

Metabolic Rate and Respiratory Quotient in Birds: Results at Different Seasons, and Comparison of Two Methods

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ABSTRACT

Our communication presents results of comparison metabolic rate and respiratory quotient values were determined in birds by two methods: Haldane gas analyzer (closed flow respirometry system) and an open flow respirometry system. In more than 40 species of Passerine birds were measured respiratory quotient (RQ) and basal metabolic rate (BMR). The analysis shows that determinations metabolic rate and RQ obtained by Haldane apparatus and the data measurement RQ obtained by an open flow respirometry systems were identical. The relationship BMR to body weight to the power of 0.72 ($BMR/m^{0.72}$) and RQ values determination by Haldane gas analyzer and an open flow respirometry system in passerine birds were identical. RQ in winter was lower than in summer. RQ weakly correlates with BMR levels. Our study shows the possibility of using data obtained from previous studies that have been cited by investigators for a long time.

Keywords: Respiratory Quotient; Indirect Calorimetry; Physiology of Metabolism; Haldane Gas Analyzer; Open Flow Respirometry System

Introduction

All living organisms are dependent on metabolism (biochemical resource use and transformation) to fuel various vital activities. Metabolic rate, and the ratio of oxidizable substrates, which shows respiratory coefficient developed in parallel, reflecting life history and are basic characteristic traits of animals [1]. The study of the respiratory quotient in energetic is of particular interest and importance. RQ is an indicator of which fuel (carbohydrate or fat) is being metabolized to supply the body with energy. The main goal our study is to show how the Haldane method and closed flow respirometry system meets the modern requirements. Our data largely agree with results reported by other authors who used drastically different methods over several decades. This allows used past studies in current time. During the oxidation of various substrates, different amounts of CO_2 are released. The ratio between CO_2 , which forms during the process of metabolism, and O_2 , which is consumed, is defined as the respiratory quotient (RQ). This parameter plays a major role in the physiology of metabolism [2,3].

To accurately estimate the metabolic costs of animals under different conditions and feeding, it is necessary to measure O_2

consumption and CO_2 release simultaneously. Many methods to measure RQ were established over a century ago by [4] and are reiterated in detail in [1,5,6]. The following publications contain information on similar issues and to the measurement of energy metabolism in endothermic animals the papers by [6-14]. Transformation oxygen consumption in the energy value depends on RQ. Reliable measurements, equivalent units must be used for the oxygen and carbon dioxide levels. Otherwise, the ratio will be skewed and will be less meaningful as a result [15,16]. It is possible to pick up very accurate readings which can be used in respiratory quotient calculations. The question arises how the data obtained by different methods relate to each other. We compared the data measurements metabolic rate and RQ obtained by Haldane apparatus and the data measurement RQ obtained by an open flow respirometry systems.

Methods

The study was performed in Moscow Region at Zvenigorod Biological Station (55°44' N, 36°51' E); more than 40 species of Passerine birds were used. The following indicators of energy

metabolism were measured: The basal metabolic rate (BMR) in birds is the fundamental scale of its energetic power and an indicator of the maximal level of the daily work output. We used the relationship $BMR/m^{0.72}$ is an interspecies indicator of daily work output and may be applicable to general physiology and population ecology [14]. The respiratory quotient (RQ) is a dimensionless ratio of carbon dioxide produced by the body to oxygen consumed by the body. Measurement of metabolic rate and RQ were made in winter (December, January) and summer (end of May, June) on non-mounting birds. Studies made on seasonal variations of metabolic rate and RQ were done at experimentally controlled temperatures, where T_A was varied from +40° to -28° C.

All experimental procedures and measurement methods are described in detail in our work [17]. Calculations and statistical processing of the results were performed using analysis of variance ANOVA. All data are expressed as the means ± SE. The differences in the present study were estimated, and significance was determined using the t-test, as appropriate. The following statistics-associated abbreviations were used in this manuscript: n, sample size; p, statistical significance; t-test for independent samples, SE, standard error. The study was performed by the laws of the Russian Federation and Moscow State University regarding the capturing and holding of wild animals, and all individuals were released after

the experiment. The average volume of consumed oxygen from the whole time of metabolic rate measurement was converted into the volume at standard temperature and pressure and then converted to kJ day according to the equation $1\text{ L of }O_2=15.97+5.16RQ\text{ (kJ)}$ [8,18] and used as an estimate of whole-organism metabolic rate.

Results

All the results of measurements of metabolic rate and RQ in both winter and summer are summarized in Tables 1&2. The relationship $BMR/m^{0.72}$ obtained by the respirometry Fox Box of Sable Systems Inc is 2.9 ± 0.42 (n=108) and 2.76 ± 0.35 (n=216) obtained by the Haldane respirometry (Table 1). The respiratory coefficient in all birds at night is lower than in the daytime. The minimal values of the respiratory coefficient birds have at middle night (Table 1). Not found any difference in determining the RQ these two methods RQ values in 12 of passerine species obtained by the Haldane respirometry at night was in the range 0.71-0.83 and on average equal to 0.763 ± 0.03 (n=108). RQ values in the same species obtained by the respirometry FoxBox of Sable Systems Inc at night was in the range 0.72-0.80 and on average equal to 0.760 ± 0.02 (n=216). There is a tendency for an increase in RQ in larger birds ($R^2 = 0,1407$), RQ correlates with BMR levels: $RQ = -0,0482BMR + 0,842$ ($R^2 = 0,3141$).

Table 1: Results of comparison the relationship $BMR/m^{0.72}$ and RQ values determination by Haldane gas analyzer (RQ¹) and an open flow respirometry system (RQ²) in birds.

Species	Body mass	n	RQ ¹	BMR/ m ^{0.72} kJ/D ¹	n	RQ ²	BMR/ m ^{0.72} kJ/D ²
Carpodacus erythrinus	21.2	1	0.712	3.53 ± 0.14	14	0.78 ± 0.017	3.2 ± 0.38
Chloris chloris	28.2	11	0.787 ± 0.019	3.69 ± 0.22	17	0.794 ± 0.021	3.36 ± 0.27
Emberiza citrinella	26.8	3	0.774 ± 0.033	3.06 ± 0.28	27	0.73 ± 0.013	2.38 ± 0.14
Erithacus rubecula	17.6	25	0.761 ± 0.04	2.45 ± 0.32	18	0.781 ± 0.016	2.36 ± 0.39
Fringilla coelebs	21	9	0.78 ± 0.035	2.68 ± 0.19	35	0.785 ± 0.011	2.74 ± 0.49
Loxia curvirostra	39.4	1	0.781	3.18	9	0.744 ± 0.028	3.11 ± 0.33
Parus ater	10.8	10	0.72 ± 0.024	2.5 ± 0.25	18	0.754 ± 0.017	2.31 ± 0.32
Parus major	16.4	31	0.79 ± 0.044	2.67 ± 0.27	20	0.722 ± 0.019	2.71 ± 0.49
Spinus spinus	14	3	0.736 ± 0.036	2.73 ± 0.38	18	0.761 ± 0.023	2.65 ± 0.26
Troglodytes troglodytes	9	4	0.746 ± 0.007	2.44 ± 0.21	16	0.757 ± 0.016	2.41 ± 0.59
Turdus merula	82.6	4	0.750 ± 0.021	3.01 ± 0.17	12	0.761 ± 0.024	2.97 ± 0.22
Turdus philomelos	62.8	6	0.825 ± 0.036	2.84 ± 0.26	12	0.753 ± 0.029	2.86 ± 0.18

Table 2: Summer and winter determination the relationship $BMR/m^{0.72}$ and RQ values by Haldane gas analyzer (RQ¹) and an open flow respirometry system (RQ²) in birds.

Species	Method	Body mass, g	n	RQ summer	BMR/ m ^{0.72} kJ/D summer	n	RQ winter	BMR/ m ^{0.72} kJ/D winter
Parus ater	1	10.8 ± 1	18	0.754 ± 0.019	3.7 ± 0.25	18	0.74 ± 0.033	4.15 ± 0.81
Parus ater	2	10.8 ± 0.95	18	0.72 ± 0.024	3.43 ± 0.34	10	0.713 ± 0.069	3.35 ± 0.21
Parus caeruleus	2	12.5 ± 1.1	7	0.737 ± 0.026	2.14 ± 0.18	7	0.727 ± 0.029	1.90 ± 0.2
Parus major	1	16.4 ± 1.2	20	0.772 ± 0.028	2.61 ± 0.27	20	0.76 ± 0.029	2.82 ± 0.32
Parus major	2	18.9 ± 1.12	31	0.79 ± 0.044	2.75 ± 0.31	12	0.781 ± 0.024	2.61 ± 0.22
Parus montanus	2	11.6 ± 0.9	10	0.745 ± 0.043	2.29 ± 0.31	8	0.749 ± 0.015	2.22 ± 0.16
Sitta europaea	2	22.9 ± 1.45	19	0.767 ± 0.032	2.29 ± 0.26	15	0.795 ± 0.023	2.46 ± 0.22

We compared metabolic rate and RQ in summer and winter for some species (Table 2). There are practically no seasonal differences in the relationship $BMR/m^{0.72}$, 2.75 ± 0.6 $n=123$ in summer 2.79 ± 0.75 $n=90$ in winter to either in the RQ or between the two methods. The relationship $BMR/m^{0.72}$ and RQ is 0.755 ± 0.02 $n=123$ in summer and 0.752 ± 0.03 $n=90$ in winter. These data indicate that lipids were the main source of energy expenditure in winter during a night. Thus, the RQ value and the metabolic rate determined using different methods were nearly identical. RQ values in 4 species of passerine birds which for many generations bred in captivity is 0.77 ± 0.01 (obtained by Haldane apparatus).

Discussion

This communication was designed to evaluate the interdependence of metabolic rate and RQ of birds and comparison results of these indicators obtained Haldane gas analyzer (closed flow respirometry system) and an open flow respirometry system. What is the significance of basal metabolic rate (BMR)? BMR is a measure of the minimum cost of organism maintenance, reflecting those basic physiological costs that are essential for life. The level of BMR among birds depends mainly on body mass, but after correcting for mass differences, there are still large differences among kinds of birds, especially between passerine birds and all other birds. In studied passerine birds RQ weakly correlates with BMR levels. The relationship $BMR/m^{0.72}$, which reflects the ability of species to perform work, has no seasonal variations and is almost the same in all studied species. It is slightly higher than in non-passerine birds [14].

Benadé et al. [2] were carried out experiments, in which oxygen content, carbon dioxide content and RQ's obtained on expired air samples by the Haldane technique, were compared with those obtained using paramagnetic and infrared analysis. No significant bias was found between Haldane and paramagnetic analysis of oxygen content. The infrared analysis yielded more consistent results for CO_2 than did the Haldane apparatus. The analysis shows that determinations RQ obtained by Haldane apparatus and the data measurement RQ obtained by an open flow respirometry systems are in confidence intervals of all data from literature [5-7,13,16,18].

We consider the mathematical and technical issues in the measurement and interpretation of open-circuit indirect calorimetry in small animals [6]. Measurement $\dot{V}O_2$ and $\dot{V}CO_2$ showed that close relationships exist between relation $\dot{V}O_2$ and $\dot{V}CO_2$ and energy expenditure derived precise equations well described in [19]. Our data indicate that in birds lipids were the primary source of energy expenditure in winter during night. It is especially interesting that the results of our RQ values mostly agree with those by other authors with drastically different methods over several decades. This conclusion itself is important and add the current study's data to the complete database. The lends further credence importance of past studies that have been cited by investigators for a long time.

The results of RQ values and the relationship $BMR/m^{0.72}$ mostly agree with those by other authors with drastically various methods over several decades. This is important, and so is the value of the addition of the current study's data to the complete database. This it lends further credence importance of past studies that have been cited by investigators for a long time. This allows used previous studies in current time.

Conclusion

The analysis shows that determinations metabolic rate and RQ obtained by Haldane apparatus and the data measurement RQ obtained by an open flow respirometry systems were identical. RQ of captivity birds and free-living birds were identical. RQ in winter was lower than in summer. Our study shows the possibility of using data obtained from previous studies that have been cited by investigators for a long time. Due to the pandemic Covid-19, the results of RQ measurements can be used in clinical practice for severe pulmonary disease, in which patients spend a significant amount of energy on respiratory effort. In these cases, increasing the proportion of fats in the diet, the respiratory quotient is diminished causing a relative decrease in the amount of CO_2 produced. This reduces the respiratory burden to eliminate CO_2 , thereby reducing the amount of energy spent on respirations.

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