy generation changes during exercising comparing lungs of male and female subjects. In: European Respiratory Society (2021). PA415-PA415.

[25] Silva C, Annamalai K. Entropy Generation and Human Aging: Lifespan Entropy and Effect of Physical Activity Level. *Entropy* (2008) **10**(2):100–123. doi:10.3390/entropy-e10020100.

[26] Çatak J. Kronik Obstrüktif Akciğer Hastaları ile Sağlıklı Bireylerin Solunum İş Yükünün Termodinamik Analizi [Thermodynamic analysis of work of breathing of healthy individuals and patients with chronic obstructive pulmonary disease]. *European Journal of Science and Technology* (2018):145–151. doi:10.31590/ejosat.472665.

[27] Feinman RD, Fine EJ. "A calorie is a calorie" violates the second law of thermodynamics. *Nutrition Journal* (2004) **3**(1):9. doi:10.1186/1475-2891-3-9.

[28] Yalçınkaya BH, Genç S, Çatak J, Özilgen M, Yılmaz B. *3.3 Mitochondrial Energy Production. Elsevier* (2018). 95–125-95–125.

[29] Çatak J, Semerciöz AS, Yalçınkaya BH, Yılmaz B, Özilgen M. 4.29 Bioenergy Conversion. In: *Comprehensive Energy Systems*: Elsevier (2018). p. 1131–1158.

[30] Silva CA, Annamalai K. Entropy Generation and Human Aging: Lifespan Entropy and Effect of Diet Composition and Caloric Restriction Diets. *Journal of Thermodynamics* (2009):1–10. doi:10.1155/2009/186723.

[31] Guenette JA, Romer LM, Querido JS, Chua R, Eves ND, Road JD, et al. Sex differences in exercise-induced diaphragmatic fatigue in

endurance-trained athletes. *Journal of Applied Physiology* (2010) **109**(1):35–46. doi:10.1152/japplphysiol.01341.2009.