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The Effect of Relative Humidity on Osmoregulation in the Squirrel Monkey (*Saimiri sciureus*)*

K. E. FRIEDL and W. N. HOLMES
University of California, Santa Barbara

ABSTRACT. Osmoregulatory balance was studied in four young, tamed squirrel monkeys (*Saimiri sciureus*, Columbia) after acclimatization to relative humidities (rh) commonly used in laboratories (30% and 50%) and to higher humidities representative of the dry and wet seasons in their natural environment (75% and 95%). The temperature was constant at 25°C and the light-dark cycle was 12:12 hours. The animals were maintained in large metabolism cages and were free moving. Water consumption and urine flow rates increased at each higher humidity from 30% rh to 75% rh and then decreased at 95% rh ($p < 0.05$). Fecal water loss was greater with higher humidity ($p < 0.05$). Evaporative water loss remained relatively constant until a break between 75% and 95% rh, at which point it decreased dramatically ($p < 0.05$). Expressed relative to total water intake, evaporative water loss demonstrated a progressive decrease with increasing humidity: 65%, 56%, 51%, and 42%, at 30%, 50%, 75%, and 95% rh. This indicates that as the humidity approaches maximum saturation, not only is the evaporative water loss component necessarily diminished, but also the apparent precipitation of alternate strategies of thermoregulation leads to a reduction in the overall water requirements of the animals. Potassium/sodium excretion ratios were relatively constant at 30%, 50%, and 95% rh but decreased significantly at 75% rh ($p < 0.05$). As a reflection of adrenocorticosteroid activity, this suggests that at 25°C, 75% rh is an optimal humidity in the maintenance of squirrel monkeys. The significant osmoregulatory alteration occurring between 75% and 95% rh provides further evidence that relative humidity may be an important factor in the seasonal physiological cycles of the squirrel monkey.

Key Words: Humidity; Osmoregulation; Water balance; Squirrel monkey; *Saimiri sciureus*; Urinary electrolytes.

INTRODUCTION

Squirrel monkeys are indigenous to equatorial environments where the climate is relatively constant and the humidity is high. In the forests of Columbia, diurnal temperatures during the dry season range from 21 to 32°C while the humidity is between 90 and 95% in the morning and drops during the day (THORINGTON, 1968). To avoid undue variances in body temperature through solar radiation, squirrel monkeys tend to adjust their level in the jungle canopy during the day. This diurnal migration, together with variations in activity, may constitute an important behavioral thermoregulatory mechanism. High levels of humidity, however, probably cannot be avoided in this manner and this may have significant osmoregulatory implications.

Although these monkeys are commonly used in research, optimal conditions for their maintenance in the laboratory have not been clearly established. Indeed, the relative humidity

*In conducting the research described in this report the investigators adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal National Academy of Sciences, National Research Council.

in most laboratory facilities may often be better suited to the comfort of the human workers than to the physiological well-being of the squirrel monkeys (BANTIN, 1966). Clearly, relative humidity is an important consideration since it is implicated as a seasonal synchronizer of the reproductive cycle in squirrel monkeys (DUMOND, 1968) and seasonal increases in relative humidity correlate with infertility in outdoor laboratory colonies (HARRISON & DUKELOW, 1973).

The present study is an attempt to assess the osmotic balance of young male squirrel monkeys maintained at constant environmental temperature following their acclimatization to a series of relative humidities corresponding to those experienced both in their natural habitat and under conditions typical of animal holding facilities and research laboratories.

METHODS

Four prepubertal male squirrel monkeys (*Saimiri sciureus*, Columbian variety) aged 24–30 months were maintained at 25°C and a constant photoperiod of 12 hr light and 12 hr dark (0500 hour, 1700 hour).

Throughout the study, the animals were kept in individual stainless steel metabolism cages (51 × 51 × 52 cm) with a perch 10 cm from the floor. The cages were solid on three sides with a 25 × 25 cm plexiglas window in the front. The top and the floor of each cage was constructed of 1.3 cm² stainless steel mesh. A large square stainless steel funnel was fitted to the floor of each metabolism cage and this contained a removable fine mesh grid to trap feces and prevent contamination of the urine that was collected in a flask below.

For two separate 1-hr periods, at 0900 and 1500 hour each day, the monkeys were transferred from their metabolism cages to standard holding cages (40 × 60 × 53 cm, with a 12-cm wide shelf 25 cm above the floor) and were allowed to feed *ad libitum* from a supply of pelleted high protein monkey food (Ralston Purina, Monkey Chow 25). This feeding schedule represents a rough duplication of the biphasic feeding pattern observed for squirrel monkeys feeding in their natural environment (THORINGTON, 1968) and in the laboratory (DUA-SHARMA & SMUTZ, 1976). During the morning feeding period the metabolism cages were cleaned and the funnels and screens were rinsed with distilled water. At the end of the feeding period, the monkeys were returned to their respective metabolism cages. Once each week the monkeys were weighed before they were permitted to start their morning meal. The monkeys were maintained on this regime for six months before the start of the experiment in order to have them become fully accustomed to their daily routine.

The daily patterns of food and water intake and the resulting patterns of urinary excretion were measured in the monkeys following their acclimatization for seven days to each of a series of relative humidities. Relative humidity (rh) in the laboratory was automatically regulated to within ±5%. Ten to thirty daily samplings were performed for each monkey at each humidity. At the end of each feeding period, food remaining in the cage was collected and weighed. Since the food became rapidly hydrated at high humidities the pellets were consistently oven-dried and reweighed. The combined amounts of dry food consumed during the morning and afternoon feeding periods each day were expressed in grams per kilogram body weight.

An *ad libitum* supply of distilled drinking water was always available in both the holding cages and metabolism cages. A small funnel was fitted under each sipper tube and connected to a flask outside the cage to collect spillage. The amounts of water consumed were estimated by measuring the volume consumed minus the volume spilled during the same interval. The

volume of water contained in the hydrated food pellets and the volume estimated to be derived metabolically from the food were added to the total consumption.

The daily urine output was measured at the beginning of the morning feeding periods and an aliquot was collected and stored at -20°C . Urine was only rarely discharged during the morning feeding period but when it was, the sample was recovered by pipette and added to the collection flask. At a later date urines were analyzed for total osmolality by freezing point depression and sodium and potassium concentrations were determined by flame photometry.

Feces discharged during the 24-hr collection period were weighed and dried to constant weight at 75°C to determine daily fecal water loss. Evaporative water loss was estimated from the difference between the total water intake and the sum of the urinary water loss and the fecal water loss. The respiratory water loss (a component of the total evaporative water loss) was estimated from the difference of the water content of expired air and ambient air and an estimate of ventilatory rate (THORINGTON, 1968).

Daily measurements for each individual were averaged for each humidity exposure. These measurements were then compared between humidities (and between monkeys) by a non-parametric analysis of variance (Friedman two way analysis by ranks; Statgraphics software, Rockville, Maryland). Significance was accepted at the $p < 0.05$ level. Values are reported as means with standard errors of the mean ($N = 4$). Regressions were fitted by the method of least squares.

RESULTS

FOOD AND WATER INTAKE

Food was consumed in approximately equal quantities during each of the two feeding periods and the total daily intake did not change when the relative humidity of the room was varied. The mean daily intake recorded at all humidities was 41.8 ± 0.8 g dry food per kg body weight. This amount of food contained 4.2 mmol Na^+ and 10.7 mmol K^+ .

The mean body weight of the monkeys did not vary significantly during the periods that they were maintained at 35%, 50%, and 75% rh. At 95% rh there was a small decrease (2%) in mean body weight for three of the four monkeys.

Daily water consumption increased with humidity up to 75% (Table 1). Following their acclimatization to 95% rh, however, the mean daily intake of water decreased relative to the previous values ($p < 0.03$).

Table 1. Components of daily water intake (ml/kg) (mean \pm SEM).

Relative humidity	Food				Total
	Drinking water	Hydration	Metabolic		
30%	123 ± 8.2	7.5 ± 0.5	21.7 ± 1.4		152 ± 9.5
50%	156 ± 22.4	7.1 ± 0.3	20.5 ± 0.7		184 ± 22.1
75%	176 ± 29.8	7.7 ± 0.2	22.3 ± 0.5		206 ± 29.9
95%	119 ± 12.8	7.2 ± 0.4	20.8 ± 1.1		147 ± 12.4

TOTAL DAILY EXCRETION OF WATER AND ELECTROLYTES

Mean daily volumes of urine excreted increased with increasing relative humidity up to a

Table 2. Daily urinary excretion rates (mean \pm SEM).

Relative humidity	Volume (mls/kg)	Sodium (mmol/kg)	Potassium (mmol/kg)	Osmolals (mosm/kg)
30%	22.7 \pm 3.3	0.42 \pm 0.15	2.92 \pm 0.20	36.2 \pm 2.6
50%	49.9 \pm 19.5	0.55 \pm 0.10	3.78 \pm 0.36	45.0 \pm 6.9
75%	64.5 \pm 22.5	0.93 \pm 0.30	3.54 \pm 0.26	56.5 \pm 3.3
95%	42.7 \pm 11.5	0.80 \pm 0.21	4.19 \pm 0.28	53.2 \pm 5.6

maximum at 75% rh (Table 2). Thereafter, increasing the relative humidity to 95% was accompanied by a decrease in daily urine flow ($p < 0.02$).

The osmotic load excreted in the urine was highest at 75 and 95% rh (Table 2) and demonstrated a progressive decrease with decreasing humidity ($p < 0.01$). No change in urinary Na^+ concentration occurred following acclimatization to the different relative humidities and changes in the daily excretion of Na^+ ($p < 0.03$) followed those described for daily urine flow (Table 2).

An examination of the daily $\text{K}^+:\text{Na}^+$ excretory ratio revealed a significantly lower ratio at 75% rh than the corresponding values observed following acclimatization to the other humidities ($p < 0.05$).

Well defined diurnal patterns were detected for water consumption, urinary volume and electrolyte excretion but these patterns did not change with humidity.

ESTIMATED DAILY WATER LOSSES VIA NON-URINARY PATHWAYS

Under the conditions of constant food intake, no detectable variations in the dry mass of feces discharged each day were detected and the mean value recorded for 44 daily samples was 7.9 ± 0.2 g per kg body weight. This amount represented $20 \pm 1.5\%$ of the dry mass of food consumed each day. The rates of fecal water loss ranged from a low value of 30.9 ± 1.2 ml per kg body weight when the monkeys were acclimatized to 50% rh, to a significantly higher value of 43.2 ± 1.7 ml per kg body weight when they were maintained at 95% rh ($p < 0.05$) (Fig. 1).

Total daily evaporative water losses were unchanged following acclimatization to relative humidities of 30% (97.2 ± 5.8 ml/kg), 50% (102.8 ± 4.3 ml/kg), and 75% (105.2 ± 14.4 ml/kg)

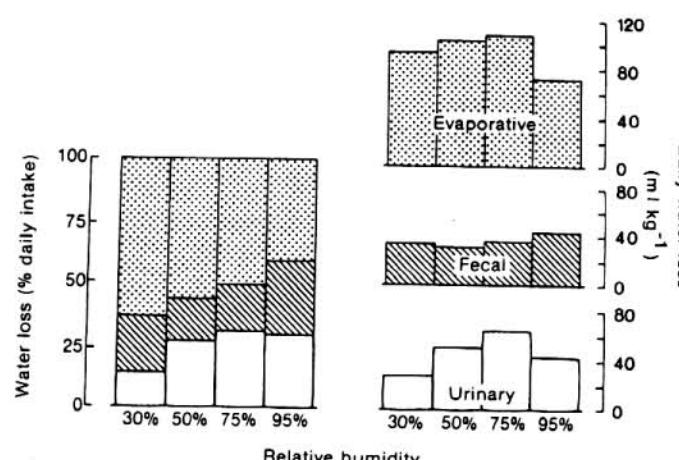


Fig. 1. Components of daily water loss at different relative humidities and 25°C. Relative water loss (left) and actual water loss (right) is shown. All three components changed significantly with relative humidity ($p < 0.05$).

but acclimatization to 95% rh was accompanied by a large reduction to 61.1 ± 6.7 ml/kg ($p < 0.04$) (Fig. 1). As a fraction of total water loss, evaporative water loss decreased with the increase in relative humidity. This fractional decline in evaporative water loss varied significantly with respect to the relative humidity where $y = 71 - 0.28x$ (y = evaporative water loss as percent of total water intake; x = relative humidity at 25°C).

The calculated daily respiratory water loss was less than 15 mls/kg at 30%. With no apparent increase in ventilatory rate this decreased to approximately 7.5 mls/kg at 95% rh.

DISCUSSION

The ambient temperatures preferred by squirrel monkeys have been described from behavioral studies in the laboratory and these preferred temperatures fall within the narrow range of the mean monthly temperatures ($23.3 - 25.6^\circ\text{C}$) which they experience in their natural environment (JAROSZ & DUKELOW, 1976; STITT et al., 1971). Similar studies on the responses to changes in humidity have not been reported although in their natural environment, squirrel monkeys experience mean monthly relative humidities ranging from 70% in the "dry" season to nearly 90% in the wet season (US Naval Weather Service, Worldwide Airfield Summaries). In this study, where the temperature was constant, the monkeys were able to respond to changes up to 75% rh with relatively minor adjustments in their water balance. At 95% rh, however, significantly greater alterations in osmotic balance occurred and this suggests that a significant shift to an alternate strategy of osmoregulation was necessary for homeostasis. At this high humidity evaporative water loss decreased, water intake was reduced and urine became more concentrated. This indicates the occurrence of a significant break point between 75% rh and 95% rh in osmoregulatory mechanisms.

The only previous report on the effect of relative humidity on the well-being of squirrel monkeys noted that at 30% rh there was an increased incidence of respiratory illness and a higher humidity (greater than 50%) helped to reduce this incidence (BANTIN, 1966). We have encountered similar problems in our laboratory and conclude that squirrel monkeys are not well suited to the lower humidity. At higher relative humidities, there is no readily apparent difference in the well being of the animals and only the discomfort of the workers discredits maintenance at 95% rh. However, the substantially lower ratio of urinary potassium to sodium excretion at 75% rh tentatively suggests that this humidity is superior to the other three humidities tested. Since no change in food intake was observed, changes in the pattern of Na^+ and K^+ excretion via either an extrarenal pathway or the feces occurred following the acclimatization to the 75% rh. This may also signify a reduction in stress at this humidity since the K/Na balance is a reflection of adrenocorticosteroid activity.

The observed osmoregulatory changes occurring between 75% and 95% rh are interesting in view of the conditions of high humidity which exist in the natural environment during the wet season. This seasonal humidity is perhaps not just coincidentally the time of decreased mating behavior, decreased serum thyroid and gonadal steroid hormone levels, and infertility (BALDWIN, 1970; COE & ROSENBLUM, 1978; KAACK et al., 1980; DUMOND & HUTCHINSON, 1967). HARRISON and DUKELOW (1973) have observed a reduction in the success rate of ovulatory induction from 65% to 0% when relative humidity increases from approximately 35% to 75% over a five-month period. Our study further implicates relative humidity as a potential regulator of seasonal cycles in the squirrel monkey with the observation that high humidity induces profound osmoregulatory alterations.

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REFERENCES

- BALDWIN, J. D., 1970. Reproductive synchronization in squirrel monkeys (*Saimiri*). *Primates*, 11: 317-326.
- BANTIN, G. C., 1966. Establishment of a squirrel monkey colony. *J. Inst. Anim. Tech.*, 17: 66-73.
- COE, C. L. & L. A. ROSENBLUM, 1978. Annual reproductive strategy of the squirrel monkey (*Saimiri sciureus*). *Folia Primatol.*, 29: 19-42.
- DUA-SHARMA, S. & E. SMUTZ, 1976. Feeding and drinking patterns in squirrel monkeys. *Indian J. Physiol. Pharmacol.*, 20: 102.
- DUMOND, F. V., 1968. The squirrel monkey in a seminatural environment. In: *The Squirrel Monkey*, L. A. ROSENBLUM & R. W. COOPER (eds.), Academic Press, New York, pp. 87-145.
- & T. C. HUTCHINSON, 1967. Squirrel monkey reproduction: the fatted male phenomenon and seasonal spermatogenesis. *Science*, 158: 1067-1070.
- HARRISON, R. M. & W. R. DUKELOW, 1973. Seasonal adaptation of laboratory-maintained squirrel monkeys (*Saimiri sciureus*). *J. Med. Primatol.*, 2: 277-283.
- JAROSZ, S. J. & W. R. DUKELOW, 1976. Temperate season outdoor housing of *Saimiri sciureus* in the northern United States. *J. Med. Primatol.*, 5: 176-185.
- KAACK, B., M. WALKER, & L. WALKER, 1980. Seasonal changes in the thyroid hormones of the male squirrel monkey. *Arch. Androl.*, 4: 133-136.
- STITT, J. T., E. R. ADAIR, E. R. NADEL, & J. A. J. STOLWIJK, 1971. The relation between behavior and physiology in the thermoregulatory response of the squirrel monkey. *J. Physiol. (Paris)*, 63: 424-427.
- THORINGTON, R. W., 1968. Observations of squirrel monkeys in a Columbian forest. In: *The Squirrel Monkey*, L. A. ROSENBLUM & R. W. COOPER (eds.), Academic Press, New York, pp. 69-85.

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Authors' Names and Address: K. E. FRIEDL and W. N. HOLMES, Department of Biological Sciences, University of California, Santa Barbara, California 93106, U.S.A.