

Gilbert L. DRYDEN, Marek GĘBCZYŃSKI  
& E. L. DOUGLAS

### Oxygen Consumption by Nursling and Adult Musk Shrews.

[With 4 Tables & 1 Fig.]

The oxygen consumption rates of 82 young *Suncus murinus* (Linnaeus, 1766), newborn to 17 days of age, have been measured and show a reduction in metabolic rate from birth to about day 8 where stabilization occurs. The rates from adult males and females are lower than the rates of temperate zone shrews which may be a result of tropical evolution. Lactating and non-lactating females showed no difference in metabolic rates. Shrews acclimated to cold temperatures increased metabolism to successfully overcome this stress.

#### I. INTRODUCTION

Relatively few studies of energy metabolism by the *Insectivora* have been undertaken and this aspect of crocidurine shrew biology has not been directly investigated. *Suncus murinus* (Linnaeus, 1766), a tropically-distributed crocidurid, is a relatively large species currently bred in an established laboratory colony. A study of its thyroidal activity has revealed no elevated metabolic indices (Dryden *et al.*, 1969) as assumed for shrews in general because of measurements of high metabolic rates of small temperate zone species (Morrison & Pearson, 1946; Pearson, 1947). We have obtained oxygen consumption values for young, for lactating and non-lactating females, and for adult male *Suncus murinus*. We have also begun to test this shrew's response to cold temperatures. This paper reports our results and compares them with oxygen consumption by other small mammals.

#### II. MATERIALS AND METHODS

The shrews used in this study were captive-born progeny of stock originally trapped in the Mariana Islands (Dryden, 1968) and inbred for successive generations in Pennsylvania (Dryden & Ross, 1971). All animals were maintained

under 14 hour light at ambient temperature (18–29°C; 5–9°C in cold room) and relative humidity (50–80%). After weaning to individual cages at 21 days of age, all shrews were fed a high protein diet of commercial cat food and a specially prepared mixture primarily of animal origin, and water *ad libitum* (Dryden & Ross, 1971). Weaned shrews and females with their litters were transferred in their home nestbox to the oxygen consumption chamber. Data from animals which left the nestbox to explore the chamber during monitoring were discarded. Thus, the oxygen consumptions reported here are from resting animals in an accepted surrounding. By use of glass-topped nestboxes we determined that many shrews actually slept through the entire procedure. Others lay quietly in the nestbox. Oxygen consumption by the empty nestbox was recorded and found repeatedly to be nil.

Immediately after monitoring oxygen consumption by a mother and her litter, the mother was removed and the young were placed in an open ceramic cup. The young shrews were returned to the chamber and the oxygen consumed by them was measured. We therefore determined resting oxygen consumption of undisturbed lactating females by subtraction and at the same time oxygen consumption by the nurslings alone. Nurslings always curled up and appeared to be sleeping, showing little apparent concern over the absence of their mother.

All oxygen consumption measurements were performed using a 1.5 liter plexi-glass chamber completely submerged in a water bath regulated to  $\pm 1^\circ\text{C}$  of animal room temperature (or carried out at cold room temperature). Nestbox temperature, recorded from a telethermistor probe, was consistently equal to water bath temperature. All animals were allowed to accommodate themselves with chamber parts open to the atmosphere for 30 min. After this they experienced oxygen injection to the chamber for 30 min before data were recorded for an additional 60 min. Tank oxygen was administered by calibrated hypodermic syringe through a rubber hose connected to the chamber. Gas pressure in the chamber was read against a mineral oil U-tube manometer. Respiratory  $\text{CO}_2$  was absorbed by 30 grams of commercially prepared particulate asbestos impregnated with KOH. Analyses of carbon dioxide remaining in the chamber at termination of the runs indicated  $1.37\% \pm 0.03\%$  (Scholander, 1947). Tank oxygen at time of injection into the system was  $83.1\% \pm 0.2\%$  (Scholander *et al.*, 1955).

### III. RESULTS

#### 1. Postnatally Developing Young

Oxygen consumption by nurslings was measured during the initial 17 days of life in 40 litters of shrews ( $n=82$ ) (Table 1). There were no statistically significant ( $P=0.05$ ) differences in consumption according to number in a litter (1–3). There was, however, a tendency for young from litters of one to have higher metabolic rates despite their greater body weight relative to those of the same age from larger litters. Data from all litters were therefore pooled for the respective age classes.

Neonatal shrews consumed the most oxygen, which, expressed in units of body weight, was twice that generally consumed by animals one week of age or older (Table 1). These differences are not explained by the small size of the neonates since, after recalculation on the basis of meta-

Table 1

Metabolic rate changes during postnatal development in 82 *Suncus murinus*.

Age (days)	Mean body wt. g	Vo <sub>2</sub> (ml O <sub>2</sub> /g hr)	kcal/kg <sup>0.75</sup> per day	Temperature (°C)	Number of Vo <sub>2</sub> determinations
0	2.7	4.32	185.4	25.5	6
1	3.7	4.15	169.1	25.8	7
2	5.0	4.03	154.7	25.1	8
3	6.4	2.96	113.6	24.8	3
4	6.7	3.18	121.7	25.3	6
5	7.9	3.11	109.1	25.0	4
6	8.8	2.58	91.4	24.7	9
7	10.3	2.43	91.2	26.5	4
8	11.5	1.99	76.4	26.4	7
9	12.0	1.94	76.6	26.0	5
10	13.5	2.33	94.1	25.5	6
11*	13.2	2.96	120.3	21.5	3
12	16.8	2.12	90.0	25.0	1
13	16.4	1.94	81.6	27.2	5
14	16.9	1.84	78.2	27.2	4
15	16.3	2.06	86.8	28.6	3
17	17.85	2.83	127.3	25.5	2

\* Deleted from regression in Figure 1 because of decreased ambient temperature.

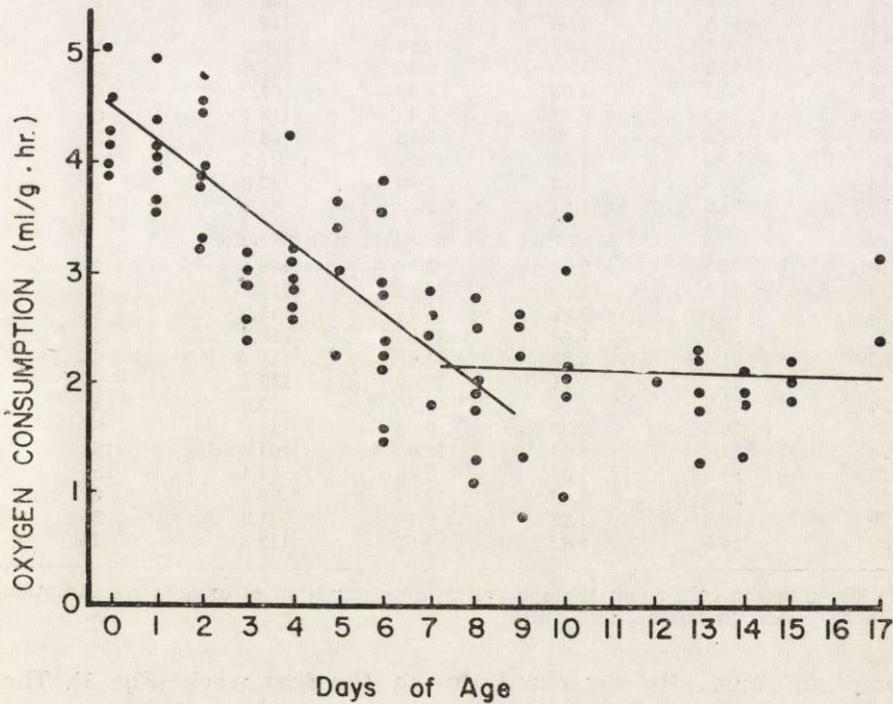


Fig. 1. Relationship of age and metabolic rate of nestling *Suncus murinus* (N=82). Regression equations for shrews 0 to 7 days old;  $Y=3.21-0.293x$  ( $r=-0.59$ ,  $n=50$ ); shrews 8—17 days old;  $Y=2.09+0.098x$  ( $r=0.53$ ,  $n=32$ ).

bolic body size ( $\text{kcal/kg}^{0.75}$ ), it is apparent that the greater metabolic rate is age-related. Oxygen requirements decreased during consecutive daily intervals and stabilized at the end of the first week of life (Fig. 1).

There apparently were two metabolic rate phases during postnatal development of this shrew under the conditions studied. Oxygen con-

Table 2

Oxygen consumption of adult *Suncus murinus* at different ambient temperatures.

Temperature (°C)	Mean body wt. g	Vo <sub>2</sub> ml/g hr	cal/g hr	kcal/kg <sup>0.75</sup> per day	Number of Vo <sub>2</sub> determinations
6 males in cold room *					
5	46.3	5.29	25.39	281.3	1
6	45.6	5.00	24.00	263.7	1
7	42.5	4.76	22.85	246.6	7
8	42.3	4.70	22.56	242.8	5
9	50.2	3.74	17.95	203.2	1
18 males from animal room					
19	44.5	2.65	12.72	138.6	4
20	43.2	2.70	12.96	140.8	2
21	47.3	2.20	10.56	118.0	2
22	48.7	1.99	9.55	106.9	5
23	50.1	1.98	9.50	107.6	3
24	49.4	1.93	9.26	104.2	4
25	51.9	2.07	9.94	113.7	6
26	53.5	1.70	8.16	94.0	11
27	52.0	1.66	7.97	91.2	10
28	49.8	1.73	8.30	93.8	4
29	53.6	1.54	7.39	85.2	1
47 lactating and non-lactating females					
18	24.2	2.76	13.25	125.1	2
19	24.2	2.61	12.53	118.9	6
20	23.9	3.22	15.45	145.7	5
21	29.5	2.48	11.90	118.7	4
22	31.4	2.38	11.42	115.1	6
23	30.5	2.71	13.00	130.4	9
24	30.5	2.34	11.20	112.6	9
25	29.7	2.06	9.88	98.6	8
26	32.1	2.09	10.00	101.4	16
27	31.3	1.85	8.88	89.4	15
28	29.3	2.09	10.00	99.9	6
29	29.9	1.82	8.74	101.3	2
30	24.9	2.43	11.66	112.8	1

\* Six males in cold room 30 days before determination of oxygen consumption and without access to nesting material.

sumption constantly decreased during the first week (Fig. 1). The regression during that period was  $Y = 3.21 - 0.293x$ . Shrews older than one week stabilized metabolic rates such that those 17 days of age, despite a weight gain of approximately 55% that at 8 days, had oxygen con-

sumptions described by a regression of  $Y=2.09+0.098x$  (Fig. 1). Caloric requirements of 8—17 day old shrews, based on metabolic body size, was the same as that of adults (see below) even though adult body weight was much greater.

## 2. Adults

Oxygen consumption rates were determined for 18 adult males, 20 adult females (sexually inactive and non-lactating), and 27 lactating females at normal animal room temperature, and for 6 adult males in the cold room at 5—9°C.

Males of this species are considerably larger (mean in this study approximately 50%) than females but oxygen consumption in kcal/kg<sup>0.75</sup> showed no statistically significant correlation with sex. Neither was there any difference in calculated metabolic rates between lactating and non-lactating females (Table 2). Because of this, results from the two groups of females were pooled for summation. Males consumed the least oxygen

Table 3

Insulative value of nest on oxygen consumption by 2 adult male *Suncus murinus* in cold room\*. *n* indicates number of determinations.

Temperature (°C)	No nest			Nest		
	Mean body wt. g	<i>n</i>	ml O <sub>2</sub> /g hr	Mean body wt. g	<i>n</i>	ml O <sub>2</sub> /g hr
7	42.5	7	4.76	39.1	1	3.91
8	42.3	5	4.70	40.3	1	3.87

\* Determinations made 5 days after nesting material provided and 35 days after shrew placed in cold room.

at 26—29°C, this being the apparent thermoneutral zone for both sexes (Table 2). If oxygen consumption at thermoneutrality is taken as 100%, then consumption by males was approximately 50% greater at 5°C. This intensive response to cold entailed a mean oxygen consumption increase of up to 10%/1°C.

## 3. Effect of Nest on Oxygen Uptake

Oxygen consumption by two males in the cold room at 7—8°C with and without access to nesting materials (dry grass) was determined. Males in bare nestboxes consumed 18% more oxygen than when they were provided with nests (Table 3). They apparently take advantage of the insulative qualities of the nest and thus compensate metabolically for the diminished chilling effect of the environment.

## IV. DISCUSSION

Although muscular coordination of young *S. murinus* before day 10 is rather poorly developed (Dryden, 1968) and nurslings generally remain in the nest, their metabolic response to air temperature is strong, even during the first week of life. The thermoneutral zone of adults is apparently near 25–26°C but shrews less than a week old seem to have a higher thermoneutral range. This suggests that their heat production mechanisms are relatively more developed than that of several rodents studied (Bashenina, 1960; Chew & Spencer, 1967).

Table 4  
Metabolic characteristics of some tropical and subtropical mammals.

Species	Body weight (grams)	VO <sub>2</sub> ml O <sub>2</sub> /g hr	kcal/kg <sup>0.75</sup> per day	Reference
<b>MARSUPALIA:</b>				
<i>Cercaertus nanus</i>	70.0	0.85	50.4	Bartholomew & Hudson, 1962
<b>CHIROPTERA:</b>				
<i>Sturnira lilium</i>	21.4	1.60	70.4	Morrison & McNab, 1966
<i>Artibeus jamaicensis</i>	41.2	1.10	57.1	Morrison & McNab, 1966
<b>INSECTIVORA:</b>				
<i>Suncus murinus</i> <sup>1</sup>				
Males	52.3	1.68	92.5	This study
Females	31.0	2.00	96.9	This study
<i>Echinops telfairi</i> <sup>2</sup>	116.4	1.15	77.4	Dryden, unpublished data
<b>PRIMATES:</b>				
<i>Cebuella pygmea</i>				
Male	133–139	0.89 <sup>3</sup>	62.3	Morrison & Middleton, 1967
Female	96–99	0.79 <sup>3</sup>	50.9	Morrison & Middleton, 1967

<sup>1</sup> Mean values determined at 26–29°C for males and at 25–29°C for females.

<sup>2</sup> Captive-raised Malagasy tenrics (n=3); 12 determinations at 22–23°C.

<sup>3</sup> Corrected to T<sub>B</sub> at 38°C.

Because of the paucity of information on the metabolic rates of post-natally developing shrews of other species, it is impossible to speculate on whether the present data are typical of either tropical crocidurids or of shrews in general. High energy requirements, however, surely are correlated with rapid body weight gain. Nursling *S. murinus* double their newborn body weight by day 3 and quintuple it before day 9. They experience a daily weight gain rate of 39% during the first week but this rapid assimilative ability decreases to 5–8%/day during the second week of life (Dryden & Ross, 1971). These rapid weight increases are, therefore, accompanied by high metabolism, which in turn, seem related chronologically to pelage development. Metabolic stabilization, as indi-

cated by oxygen consumption, occurs after the young shrew's dorsal and belly underfur coat emerges.

Aside from the metabolic rates of young shrews, these results from tropical crocidurids are interesting in comparison with similar data from systematically distinct temperate zone soricines. Thus, *S. murinus* adults have lower energy demands than adult *Sorex araneus* or *Sorex minutus* (Gębczyński, 1965, 1971). The energy requirement of musk shrews at thermoneutrality is less than 10 cal/g hr. In common and lesser European shrews minimal requirements are 19 cal/g hr, and often much greater.

Temperate zone shrews have much higher metabolic rates than do comparably sized temperate zone rodents (see Gębczyński, 1971) but there are no data available for tropical rodents equivalent in weight to musk shrews. It is established, however, that resting marsupials exhibit metabolic indices similar to those of comparably sized eutherians (Dawson & Hulbert, 1970). We have, therefore, compared musk shrew metabolism with that of other small tropical mammals including marsupials (Table 4). Examination of these limited data indicate that among small tropical mammals, *S. murinus* has an elevated metabolism, perhaps as much as 80% greater than some.

Our finding that lactating females have no greater oxygen demand than non-lactating females is contrary to general opinion about small mammals (Grodziński & Górecki, 1967). Perhaps our failure to detect differences can in part be explained by our monitoring method. Since females were monitored with their nurslings, it is possible that maternal—infant contact (social effect on metabolism) diminished their oxygen demands, in effect balancing the metabolic cost of milk production.

We emphasize that while musk shrews have low metabolic rates compared with that of temperate zone shrews, they can tolerate cold. Thus, their consumption of 10% more oxygen following a 1°C fall in environmental temperature is higher than that of *Sorex araneus* and *Sorex minutus*, both much smaller than *Suncus*. This suggests that although *Suncus* can metabolically respond to decreased environmental temperature, it nevertheless has poor physical thermoregulatory capabilities, which may be expected in tropical species.

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G. L. Dryden,  
Biology Department,  
Slippery Rock State College,  
Slippery Rock, Pennsylvania 16057, USA.

M. Gębczyński,  
Polish Academy of Sciences,  
Mammals Research Institute,  
17-230 Białowieża, Poland.

E. L. Douglas,  
Dalton Research Center,  
University of Missouri—Columbia,  
Columbia, Missouri 65201, USA.

Gilbert L. DRYDEN, Marek GĘBCZYŃSKI i E. L. DOUGLAS

TEMPO METABOLIZMU U MŁODYCH I DOROSŁYCH *SUNCUS MURINUS*

## Streszczenie

Zmierzono tempo zużycia tlenu u młodych *Suncus murinus* (Linnaeus, 1766), ryjówki należącej do podrodziny *Crocidurinae* a zamieszkującej obszary subtropikalne i tropikalne. Stwierdzono, że tempo metabolizmu jest najwyższe u osobników najmłodszych, w pierwszych dniach po urodzeniu a stabilizacja do poziomu właściwego dorosłym następuje w drugim tygodniu życia (Tabela 1, Ryc. 1). Zużycie tlenu przez dorosłe same i samice jest wyraźnie niższe niż u ryjówek z rodzaju *Sorex* zamieszkujących strefę umiarkowaną (Tabela 2). Tropikalne ryjówki mają metabolizm około 80% wyższy niż porównywane z nimi inne gatunki ssaków występujących w tej samej strefie (Tabela 4). Nie stwierdzono by metabolizm aktywnych płciowo samiec był wyższy niż u samic nieaktywnych. Mimo względnie niskiego, jak na przedstawicieli ryjówek, tempa zużycia tlenu reakcja na działanie chłodu jest u *Suncus murinus* wyraźniejsza niż u *Sorex araneus* i *S. minutus*. *Suncus* potrafią także dobrze wykorzystywać izolacyjne właściwości gniazd, co umożliwia im niżenie tempa zużycia tlenu (Tabela 3).