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16. Abstract

Animals occasionally die from heat stress encountered during shipment in the nation's transportation systems. To provide a basis for a series of studies on shipping crates, environmental conditions, etc., as may be encountered in air transport of dogs, we sought to establish a suitable tolerance endpoint for heat/humidity stress in dogs. We monitored the heart rate, respiratory/panting rate, and rectal temperature of 10 male beagle dogs exposed to an air temperature of 95 $\pm 1^{o}$F (relative humidity 93 ± 2 percent) for less than 24 hours. Of the first six animals, two died during exposure, two died after being removed from the test chamber, and two survived a 24-hour exposure. Based on observations from these six dogs, a rectal temperature of 108^{o}F was tentatively chosen as the tolerance endpoint for subsequent tests. Of four additional animals tested, two were removed from the environmental chamber when their rectal temperature reached 108^{o}F and the two others finished the test with a rectal temperature not exceeding 102.7^{o}F. No ill effects were noted in any of the surviving six animals during a 7-day post-observation period. These and subsequent findings indicate a rectal temperature of 108^{o}F can be safely tolerated and can serve as a tolerance limit for additional studies of heat and humidity effects on dogs.

17. Key Words	18. Distribution Statement
Heat Stress, Environmental Stress, Animal Physiology, Heat Tolerance Endpoint, Beagle Dogs, Animal Shipment	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

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TOLERANCE ENDPOINT FOR EVALUATING
THE EFFECTS OF HEAT STRESS IN DOGS

INTRODUCTION

In hot weather, dogs and other animals occasionally die during shipment by air; some survive the stress of shipment but apparently suffer permanent damage. Cargo compartments of commercial aircraft were not designed to provide live animals with a desirable living environment. To the contrary, the cargo compartments of such aircraft are designed to contain and suppress the spread of fire should such occur (8). The Federal Aviation Administration (FAA) has no regulations to assure a healthy environment for pets, laboratory test species and other categories of animals carried in the cargo compartments of large passenger aircraft.

By means of the Animal Welfare Act, which is administered by the United States Department of Agriculture (USDA), the U.S. Congress has sought to provide for safe and humane treatment of animals during transport. The act specifies that environmental air temperature for holding animals in terminal facilities be limited to a range of 45^{o}F to 85^{o}F (4). The USDA regulations also provide for minimal ventilation of containers used for transporting dogs by stipulating that a shipping container have at least 14 percent of its wall surface area open for ventilation (5). Since no experiments had been conducted to test the effects of these holding temperatures and ventilation specifications, the USDA requested and provided financial assistance to the FAA for studies relating to acceptable holding temperatures for animals and the adequacy of the crate ventilation standard.

In the current study we looked for a useful indicator of maximum safe heat stress in dogs, from which animals could recover uneventfully without persistent harmful effects. Such an indicator or endpoint could be useful in other studies to delineate heat, humidity, and ventilation parameters for safe and humane shipment.

METHODS AND PROCEDURES

At the time of this study the USDA limiting environmental temperature for shipping dogs was 95^{o}F. We chose this temperature for the experimental protocol, combined with a high relative humidity (RH) of 93 $\pm$2 percent to provide added stress. All animals were to be monitored and observed for a period not to exceed 24 hours. Ten mature, young, male, beagle dogs were selected for this study. They weighed between 17 and 33 pounds. Noninvasive methods of monitoring rectal temperature (RT), heart rate (HR), and respiration/panting (R/P) were used. An expandable pneumograph around the thorax measured R/P. The HR was recorded via three electrodes, located over the right and left thorax at the fourth intercostal spaces and over the upper sternum. The RT was measured using a flexible thermistor probe inserted about 6 inches past the anal sphincter. An elastic net served to keep the sensors and wire leads in place (Figure 1). The dogs were free to move about

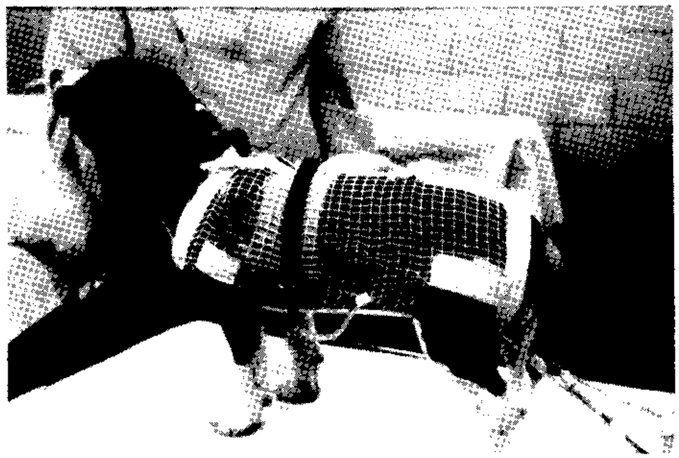

Figure 1. Beagle dog prepared for monitoring of rectal temperature, heart rate, and respiration/panting rate.

the enclosure, but were fitted with muzzles to prevent their chewing the leads. The muzzles did not interfere with respiration, open-mouth panting, or extension of the tongue. The dogs were tested individually in wooden-frame crates (30 x 18 x 22 inches) covered with a number 4 mesh wire (Figure 2). Prior to testing, the animals were accustomed to the muzzle and crate for about 2 hours each day for 3 days. On the morning of testing, dogs were fed one-fourth can of moist food about 8:00 a.m. (2 hours before exposure). An hour later they were prepared for monitoring, placed in the crate, and base-line measurements were made for 30 minutes outside the environmental chamber. At 10:00 a.m. the crated dogs were placed inside a chamber where heat and humidity had been adjusted to a 95 $\pm 1^{\circ}$F and 93 ± 2 percent RH environment. These conditions were maintained throughout the exposure period. Respiration/panting and heart rate were recorded for 30 seconds at 5-minute intervals. Rectal temperature was continuously displayed on a Digitec Thermistor Thermometer*.

*United Systems Corporation. Dayton, Ohio, Model 5820.

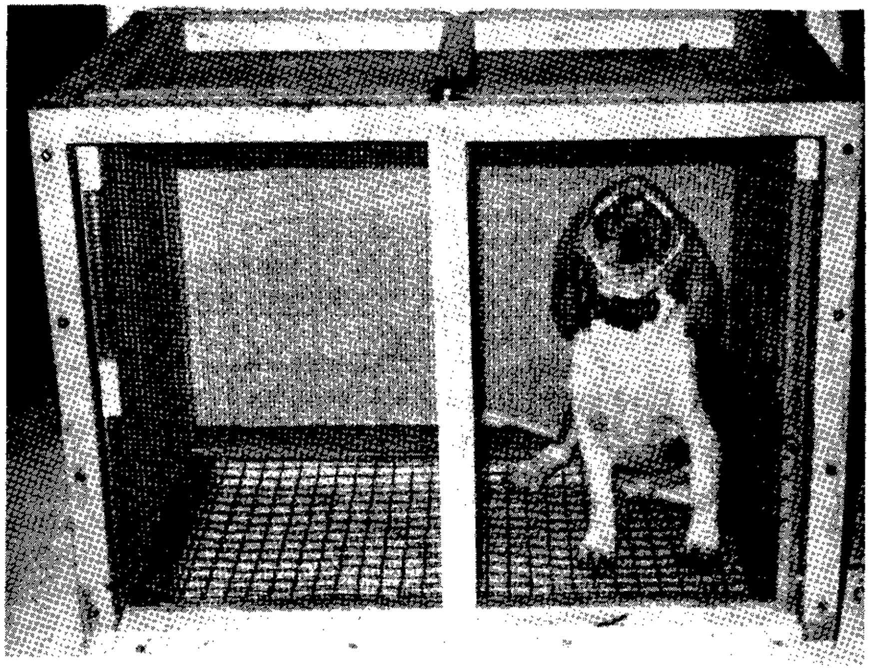

Figure 2. Crate used for exposing dogs to a heat/humidity stress environment. The dog was free to move about.

The dogs received no drugs prior to or during testing and were given no food or water during heat exposure. The chamber was lighted and the dogs were observed continuously through a window in the chamber. The animals were not disturbed during the exposure and monitoring except for occasional adjustments of sensors or leads. In addition to recording RT, HR, R/P, and chamber conditions, the dogs were observed for changes in behavior (barking and excessive activity). Simple activities such as slow rising, repositioning of the body, and slow movement in the crate, were not considered significant and were not recorded as activity. Deliberate agitated activity such as pawing at the crate walls, continuous circling, tossing of the head to shed the muzzle, rubbing the muzzle back and forth on the floor of the crate, and aggressive acts on the sensor guards were recorded. Any such activity displayed by a dog during a 5-minute period was noted. Animals could be rated over a longer observation period by the number of 5-minute intervals in which they displayed significant activity (see Table 1).

To permit a timely selection of conditions that produce significant physiological endpoints, it was necessary to stress some dogs to the point of death. To conserve animals, we used a bracket design to establish a presumptive endpoint. Animals that died from heat stress were necropsied. Gross and microscopic observations were recorded. Surviving animals were observed for 7 days, with notation being made of their clinical condition and vital signs. Pre- and post-exposure X-rays of the lungs, hemograms, urinalyses, and blood urea nitrogen levels were compared.

TABLE 1. PHYSIOLOGICAL RESPONSES DURING HEAT EXPOSURE

Dog	Time (h) to RT of 108°F	RT (°F) at:			ΔHR (BPM; 0-1.5h)	ΔR/P (RPM; .5-1.5h)	ACTIVITY*		
		.5h	1h	1.5h			0-.5h	.5-1h	1-1.5h
3	1.6	103.1	106.4	107.7	+106	-128	2	5	3
5	1.8	104.1	107.1	107.9	+ 60	- 68	6	6	6
8	2.0	105.6	106.4	107.1	+ 42	- 56	6	4	6
7	9.7	104.7	106.8	107.9	+ 30	- 36	4	3	6
6	15.7	101.9	102.9	104.0	+ 22	- 16	0	0	0
4	19.4	103.4	103.7	103.8	+ 16	- 4	0	0	0
2	23.3	103.2	103.3	103.2	+ 4	- 8	1	0	0
9	†	103.1	104.0	104.3	+ 4	+188	0	0	0
10	†	103.5	104.3	104.7	+ 24	+ 4	0	0	0
1	‡	102.3	102.7	102.6	+ 54	+ 4	0	0	0

* Represents number of 5-minute intervals during the observed .5h during which one or more displays of activity were noted; e.g., 6 indicates activity/barking occurred in each 5-minute interval.

ΔHR, ΔR/P is change in heart rate and respiration/panting rate at later compared to earlier time.

† Equipment failure, Dogs 9 and 10 removed at 20h, RT 102.5°F, and 23.2h, RT 102.7°F respectively.

‡ Maximum RT 103.5°F.

RESULTS

The RT's, HR's, and R/P's for each dog during heat exposure are presented in the Appendix. Results from the first six dogs were the basis for using a rectal temperature of 108°F as the indicator of the safe physiological heat stress endpoint. The last four dogs helped substantiate that indicator.

Of the first six tests, dog 1 survived the 24-hour exposure without ill effect, reaching a maximum RT of 103.5°F, with no precipitous changes in R/P or HR. Dogs 3 and 4 died in the chamber with RT's of 113.1°F and 113.7°F respectively. It was observed in both animals that at an RT of 110°F the HR showed a notable increase and there was some decline in R/P, both suggestive of rapid decompensation of the animals. When dogs 5 and 6 began to show similar HR and R/P changes at RT's of about 110°F, they were removed from the environmental chamber to room temperature. Monitoring was continued and both animals died within 5½ hours of removal. Dog 2 survived the 24-hour chamber exposure and had an RT of 109°F when removed. Before being taken from the chamber, this animal had also shown some indication of a noticeable increase in HR and declining R/P. However, he survived and had no clinically observable sequela of the stress during the 7-day postexposure observation period.

These observations provided support for an RT of 108°F as a suitable indicator of severe heat stress, but a level of tolerable stress for dogs. The decision was made to test this observation by removing from the chamber any animal whose RT reached 108°F.

Dogs 7 and 8 were removed from the chamber when their RT reached 108°F in 9.7 and 10.9 hours, respectively, and each recovered under ambient conditions without sequela. Dog 9 was removed at 20 hours because of equipment problems. His RT never exceeded 104.5°F and he suffered no subsequent ill effects from the testing. Dog 10 was removed from the chamber at 23.2 hours, also, because of equipment problems. His RT never exceeded 105.3°F and he too suffered no residual ill effects. Had there been no technical problems, both dogs probably would have tolerated the entire 24-hour exposure with RT's not reaching 108°F.

A number of other observations on these severely stressed animals merit discussion. Four of ten animals died as a result of the heat. The manner of death is of clinical interest. Of the dogs that died in the chamber, one displayed a considerable amount of activity during the exposure and reached an RT of 109.4°F at 2 hours. He then became quieter and was able to compensate for the heat stress, as evidenced by an RT of 106.7°F at 5 hours. However, his RT again rose to 109°F at 8 hours, at which time a distinct increase in HR and decrease in R/P occurred. Beyond 109°F there were further precipitous changes (Figure A-3), probably indicating decompensation The animal appeared extremely exhausted and died quietly without tetany or convulsions. At necropsy, 30 minutes after death, all internal organs were still hot to the touch. The lungs were dark red and blood flowed freely

† Equipment failure, Dogs 9 and 10 removed at 20h, RT 102.5°F, and 23.2h, RT 102.7°F respectively.

‡ Maximum RT 103.5°F.

from the cut surfaces. There were a few small hemorrhages around the apex of the heart, and hemorrhagic foci were noted in the trachea, kidneys, and small and large intestines. The brain was hyperemic. All other organs were not remarkable.

The second dog that died in the chamber was relatively quiet throughout exposure. His RT rose slowly and progressively and at about 109°F his HR increased and R/P decreased markedly and decompensation was indicated. This animal also appeared exhausted and died quietly. As with the previous dog, the organs were hot to touch at necropsy. The lungs were congested, dark red, and had some hemorrhage along the periphery. There were petechial hemorrhages near the apex of the heart; the stomach contained blood and demonstrated numerous small foci of hemorrhage in the gastric mucosa. The spleen was pale and shrunken. There was congestion of the small intestine and brain. Other organs were not remarkable.

Two dogs (5 and 6) were removed from the stressful environment when their RT's reached 110°F. Dog 5 began to show a sharper increase in HR and a declining R/P rate at an RT of 109°F. After being removed from the chamber and placed at ambient condition, his RT declined to 103.2°F in 2.3 hours but rose again to 108.3°F, at which time he died, 5.5 hours after being removed from the chamber. During the postexposure period the HR ranged between 316 and 208, averaging 263 beats per minute (BPM), and R/P was less than 200 per minute. There was no panting after 45 minutes at ambient conditions. The RT of Dog 6 dropped to 102.5°F during postexposure monitoring; he died at 1.8 hours after removal. His HR ranged between 296 and 156, averaging 231 BPM; R/P decreased from 164 to 68 per minute. Both dogs vomited blood after being removed from the heat chamber.

Two dogs (7 and 8) were taken from the chamber when their RT's reached 108.2°F and 108.1°F respectively. After removal, they appeared exhausted and lay quietly. Their body temperatures returned to lower levels; HR's increased initially but then decreased, while R/P's remained virtually unchanged and then declined. When RT's returned to normal levels, the dogs' activities increased; they were returned to living quarters and drank controlled quantities of water. Twenty-four hours after removal from the chamber the animals appeared normal.

There was considerable variation in the behavior of the dogs that appeared to affect tolerance of the heat stress. Animals showed varying degrees of excitement during the preconditioning but on the day of testing were generally calm during baseline data collection. When placed in the environmental chamber some dogs displayed more barking and excessive activity than others. This increased activity during the first, second, and third half hour of exposure is shown in Table 1 on a scale of 1 through 6.

From observations on these 10 dogs, as well as on many other similar male beagles separately monitored for RT alone, it appeared that tolerance to heat and humidity, as carried out in this paradigm (and others of shorter duration but more stressful), was strongly related to animal behavior in the first portion of the exposure period. Values illustrating physiological and activity variability in the initial 1.5-hour period (shortest tolerance time for any dog was 1.6 hours) are presented in Table I. Based on time to reach an RT of 108°F the dogs fell into three general categories: least tolerant, under 10 hours; intermediately tolerant, less than 24 hours; and most tolerant, not reaching an RT of 108°F in 24 hours.

Least tolerant animals had appreciably higher RT's at 1 hour and were near the 108°F endpoint at 1.5 hours, while more tolerant animals maintained a significantly lower body temperature. Least tolerant animals appeared to have appreciably increased HR's for the first 1.5 hours and the HR appeared to parallel increases in RT. Least tolerant dogs showed a decrease in R/P at 1.5 hours as compared to the R/P at .5 hours. This decrease in R/P (also in dogs of intermediate tolerance) probably signifies that the animals had reached their peak R/P performance by 1.5 hours and were experiencing generalized physiological decompensation, reflected in inability to sustain a rapid R/P rate for temperature regulation. In contrast, the most tolerant animals were still able to increase R/P at 1.5 hours and thus continued to dissipate heat.

The relationship of increased activity and heat intolerance, noted in the many other dog studies, was equally dominant here. The least tolerant animals all were noted to have significantly greater activity during the first, second, and third half hours than their more tolerant counterparts.

Dehydration was measured as weight loss during heat exposure but the findings were complicated by urination and occasional defecation. Considering this, weight loss ranged from 0.8 to 3.2 pounds with none of the animals losing more than 11 percent of their initial weight during exposure. Dehydration appeared not to be a limiting factor in these animals' abilities to compensate for the stress.

Animals that tolerated the stress testing, although showing signs of exhaustion, readily returned to normal within 24 hours. X-rays of the thorax, hematologic checks, blood chemistries, and urinalyses revealed nothing that indicated permanent or sustained stress-related change. Clinically these animals appeared no different from animals that had not been stressed.

DISCUSSION

For anticipated applied research on heat stress effects on dogs transported in various shipping containers, we needed to establish a practical indicator of a heat stress endpoint that was near the ultimate tolerance level but yet safe for the animals. Invasive techniques that would cause additional stress were not seriously considered. Physiological parameters that could easily be monitored noninvasively in dogs were HR, R/P, and RT. Of these, rectal temperature appeared to be a slow changing parameter, easy to monitor, and probably best expressive of integrated responses to heat stress.

Dogs in air shipment could be en route 24 hours and, under the most severe conditions, would not receive water. The condition of 95°F, 93 ± 2 percent RH without water intake was chosen as a reasonable stressor protocol for determining the desired endpoint. Any chosen endpoint was to be bracketed downward rapidly to minimize the number of dogs stressed to an extreme.

Panting is the primary overt expression of heat dissipation response. Crawford (2) suggested that the most efficient panting rate for dogs is between 300 to 360 pants or cycles per minute. A dog's main heat compensating response is to evaporate moisture from the upper respiratory tract, mouth, and tongue. Environmental moisture (humidity) interferes with dissipation by reducing evaporative cooling from such wet body surfaces. Thus heat and humidity are integrally related in heat stress of dogs.

Increasing the body heat load in the dog should be met by increased panting to promote effective evaporative cooling. There were primarily two patterns of panting. One pattern was manifested by dogs developing a fast panting rate relatively early during the stress and effectively maintaining a high rate throughout the test period; the other pattern was shown by animals that failed to withstand the heat and their R/P usually rose to a fast rate early during exposure, then progressively diminished, with a further abrupt decline when RT reached about 109°F. This latter more precipitous decrease apparently signaled a marked failure to dissipate body heat.

The normal HR for dogs is between 70 and 120 beats per minute (3). Heart rate generally will increase with increased activity and with increased need to transfer heat to the periphery and lungs for heat dissipation. Heart rate should rise as a reflection of increased core temperature and associated increase in general metabolism. When RT's reached about 109°F there was a decrease in R/P, and a significant increase in HR, indicating the animal's failure to cope with total heat stress.

Frankel (7) reported that 50 percent of dogs (LD-50) died when the RT reached 107.1°F. His animals were of unspecified sexes, ages, sizes, and breeds. Folk (6) stated that 42°C (107.6°F) is a fatal body temperature for the dog. Results from the current protocol, and subsequent separate studies, have shown that healthy young adult male dogs of the beagle type can be stressed to 108°F and recover. Frankel's figure for the heat LD-50 for dogs may need to be reevaluated. Clinicians and researchers should recognize that our experiments had as their objective a specific endpoint for use in specialized heat research studies. The beagle, a rather docile breed, is a standard laboratory animal and is raised precisely for biomedical studies. It is of medium size and has short hair. All these factors suggest it may be able to tolerate heat stress better than dogs of different ages, breeds, coats, and conformation. Results from these 10 dogs and subsequent experiments on more than 100 beagles (using greater external heat loads and shorter exposure periods), confirm that an RT of 108°F is a tolerable and safe endpoint for studying heat stress in dogs of this type.

Core temperature is a function of the balance between metabolic heat production, exogenous heat load and heat dissipation to the environment. Metabolic heat production is related to basic metabolic rate and work. Body activity generates heat, as exemplified by shivering to generate body heat to compensate for excessive heat loss on exposure to cold (1). The barking, pawing, chewing, and other activities, as noted in some of the test animals, would tend to increase the endogenous heat load. Animals, who remained quiet and did not expend energy in bodily movements, tolerated the heat stress better than those animals that displayed increased activity. The latter usually had a rapid rise in RT which persisted until the activity slowed markedly or ceased. During the entire observation period such animals never tolerated the stress as well as those that remained calm. This observation suggests that the docile animals and breeds probably can tolerate the heat stresses of shipment better than high-strung, nervous-type animals. This same finding also suggests that tranquilizing excited or nervous animals with drugs may aid tolerance of heat stress during shipment. Research to identify suitable tranquilizing agents is planned.

We are aware of a number of anecdotal reports of animals that were shipped and thereafter were never the same: hunting dogs that had impaired ability to point birds; dogs shipped for stud service that were of no value for breeding after shipment; and animals that were listless, etc., after shipment. Conceptually, a dog could be stressed short of death and suffer a chronic debility. We looked for, but could not find, any identifiable changes in the animals that survived the stress. Subsequently, in handling over 100 dogs stressed to an RT of 108°F, we have not observed or identified any change in any of the animals that could be related to the episode of heat stress.

Generally the treatment of heat stroke is to implement forced cooling as soon as possible. In extreme heat stroke this is probably mandatory. Two animals that were removed from the chamber alive, with RT's of 110°F, subsequently died. Obviously at that temperature they were unable to dissipate body heat and might have been saved by forced cooling. On the other hand, dogs whose RT reached 108°F were able, at room temperatures of 70°-75°F, to dissipate excess heat and return to a body temperature of 101.5°F without water intake, forced cooling, or other clinical intervention. This observation has been confirmed in many additional beagle dogs and is worthy of notation by pet owners and veterinarians.

Rectal temperature is not a sophisticated physiological measurement. It is readily obtained and can be recorded continuously with a thermocouple in the rectum and a suitable external recording device. The rectal probe is tolerated well by dogs. Rectal temperature reflects core temperature and is relatively slow to change, being buffered by the total mass of the animal's body and the specific heat of tissues. It reflects the sum total of many physiological processes, especially as related to handling body heat. It has become a practical heat stress indicator for use in our studies. As a result of our observations we can recommend an RT of 108°F in young beagle type dogs as a physiological indicator of safe and tolerable heat stress exposure, from which animals can recover without residual effect.

APPENDIX

RT = Rectal temperature (figure readings are actual hourly reading).

HR = Heart rate (figure readings are the average of the readings measured at 5-minute intervals for each hour).

R/P = Respiration/panting rate (figure readings are the average of the readings measured at 5-minute intervals for each hour).

Cycles Per Minute - Used for heart rate and respiratory/panting rate.

Graphs showing Hours of Heat Exposure/Cycles Per Minute/Rectal Temperature

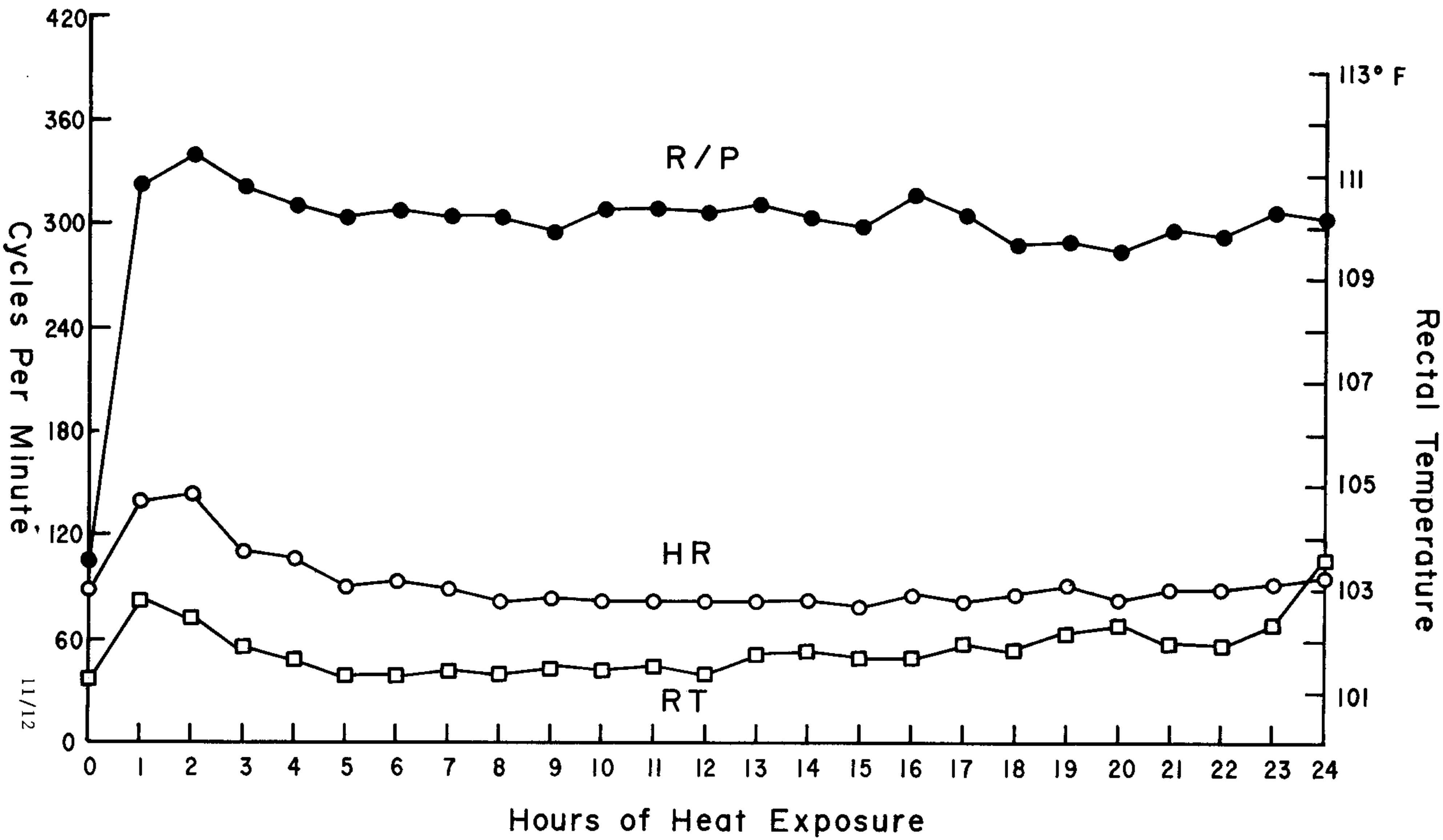

Figure A-1 Dog 1

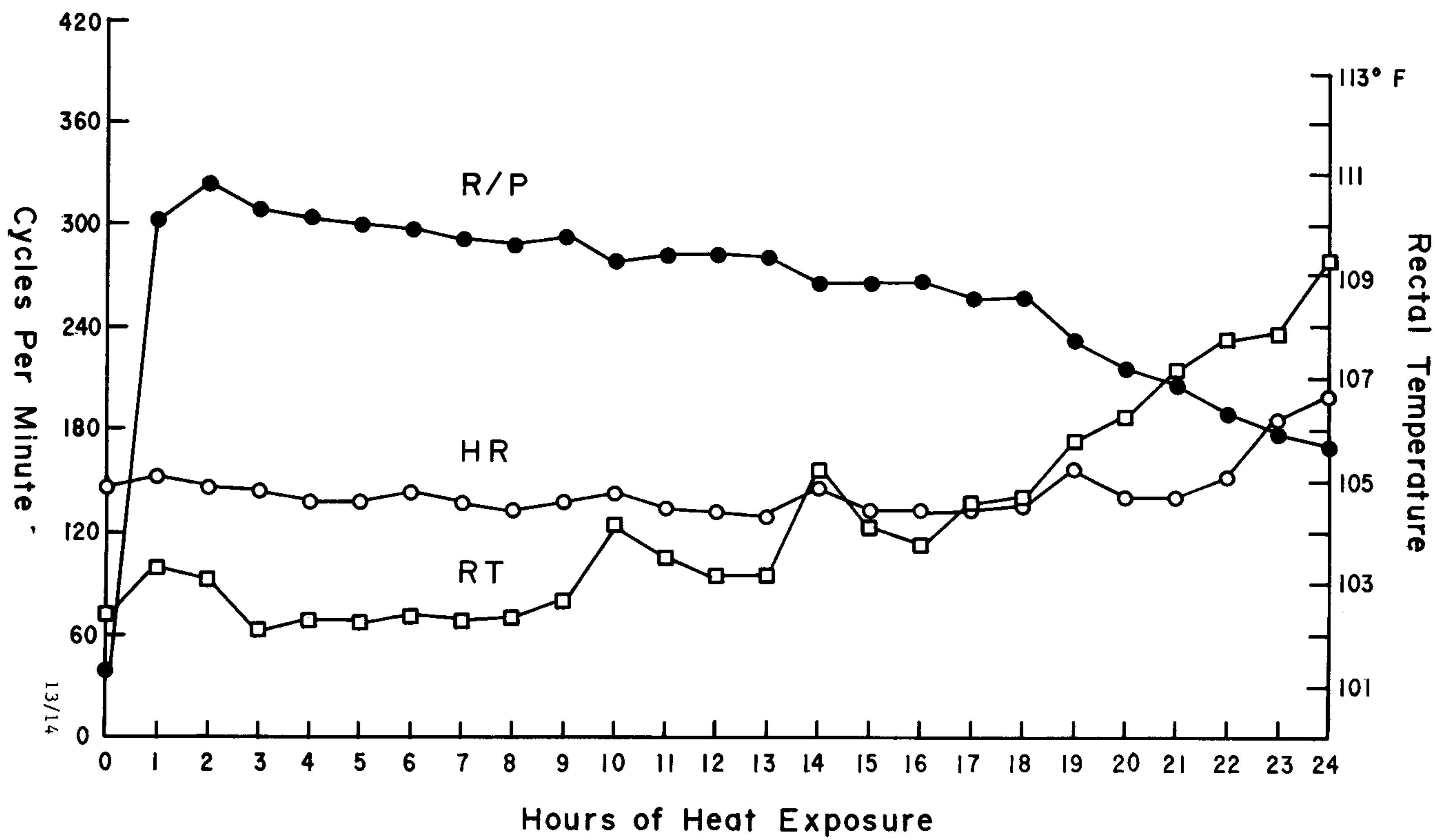

Figure A-2 Dog 2

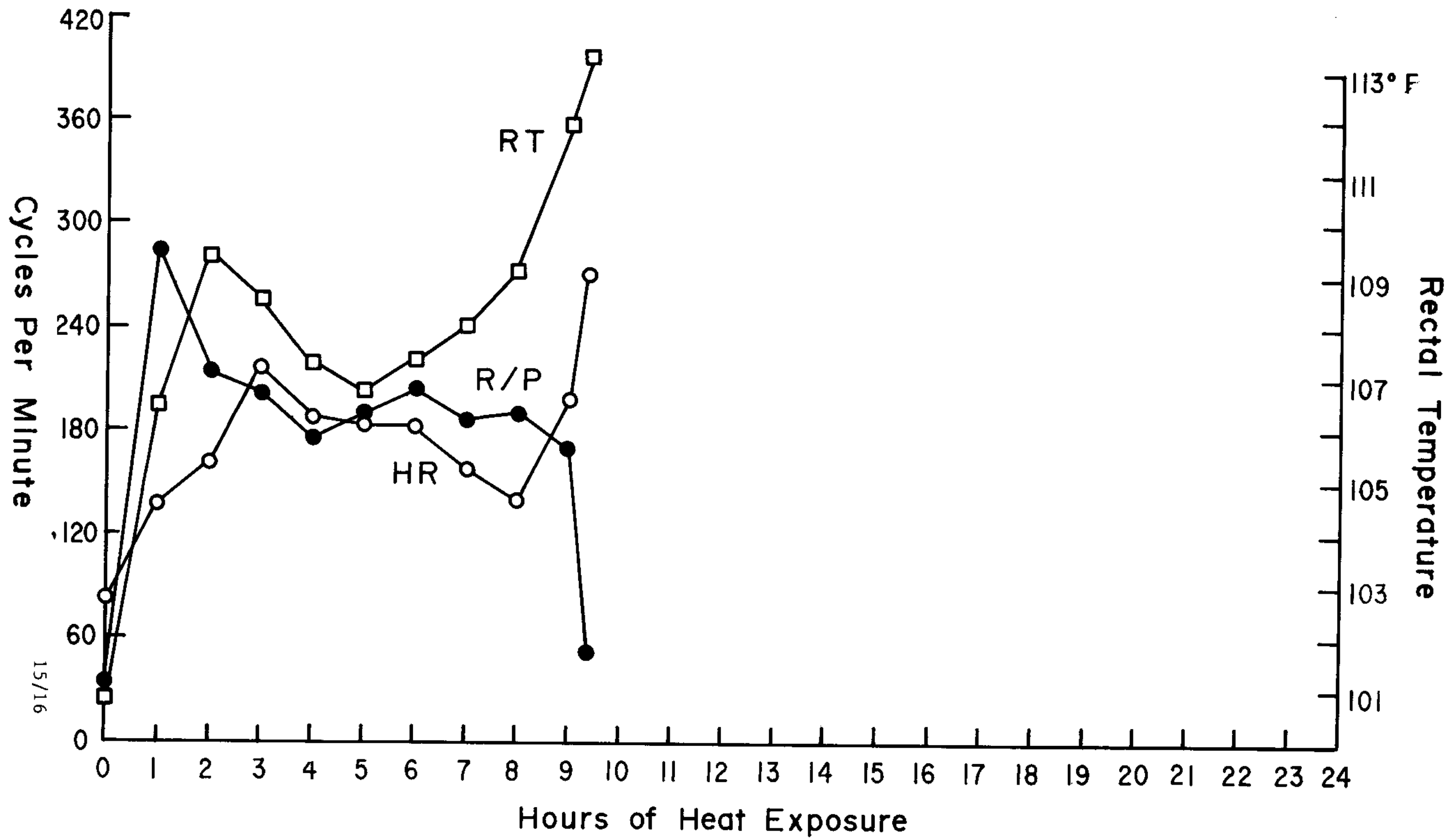

Figure A-3 Dog 3

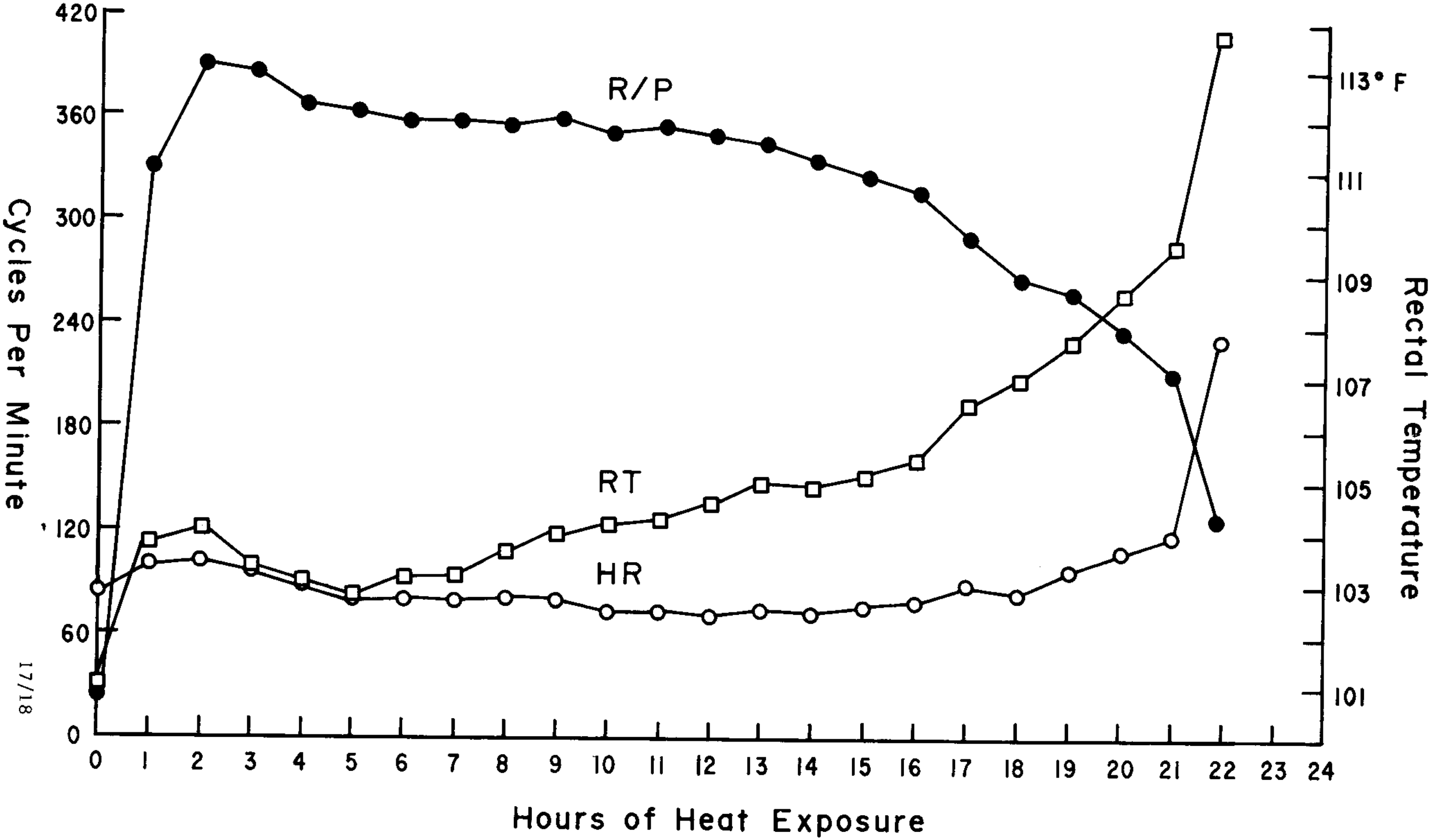

Figure A-4 Dog 4

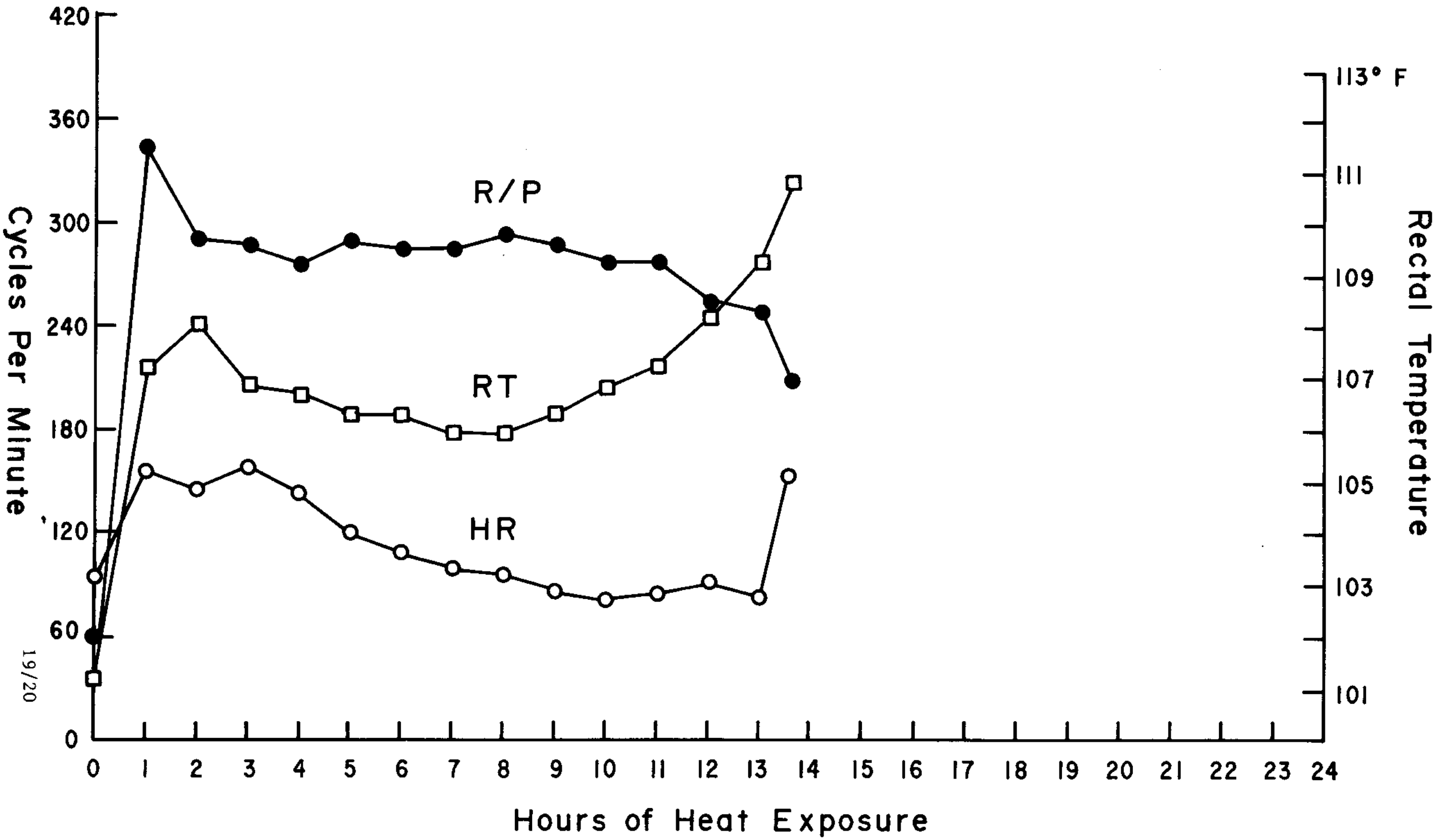

Figure A-5 Dog 5

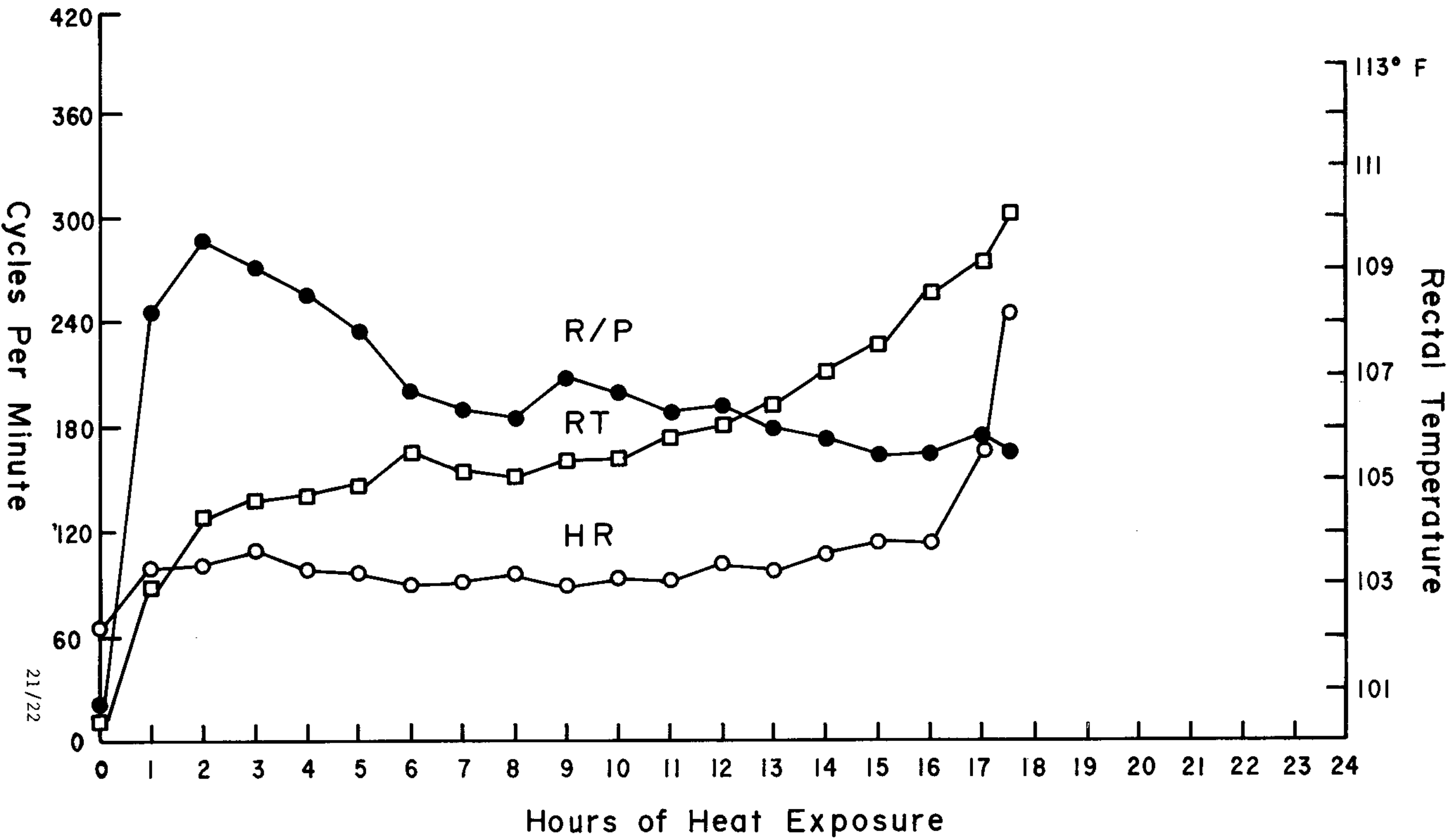

Figure A-6 Dog 6

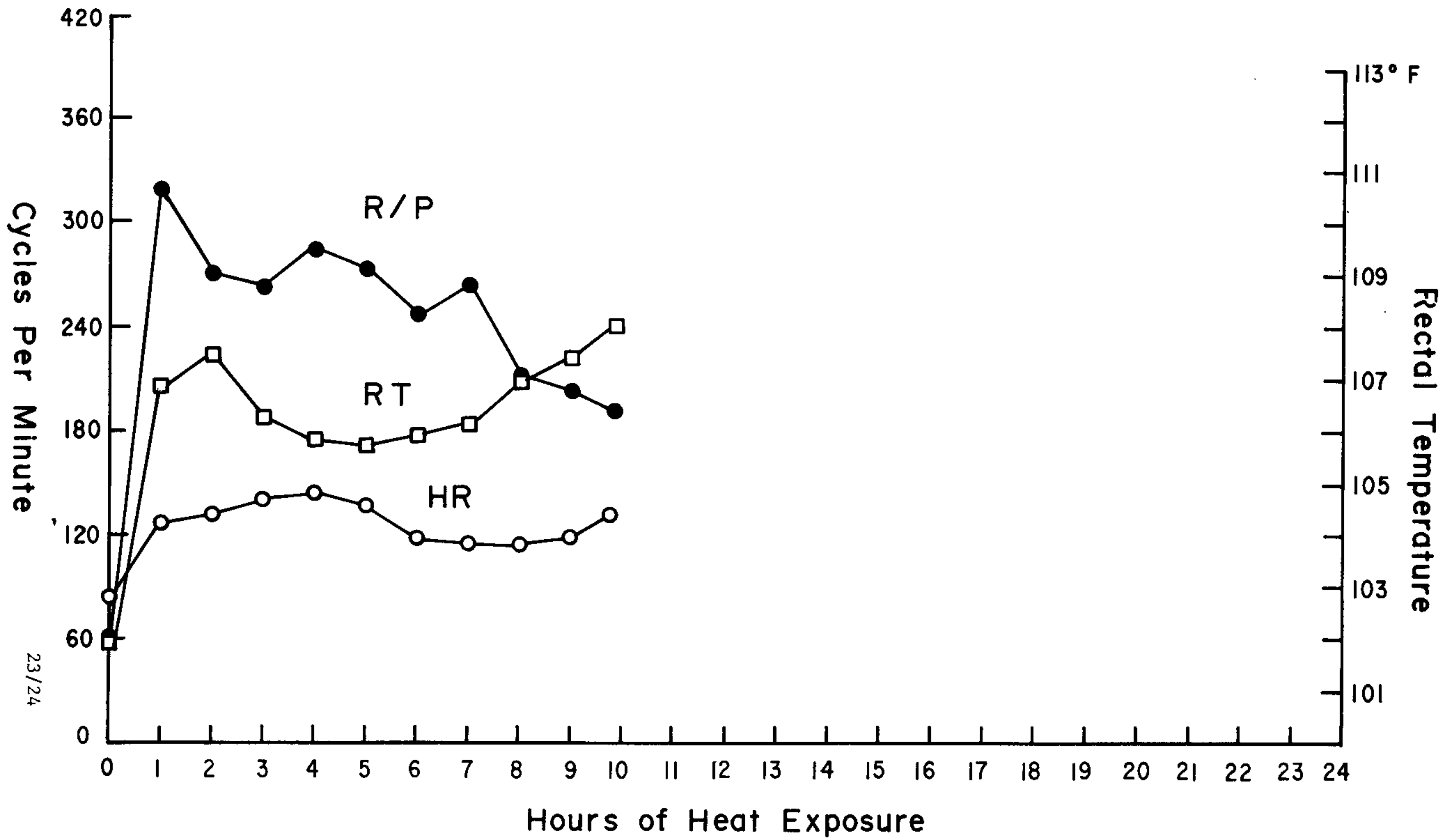

Figure A-7   Dog 7

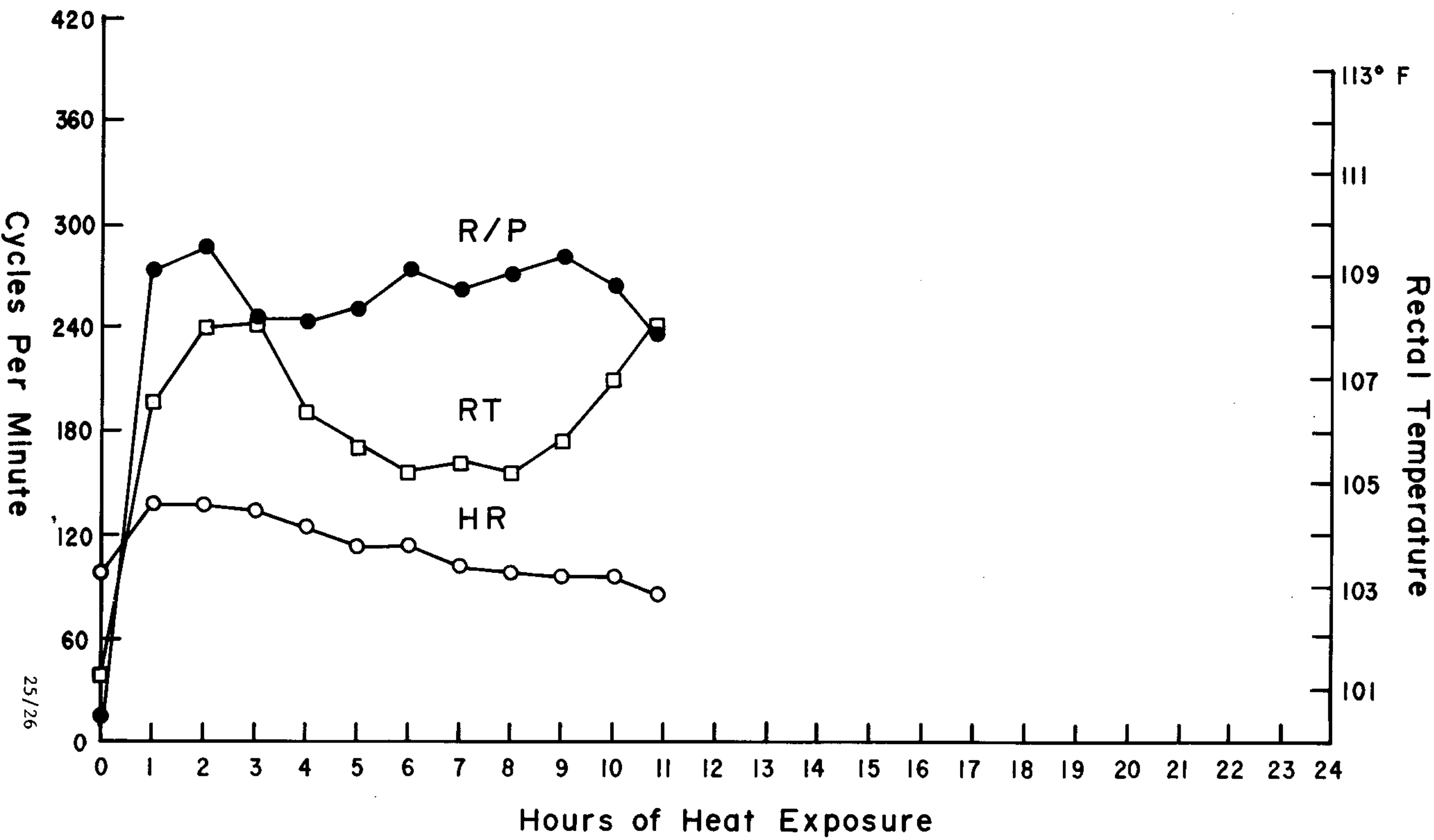

Figure A-8 Dog 8

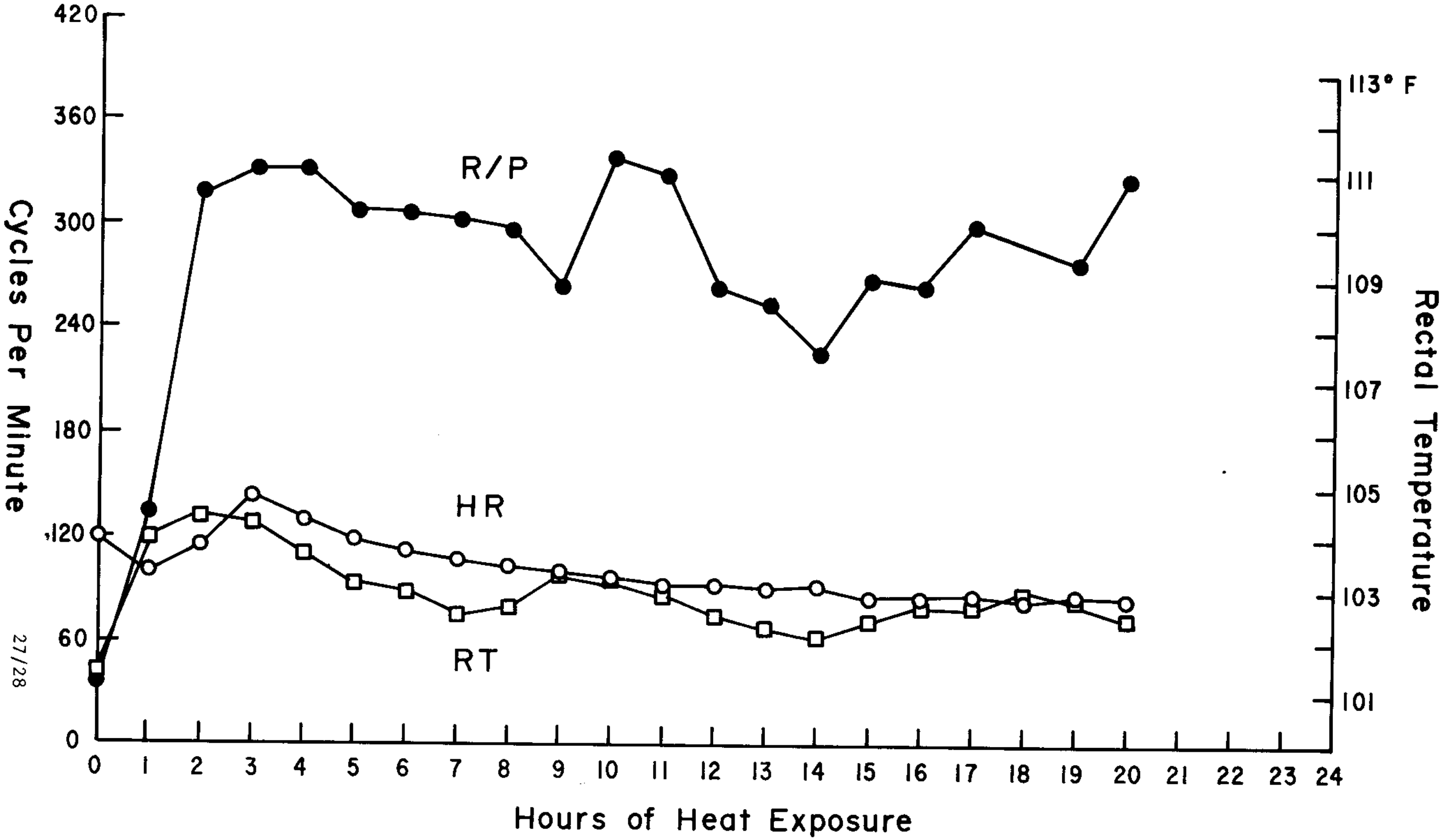

Figure A-9 Dog 9

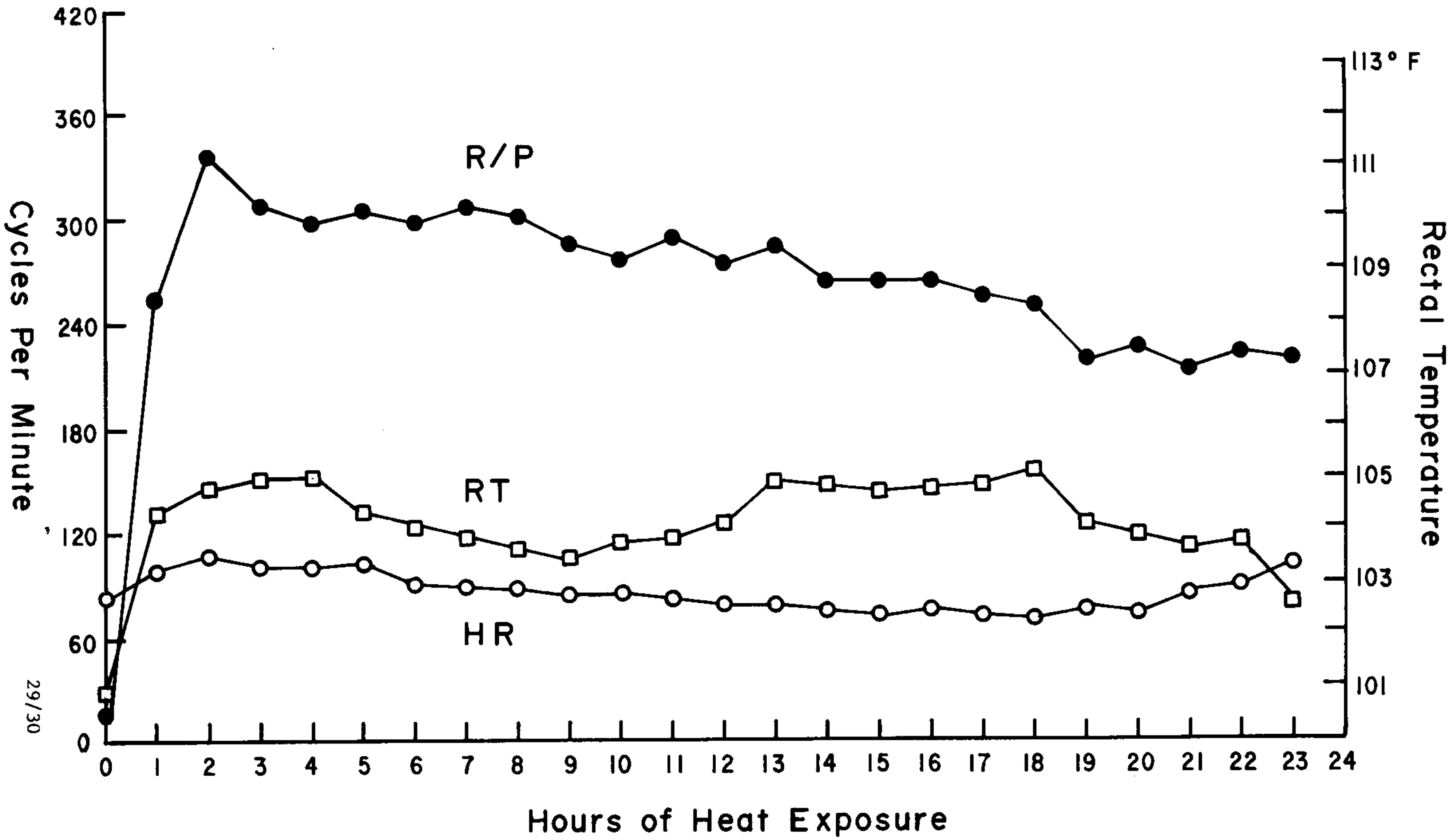

Figure A-10 Dog 10

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