A Comparison of the Energy Metabolism and Cooling Rate Methods of Determining Thermal Conductance in Mongolian Pheasants (Phasianus colchicus mongolicus)

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A Comparison of the Energy Metabolism and Cooling Rate Methods of Determining Thermal Conductance in Mongolian Pheasants (*Phasianus colchicus mongolicus*).

Honor's Thesis by

Robert Pendleton
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Abstract

Thermal conductance is defined as the net rate of heat transfer from an organism to its environment. Previous studies have employed two methods of measuring thermal conductance: the oxygen consumption method and the cooling rate method. This study was designed to determine if the two methods give similar conductance values for the same animal. Mongolian Pheasants (Phasianus colchicus mongolicus) were used. The results from this study suggest that the two methods don't give similar conductance values. I found that conductance values measured by the oxygen consumption method on a live animal were lower than those conductance values measured by the cooling rate method on a dead animal.
Introduction

Thermal conductance is often defined as the net rate of heat transfer from an organism per degree centigrade difference between body temperature and ambient temperature (McNab, 1979). Thermal conductance values are often derived from a near Newtonian model of heat loss of a homeotherm below thermoneutrality:

\[ Q_L = C (T_b - T_a) \]

where \( Q_L \) is heat loss, \( C \) is conductance, \( T_a \) is ambient temperature, and \( T_b \) is the animal's body temperature (Herried and Kessel, 1967).

An alternative way of describing thermal conductance is simply through an expression of the first law of thermodynamics. The first law may be stated as, "the summed energy flowing into and generated by a homeotherm (in steady state) must equal the energy flowing from the animal" (Tracy, 1972: 650).

Both of these descriptions help describe thermal conductance which, in homeotherms, can be a very complex process when factors such as blood flow, piloerection, postural changes, and feather fluffing of birds are considered. The reciprocal of thermal conductance in homeotherms is the insulation of the animal, i.e., the greater the insulation of the animal, the smaller its thermal conductance.

The two methods used in past research to determine thermal conductance are the cooling rate method and the oxygen consumption method. Historically, the cooling rate method is the one used by wildlife biologists when preparing tables of body cooling rates for a newly-introduced game species.

The cooling rate method involves sacrificing the animal and measuring its rate of cooling. This rate of cooling can then be expressed as a log function and converted to thermal conductance (Herried and Kessel, 1967).
The regressing oxygen consumption method, the second method used, involves measuring an animal's oxygen consumption at different temperatures below the animal's lower critical temperature (Calder, 1984). By measuring the animal's oxygen consumption below the thermoneutrality range, it can be assumed that the animal has maximized its insulative properties by reducing superficial blood flow and making pilomotor adjustments (Calder and King, 1972). The slope of the line relating the oxygen consumption to these cold environmental temperatures can then be directly related to thermal conductance (McNab, 1979; Calder and King, 1972).

Analysis of past research shows that the two methods have been assumed to give the same thermal conductance values for a given animal (Herried and Kessel, 1967). In fact the Herried and Kessel study (1967) reported no significant difference in the thermal conductance values from the two different methods for animals of the same species with similar body weights. However, the problem in the assumptions made in previous studies is that no one has ever calculated thermal conductance values by both methods on the same animal.

It is often a problem of wildlife personnel to determine the time of death of an animal that may have been killed several hours prior to the opening of a hunting season. Wildlife enforcement personnel can measure an animal's core body temperature as well as the environmental temperature and then refer to tables of body cooling rates of the particular species to estimate the time of death of the animal. In the past, the rates of body cooling used have been determined by sacrificing large numbers of animals of different game species and measuring their rate of cooling.

This project was designed to determine if the cooling rate method and the regressing oxygen consumption method give similar thermal conductance values for the same animal. Based on the evidence in previous studies it was hypothesized that the
conductances measured would be similar for either method. If the hypothesis was found to be correct, wildlife biologists should no longer need to use the cooling rate method to determine tables of body cooling rates for a newly introduced species.

**Methods**

Six Mongolian Pheasants (*Phasianus colchicus mongolicus*) were used for this study. Five of the six pheasants were male, and all pheasants were 1-2 years old. The pheasants weighed between .975 kg and 1.75 kg. Mongolian Pheasants were chosen for a couple of reasons. First, the pheasants are easily obtained because they are raised in this locality. Secondly, it was desirable to use an animal that is a game species or a close relative to a game species. The Mongolian Pheasant is a close relative to the Ring-necked Pheasant (*Phasianus colchicus colchicus*) which is hunted in the intermountain area. Because of this, the results of this study can be directly used by wildlife biologists.

The six Mongolian Pheasants were obtained in Salt Lake City, Utah, and were housed in a pen at the Willow Park Zoo in Logan, Utah, where they were fed and watered regularly by zoo employees. Individually, each pheasant was transported from the zoo to Utah State University for study. After transporting the bird to Utah State the pheasant was weighed and placed in a 2m x 1m x 1.5m pen until oxygen consumption measurements were performed.

Prior to each set of oxygen consumption measurements, the pheasant was not fed for approximately 12 hours to ensure that the bird was in a postabsorptive state. Oxygen consumption measurements were performed at approximately the same time of day, between 11:00 am and 6:00 pm, to try minimize the consequences that can be encountered if the circadian activity of the birds is ignored (for explanation see Aschoff, 1981).
Ambient temperatures of 10 C to -5 C were selected for the oxygen consumption measurements. It was assumed that these temperatures are below the animal's lower critical temperature.

The oxygen consumption system included a pump placed downstream from a 91 cm x 61 cm x 31 cm sealed metabolism chamber which is where the pheasant was placed prior to the run (figure 1). The metabolism chamber was placed inside a large environmental chamber to regulate the ambient temperature.

Figure 1. Illustration of the set-up used to measure oxygen consumption. Thermocouples were also used to measure ambient temperature and temperature of the air flow through the system.

Air was drawn from the surroundings through the metabolism chamber and into the rest of the system. With this type of set-up, it is assumed that the percentage of oxygen in the air going into the metabolism chamber was 20.95% so that the analyzer could be calibrated for each oxygen consumption run. The air was drawn out of the chamber through approximately thirty feet of 7/16 inch Nalgene tubing and into cylinders of Drierite and Ascarite which removed the water vapor and carbon dioxide respectively. The air
was then drawn into a SA-3 oxygen analyzer by a secondary pump. The oxygen analyzer displays the percentage of oxygen in the air sample. This value was then sent to an Acorn computer on which a program by John Lighton (Data Gathering and Analysis, version 3.1, copyright 1985) plots the percent oxygen in the air sample against time.

Also recorded during a given oxygen consumption run were the ambient temperature in the metabolism chamber and the temperature of the air flow sample. Both of these temperatures were measured with copper-constantine thermocouples connected to millivolt- amplifiers. The Acorn computer converted the output of the millivolt amplifiers to temperature, degrees C, and plotted the values against time.

In addition, barometric pressure and rate of air flow through the system were recorded periodically throughout a particular run. Barometric pressure was measured with an Ultimeter, professional altimeter/barometer.

Prior to each set of oxygen consumption runs, the pheasant was placed in the metabolism chamber and allowed to calm down for 2 hours before measurements were recorded. Each oxygen consumption run at a particular environmental temperature lasted about 2-3 hours. Typically, I made two successive oxygen consumption measurements, each at different environmental temperatures, on a given day. Before each set of oxygen consumption runs, the Ascarite and Drierite were changed and the system was checked for leaks by creating a nitrogen saturated environment around the connections in the system and recording any drop in the percent of oxygen exiting the system. Nitrogen saturation was performed until the connections were secure enough that the percent oxygen didn't drop below 20.90%.

Eight to ten oxygen consumption measurements were performed at different cold environmental temperatures on each pheasant.
Following the oxygen consumption runs, the pheasant was euthanized with nitrogen gas. Immediately after death, the carcass was placed in a suspended nylon mesh hammock (figure 2). This type of hammock arrangement was used to minimize effects on insulative properties that might occur by the set-up.

Figure 2. The pheasant carcass was suspended in a nylon mesh hammock to measure the rate of cooling. The hammock provided little added insulation.

A thermocouple was inserted approximately 12.7 cm into the cloaca of the animal to get a good measurement of the animal's core body temperature. Another thermocouple was placed approximately 2-2.5 cm into the pectoral mass of the bird using a wide-bore syringe needle (figure 3). Both thermocouples were held in place by taping the wires to the hammock. A third thermocouple was suspended near the carcass to measure the ambient temperature in the chamber which was set at about 0°C. All three thermocouple signals were amplified by millivolt amplifiers and relayed to the Acorn computer system where the signals were converted to °C by calibration equations. The temperatures were plotted by the system over a 10-12 hour period while the carcass cooled.
Figure 3. Thermocouples were placed in the cloaca and the pectoral mass of the animal carcass to measure the rate of cooling at these locations.

Data Analyses

All data were stored on computer disks by the Acorn computer system and were converted to thermal conductance values. The computer program by John Lighton that was used to compute oxygen consumption in units of ml O$_2$ / g * hr asks for barometric pressure, temperature of the air flowing through the system, mass of the animal, drift in the recording system during a run, and the location of the pump which for this system was downstream. The computer program was designed to use these values to account for system error as well as to convert the oxygen values to standard temperature and pressure values. The computer then generated a graph plotting oxygen consumption versus time (figure 4). I then selected a region of the graph where the animal’s oxygen consumption had stabilized for a period of time and calculated the average oxygen consumption over that period. This same procedure of calculating the average basal oxygen consumption at a particular
temperature was repeated for each of the ambient temperatures on each pheasant.

Figure 4. This graph illustrates oxygen consumption over time. The average \( \text{O}_2 \) consumption during a region of stability on the graph is used as the basal \( \text{O}_2 \) consumption for the pheasant at that particular environmental temperature.

Then, for a particular bird, each average oxygen consumption was plotted against its corresponding ambient temperature (figure 5). A regression line was fit through these data points by the least squares method. The line has the value of \( \text{ml O}_2 / \text{g} \times \text{hr} \times \text{C} \). This value times 4.8 cal / ml \( \text{O}_2 \) [a well established conversion factor (Herried and Kessel, 1967)] converted it to thermal conductance.
Figure 5. An example of a regressing oxygen consumption plot. Each point represents the average oxygen consumption for the bird at that particular environmental temperature. The slope of the line is then converted to conductance.

The cooling rate data were then converted to thermal conductance values. During the cooling rate measurements the computer recorded the cooling rate (figure 6).

Figure 6. An illustration of a cooling rate graph from the breast location of a pheasant. This cooling rate is expressed as a log function to calculate conductance.
This cooling rate, for both the cloaca and breast location on a given bird, was then expressed as a log function of: \( \text{LN} (T_b - T_a) \). This gave a straight line. The slope of this line, which has the units of \( \text{hr}^{-1} \), was then multiplied by the specific heat of animal tissue, 0.83 cal/g*°C, to give thermal conductance values.

**Results**

The results showed several interesting things (figure 7). First, I found that it was extremely difficult to measure thermal conductance by the oxygen consumption method. In fact, for two of the pheasants I was unable to pinpoint a thermal conductance value.

<table>
<thead>
<tr>
<th>Mongolian Pheasant Conductance Values</th>
<th>Pheasant</th>
<th>Breast Location</th>
<th>Cloaca Location</th>
<th>( O_2 ) method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(cal/g<em>hr</em>°C)</td>
<td>(cal/g<em>hr</em>°C)</td>
<td>(cal/g<em>hr</em>°C)</td>
</tr>
<tr>
<td>Mona</td>
<td>0.0791</td>
<td>0.1316</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>r-squared</td>
<td>0.998</td>
<td>1.00</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td>MonB</td>
<td>0.1177</td>
<td>0.1146</td>
<td>0.0717</td>
<td></td>
</tr>
<tr>
<td>r-squared</td>
<td>0.996</td>
<td>0.997</td>
<td>0.993</td>
<td></td>
</tr>
<tr>
<td>MonC</td>
<td>0.1121</td>
<td>0.1334</td>
<td>0.0297</td>
<td></td>
</tr>
<tr>
<td>r-squared</td>
<td>0.998</td>
<td>0.998</td>
<td>0.185</td>
<td></td>
</tr>
<tr>
<td>Mond</td>
<td>0.0997</td>
<td>0.0633</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>r-squared</td>
<td>0.988</td>
<td>0.991</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>Mone</td>
<td>0.0551</td>
<td>0.0869</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>r-squared</td>
<td>0.997</td>
<td>0.984</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>MonF</td>
<td>0.0968</td>
<td>0.0983</td>
<td>0.0498</td>
<td></td>
</tr>
<tr>
<td>r-squared</td>
<td>1.00</td>
<td>0.993</td>
<td>0.048</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7.** Table of thermal conductance values on six mongolian pheasants from the oxygen consumption method and the cooling rate method. The values suggest that the two methods do not give similar conductance values.
The most significant results were from the second pheasant studied, labeled monb. The thermal conductance calculated by the oxygen consumption method for this pheasant was 0.0717 cal/g·hr·C with an $R^2$ value of 0.993 (Figure 8). Conversely the thermal conductance values at the breast and cloaca location were 0.1177 cal/g·hr·C and 0.1146 cal/g·hr·C respectively. The coefficients of determination for these thermal conductances were 0.996 for the breast and 0.997 for the cloaca location.

Regressing Oxygen Consumption (monb)

![Graph]

Figure 8. Regressing oxygen consumption of monb. A conductance of 0.0717 cal/g·hr·C was calculated with an $r$-squared value of 0.993. The conductance values measured by the cooling rate method were both higher than this value from the $O_2$ method.

These results indicate that the two methods of measuring thermal conductance do not give similar values. Measurements on the other pheasants also indicate that the two methods do not give similar thermal conductance values. However, the data on the other pheasants had extremely low $R^2$ values and so there is little statistical backing to their values.
Discussion

Herried and Kessel (1967) have assumed that thermal conductance can be calculated by either the oxygen consumption method or the cooling rate method with similar results. Although my results indicate that this is not the case, several things must be considered: explanations for why conductance might be different when using the different methods, statistical significance of results, complications of the concept of thermal conductance, and suggested future studies.

There are several physiological factors that play major roles in thermal conductance in a living animal. A few of these are postural changes of the animal, reduced or increased blood circulation near the surface of the animal, and feather fluffing. All of these can play a major role in thermal conductance by increasing or decreasing the animals insulative properties. Other factors that may also affect thermal conductance measurements by the oxygen consumption method are the absorptive state of the animal and the time of the oxygen consumption run in the circadian phase of the bird.

All of the forementioned factors can play a major role in the animal's oxygen consumption at low temperatures. To try and overcome some of these problems, the pheasants were without food for at least 10 hours before each oxygen consumption run to ensure that the animals were postabsorptive on every oxygen consumption run. Also, most of the oxygen consumption runs were performed at about the same time of day since resting oxygen consumption in birds has a circadian rhythm. It has been shown that thermal conductance can be 50% higher when oxygen consumption is measured during the animal's active phase (Aschoff, 1981).

Since I attempted to eliminate the error that can come from the
circadian rhythm of metabolism and the absorptive state of the animal, my results imply that the other physiological factors such as feather fluffing, reduced surface blood flow, and postural changes play a major role in thermal conductance. Herried and Kessel (1967) speculated that thermal conductance measured by the two methods would be the same since the absence of feather fluffing and postural changes in the dead animal is counterbalanced by the greater heat loss through respiration and blood flow in the live animal. The results of my study, however, would indicate that feather fluffing and postural changes have a greater contribution to thermal conductance than heat loss through respiration and blood flow.

Despite the trends in my results, one must be cautious about their significance. All of the r-squared values for the thermal conductances obtained by the oxygen consumption method were extremely low with one exception (pheasant monb). Because of the low r-squared values, the statistical backing to these findings is weak. However, I feel that the results suggest that the two methods do not yield similar thermal conductance values.

The concept of thermal conductance in homeotherms has been widely criticized because it offers an oversimplified explanation of a very complex interaction (Tracy, 1972; Bakken, 1976). There are so many factors that are involved in thermal conductance in a homeotherm that in reality it is extremely difficult to accurately define. McNab (1979) states thermal conductance calculated by the oxygen consumption method, "usually leads to an erroneous estimate of thermal conductance" (McNab, 1979: 146).

Although I obtained statistically significant results on one of the six pheasants, the results obtained on the other five birds tend to support the idea that thermal conductance measurements on a live animal are a difficult task that can lead to much error. This is well illustrated in the graphs of oxygen consumption versus temperature.
on all five birds except monb (Appendix A).

I performed 2-3 oxygen consumption runs at different ambient temperatures on a given day. However, I would suggest in any future studies that the number of oxygen consumption runs should be limited to one in a given day. It is my opinion that this would produce more reliable results with the animal being more likely to be in the same state of rest for each run. I feel that other sources of possible error were considered and accounted for in my study.

In conclusion my findings suggest that thermal conductances measured by the oxygen consumption method are not similar to thermal conductances calculated by the cooling rate method. The difficulty of calculating thermal conductance by the oxygen consumption method was also illustrated in my findings. It is my feeling that the oxygen consumption method is not a feasible method for wildlife biologists to use when preparing tables of body cooling rates for their enforcement personnel for two reasons. One, my findings imply that a different thermal conductance value is measured on a live bird, and secondly the oxygen consumption method is very time consuming as well as a hard method to use to accurately calculate a conductance value.
References


This graph illustrates the regressing oxygen consumption measurements of pheasant, mona. The slope of the line was calculated to be approximately equal to 0.0.
A.2 This graph illustrates the cooling rate of pheasant, mona, from the breast location.

A.3 This graph illustrates the LN function of the cooling curve from the breast location of pheasant, mona. Conductance was calculated to be 0.07906 cal/g*hr*C with an r-squared value of .998.
A.4 This graph illustrates the cooling rate of pheasant, mona, from the cloaca location.

A.5 This graph illustrates the LN function of the cooling curve from the cloaca location of pheasant, mona. Conductance was calculated to be 0.1316 cal/g*hr*C with an r-squared value of 1.00.
This graph illustrates the regressing oxygen consumption measurements of pheasant, monb. Conductance was calculated to be 0.0717 cal/g·hr·C with an r-squared value of 0.993.
A.7. This graph illustrates the cooling curve from the breast location of pheasant, monb.

A.8. This graph illustrates the LN function of the cooling curve from the breast location of pheasant, monb. Conductance was calculated to be 0.1177 cal/g*hr*C with an r-squared value of 0.996.
This graph illustrates the cooling curve from the cloaca location of pheasant, monb.

This graph illustrates the LN function of the cooling curve from the cloaca location of pheasant, monb. Conductance was calculated to be 0.1146 cal/g*hr*C with an r-squared value of 0.997.
This graph illustrates the regressing oxygen consumption measurements of pheasant, monc. Conductance was calculated to be 0.02967 cal/g/hr*C with an r-squared value of 0.185.
A.12  This graph illustrates the cooling curve from the breast location of pheasant, monc.

A.13  This graph illustrates the LN function of the cooling curve from the breast location of pheasant, monc. Conductance was calculated to be 0.1121 cal/g*hr*C with an r-squared value of 0.998.
A.14 This graph illustrates the cooling curve from the cloaca location of pheasant, monc.

A.15 This graph illustrates the LN function of the cooling curve from the cloaca location of pheasant, monc. Conductance was calculated to be 0.1334 cal/g*hr*C with an r-squared value of 0.998.
This graph illustrates the regressing oxygen consumption measurements from pheasant, mond. Conductance was calculated to be 0.0.
A.17 This graph illustrates the cooling curve from the breast location of pheasant, mond.

A.18 This graph illustrates the LN function of the cooling curve from the breast location of pheasant, mond. Conductance was calculated to be 0.0997 cal/g*hr*C with an r-squared value of 0.988.
A.19 This graph illustrates the cooling curve from the cloaca location of pheasant, mond.

A.20 This graph illustrates the LN function of the cooling curve from the cloaca location of pheasant, mond. Conductance was calculated to be 0.0633 cal/ g*hr*C with an r-squared value of 0.991.
A.21 This graph illustrates the regressing oxygen consumption measurements from pheasant, mone. Conductance was calculated to be approximately 0.0.
A.22. This graph illustrates the cooling curve from the breast location of pheasant, mone.

A.23. This graph illustrates the LN function of the cooling curve from the breast location of pheasant, mone. Conductance was calculated to be 0.05505 cal / g\*hr*C with an r-squared value of 0.997.
This graph illustrates the cooling curve from the cloaca location of pheasant, mone.

This graph illustrates the LN function of the cooling curve from the cloaca location of pheasant, mone. Conductance was calculated to be 0.08689 cal/g*hr*C with an r-squared value of 0.984.
A.26 This graph illustrates the regressing oxygen consumption measurements from pheasant, monf. Conductance was calculated to be 0.0498 cal / g*hr*C with an r-squared value of 0.048.
A.27  This graph illustrates the cooling curve from the breast location of pheasant, monf.

A.28  This graph illustrates the LN function of the cooling curve from the breast location of pheasant, monf. Conductance was calculated to be 0.0968 cal/g*hr*C with an r-squared value of 1.00.
A.29 This graph illustrates the cooling curve from the cloaca location of pheasant, monf.

A.30 This graph illustrates the LN function of the cooling curve from the cloaca location of pheasant, monf. Conductance was calculated to be 0.0983 cal/g*hr*C with an r-squared value of 0.993.