Effects of Locomotory Activity, Temperature and Hunger on the Respiratory Rate of *Lycosa T-insignita* Boes. et Str. (Araneae: Lycosidae)

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The effects of locomotory activity, temperature and hunger on the respiratory rate of a spider, *Lycosa T-insignita*, were studied. The relationship between the carbon dioxide output and the body weight of the nymphs was linear when plotted on log-log co-ordinates. The slope of the line approximated 1. During periods of inactivity, the relationship between carbon dioxide output of final instar females and temperature can be expressed by the equation \( R = R_o Q^t \) or \( \log R = \log R_o + (\log Q)t \). The respiratory energy loss measured as carbon dioxide output per mg fresh weight per hour was determined at different temperatures for both active and resting final instar females. The calorific equivalents of respiratory energy loss during activity were shown to be 3-6 times higher than during rest. The carbon dioxide output per mg fresh weight decreased slightly with the spider's development from the early stage of the final instar to the adult stage, but showed fluctuations which accorded with changes in feeding activity. In fasting final instar nymphs the carbon dioxide output decreased sharply during the first 5 days, but thereafter the decrease was not marked. The decreased respiratory rate recovered up to the 70-80 per cent level when food was provided for 3 days.

INTRODUCTION

As respiration is a basic aspect of the metabolism of living organisms, the measurement of respiratory rate of an animal under different conditions will give an important information to the change in metabolic activities of the animal under that conditions.

In this paper, the carbon dioxide output of a spider (*Lycosa T-insignita* Boes. et Str.) which is known to be an important predator on some agricultural insect pests was measured. In order to obtain a basic knowledge of the change in metabolic activity of the spider in relation to temperature and feeding, experiments were made during resting and active periods at different temperatures, and at different levels of hunger.

MATERIALS AND METHODS

Spiders were collected from the field of our institute, Nishigahara, Tokyo, during the period of late September to late October 1968.

The carbon dioxide output was measured with an infrared gas analyzer (BECKMAN IR 215). Fig. 1 shows the gas analyzer connected by vinyl tubes...
to a respiration chamber, an air circulation pump, and a flowmeter so as to form a closed circuit. The speed of air current in the circuit was kept at 70-80 ml per minute.

In the case of the measurement of CO₂ output during rest a long strip of a paper was placed on the bottom of the respiration chamber (Fig. 1-A), thereby reducing the locomotory activity of the experimental animal to a minimum. Measurements were started 10 minutes after the spider's introduction into the chamber, and continued for one hour. The time occupied by locomotory activity never exceeded one sixth of the total measurement time.

In the case of measurement during activity, the experimental animal was continuously stimulated by a rolling plastic ball (7 mm in diameter and about 200 mg in weight). The plastic ball replaced the paper strip, and was rolled by swaying the chamber gently by hand (see Fig. 1-B). Careful manipulation of the ball kept the spider running or walking during the entire period of the measurement. The proportion of time spent running as opposed to walking was not determined as it was difficult to make a clear distinction between these two activities, but the spiders continued to run excitedly more than two third of the total measurement time.

Where experimental animals were kept in the laboratory before the measurement of CO₂ output, they were placed individually in plastic containers, 7.0 cm in height and 4.2 cm in diameter, and kept in an insectary at 25°C with illumination for 16 hours each day. The humidity in the container was maintained by a small glass tube containing wet cotton. The provided food was Drosophila melanogaster adults, each spider was given 20 flies a day, and the number of flies eaten was recorded.

RESULTS AND DISCUSSION

Respiratory Rate in Relation to Body Weight

Fig. 2 shows the relationship between CO₂ output at rest and fresh body
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weight of the nymphs. In this experiment, the measurements were made immediately after collection of spiders from the field.

![Graph showing relationship between CO₂ output and body weight.](image)

**Fig. 2** Relationship between CO₂ output during rest and body weight of nymphs plotted on log-log co-ordinates. The solid circles show the male nymphs of the final instar.

Fig. 2 shows that CO₂ output was directly proportional to increase of fresh body weight. The constant $b$ for the regression equation was 0.967, very close to 1. It is generally held for many animals, both vertebrate and invertebrate, that the relationship between respiratory rate and body weight follows the "surface law", i.e. respiration increases proportionally to the surface area of an animal or the $2/3$ power of body weight. However, the result obtained in this experiment did not accord with this view.

**EDWARDS (1953)** stated that the surface law mainly applies to animals possessing a large range in body weight, or those which have a similar body structure throughout their life, e.g. the hemimetabola. On the other hand, **BERTALANFFY (1957)** described 3 different types of dependence of metabolic rate on body size. The first type is represented by a proportional increase of metabolic rate to surface area or the $2/3$ power of body weight; representatives of this type include fish and invertebrates such as crustaceans, clams and ascarids. In the second type, the metabolic rate is proportional not to the surface area but to the weight itself; this type is generally found in growing larvae of the holometabolous insects and to larvae and adults of the hemimetabolous ones. The third type is intermediate between the above mentioned ones; some species of pond snail and flatworm show this relationship. It is now clear that a considerable number of reports supports the fact that many arthropod animals, especially insects, belong to the second or third type of metabolic rate-body size relationship described by **BERTALANFFY**.

**Respiratory Rates During Rest and Activity in Relation to Temperature**

It is well known that the relationship between respiratory rate and temperature generally follows an exponential-like curve. In the present experiment made on female nymphs in the final instar, the same relationship was obtained (Fig. 3-A).

This relationship can be expressed by the equations;
\[ R = R_0 e^{t}, \quad \text{or} \quad \log R = \log R_0 + (\log Q) t, \]  
\[(1)\]

where \( R \) is respiratory rate at \( t \)°C, \( R_0 \) a constant showing the theoretical respiratory rate at \( t=0 \)°C, and \( Q \) a constant which can be termed the "thermal coefficient for respiration" for a particular animal species. Equations (2) implies that when \( \log R \) is plotted against \( t \), a straight line is obtained. From this graph, the constant \( R_0 \) and \( Q \) are easily calculated. In addition, a theoretical threshold of respiration \( t \) can be estimated by assuming \( R=0 \).

Fig. 3-B\(^1\) shows that observed values of CO\(_2\) output during resting and active periods under different temperature conditions accord well with the straight lines calculated from equation (2). In the case of respiration during rest the constants, \( \log R_0 \) and \( \log Q \), and the theoretical threshold of respiration were estimated to be \(-0.4784, 0.0403, \) and \(11.9^\circ \text{C} \), respectively. The last figure, \(11.9^\circ \text{C} \), is quite theoretical, since respiration does not actually stop below this temperature, but may be at a lower level as indicated by the dotted line of Fig. 3-A. In other words, this threshold indicates a limit of temperature above which the spider is able to exhibit its normal activities. However, the calculation of the respiration threshold during activity may be meaningless because the movement of the spider would probably be sharply retarded or stop at temperatures below a certain limit, a limit lower than the theoretical threshold of respiration.

Equation (2) is the same as that used by BERTHET (1963) in expressing the change in \( \text{O}_2 \) uptake of oribatid mites in relation to different temperatures. BERTHET stated that the \( b \) values (\( \log Q \) in this paper) calculated for 16 species of oribatid

\(^1\) Actual figures were multiplied by 10 for convenience of calculation.
mites ranged from 0.04 to 0.07 and the $Q_{10}$ was equal to the antilog of 10$^b$.

Table 1 shows the estimated respiratory energy losses by the final instar female nymphs during the resting and active periods under different temperature conditions, and, for comparative purposes, estimated values for several predatory arthropods. In these calculations, calorific values were estimated assuming $R.Q. = 0.85$, since the spider usually took protein-rich food and the average $R.Q.$ for a mixed diet is said to be 0.85 (Engelman, 1966, p. 90). When the $R.Q.$ is assumed to be 0.85, the calorific equivalent of 1 $\mu l$ CO$_2$ is 0.00572 cal.

According to Table 1, the converted values of the respiratory energy loss per g fresh weight per day during rest approximated the values obtained for species of predatory arthropods reported by several authors. However, these figures were obtained by different methods under different conditions, so that we can not draw comparisons easily, indeed. Phillipson (1962) stressed that it was essential to obtain figures for day and night respiration in order to get an accurate estimation of the respiratory activity of a particular species.

The calorific values of respiratory energy loss during activity under different temperatures were 3-6 times higher than that during rest. This difference was very small when compared with the differences observed between the values of O$_2$ uptake during flight and resting in many insect species. According to the table
compiled by Keister and Buck (1964, p. 632), in which the data presented by many authors on O2 uptake during flight and resting in many insect species are summarized, the ratios between the values of O2 uptake during flight and rest ranged from 6 to 140, giving 44.7 on average for 20 species tested (flight induced by drugs or other abnormal manner excluded). It is reasonable to conclude that flight needs far more energy than walking or running.

As shown in the last column of Table 1, the ratios between the values of CO2 output during rest and activity decreased as the temperature rose. The reason for such a tendency is not clear, but it is suggested that the respiratory energy loss during rest rises sharply with temperature increase.

Changes in Respiratory Rate During the Final Instar and Adult Stages

Fig. 4 shows changes in respiratory rate during final instar and adult stages in relation to changes in body weight and feeding activity. In this experiment, large nymphs collected from the field were reared in the insectary until they developed into final instar nymphs. The measurements of body weight and of CO2 output during rest started 3 days after the moult into the final instar, and were continued at 4-5 days intervals up to the adult stage. The feeding activity of the spider was recorded as the number of Drosophila adults consumed per day.

Fig. 4 shows that the respiratory rate, expressed as CO2 output per unit fresh body weight, decreased slightly from the early stage of the final instar to the

![Graph](image-url)

Fig. 4  Changes in the CO₂ output during the period from the final instar to adult stage in relation to changes in body weight and feeding activity. The arrows M and C indicate moultng and copulation, and the symbols + and − show averages for the male and female, respectively.
Respiratory Rate of *Lycosa T-insignita*

adult stage, despite of a remarkable change in body weight, especially in the female. However, the respiratory rate fluctuated considerably with changes in feeding activity, this is the respiratory rate rose when feeding activity increased and fell when it decreased. As already reported by Miyashita (1968 a, b), feeding activity rose sharply just after moulting in both sexes and just after copulation in the female; the rate of increase in the body weight of females was also much higher in these stages. Edwards (1953) presented somewhat different result in an insect, *Oncopeltus fasciatus*. That is, the O₂ uptake of this insect from egg to the adult stage was shown by a curve with violent fluctuations, but the maxima of each fluctuation occurred not after moulting, but at the time of moulting. In the case of harvestspider females, the respiratory rate per unit fresh body weight rose in the presence of developing oocytes in the ovary, but decreased in the presence of the fully developed ones (Phillipson, 1962).

Changes in Respiratory Rate in Relation to Hunger

Fig. 5 shows the relationship between changes in respiratory rate of the final instar nymph and the degree of hunger. The experimental spiders were prepared in the same manner as in the previous experiment, but food was withheld after the third day from the beginning of the final instar. The CO₂ output during rest was measured after a certain fasting period and again after feeding for 3 days following the fasting period.

![Graph showing changes in CO₂ output and body weight](image)

**Fig. 5** Changes in CO₂ output and body weight of the final instar nymph in relation to the duration of fasting period. The symbols + and — show averages for the male and female, respectively.

It is clear from Fig. 5 that the respiratory rate decreased sharply during the first 5 days of fasting, but thereafter showed no marked decrease. This tendency accorded roughly with the decreasing trend of body weight. In other words, when the spider was forced to live under fasting conditions for a considerable period, the respiratory rate was kept at a low level. This low level of respiration
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is probably the lowest energy loss necessary for maintaining the minimum life, and such an ability to keep the respiratory rate at low level for a long period seems to be closely connected to the strong resistance to hunger of the spider. Unfortunately, in the present experiment the analysis of R.Q. was impossible, but a change in R.Q. related to the degree of hunger is suspected. According to Richman (1958), the R.Q. of unfed Daphnia pulex dropped from 1.13 to 0.71 during a 6-day period.

Itō (1964) showed that the respiratory rate of Lycosa pseudoannulata adults decreased after several days fasting but recovered when food was again provided. According to his estimate, the percentage decrease in respiratory rate per g fresh weight due to fasting was, on average, 16.3 per cent. In the present experiment, the percentage decrease in respiratory rate per mg fresh weight due to fasting for the first 5 days was 41.0 per cent in the male and 46.7 per cent in the female. However, a decreased respiratory rate in fasting spiders was quickly recovered by feeding for 3 days. When the average for measurements made after 5 different fasting periods was considered, the respiratory rate rose to 81.0 per cent (male) and 70.2 per cent (female) of the values observed before fasting.

In Glossiphonia complanata (Mann, 1956) and Daphnia pulex (Richman, 1958), no remarkable change in O$_2$ uptake was observed even under fasting conditions lasting for a week.

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