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CENTRIFUGATION OF THE WHITE-FRONTED CAPUCHIN MONKEY, Cebus albifrons (Humboldt)

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CENTRIFUGATION OF THE WHITE-FRONTED CAPUCHIN MONKEY, *Cebus albifrons* (Humboldt)*

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NAVAL AEROSPACE MEDICAL INSTITUTE
NAVAL AEROSPACE MEDICAL CENTER
PENSACOLA, FLORIDA

SUMMARY PAGE

THE PROBLEM

In planning for biological experiments aboard space vehicles it is necessary that the orbiting specimens be able to tolerate certain maximum acceleration levels. Non-human primate specimens will be required for these experiments, and the screening for likely candidates is being carried out. A promising monkey is Cebus albifrons (Humboldt), the white-fronted capuchin, which has not heretofore been exposed to higher than normal levels of acceleration insofar as we are aware. Three unanesthetized, restrained capuchins were placed on a centrifuge and exposed to five headward-directed acceleration levels extending up to 10 g. Their electrocardiograms were recorded before, during, and after each test; skin temperatures were taken before and after the exposures; and breathing rates were measured from the ECG.

FINDINGS

The electrocardiograms of three C. albifrons (one male, two female) accelerated on a centrifuge show that at the beginning there is marked tachycardia. Bradycardia appears within 6-7 minutes at 7.5 g and by $1\frac{1}{2}$ minutes at 10.3 g. A squeal usually accompanies the onset of bradycardia. There were no significant skin temperature changes. The breathing rates before and after centrifuging were from 40-50 breaths per minute with an increase to 75-80 breaths per minute during exposure. Upon returning to 0 g the normal heart rate soon appears.

The ECG findings indicate that the autonomic nervous system is a prime contributor to the bradycardia which results from insufferable acceleration. Cebus is a good animal in which to study this cardiac phenomenon.

Our results indicate that Cebus albifrons is satisfactory for use in space-located laboratories.

ACKNOWLEDGMENTS

Dr. D. E. Beischer has given encouragement and guidance to this pilot experiment using a centrifuge for small animals for which I am very appreciative. Mr. J. M. Cloud, Engineering Technician, under whose supervision the centrifuge was constructed, cooperated in every phase of the project and it is for this that I extend to him my gratefulness. I wish to thank Dr. Fred Guedry and Mr. Carroll Hixson for their generosity in giving time and thought to discussions about acceleratory forces.

Experiments reported herein were conducted according to the principles enunciated in "Guide for Laboratory Animal Facilities and Care" prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences, National Research Council.

INTRODUCTION

The National Aeronautics and Space Administration is planning to use nonhuman primates in space experiments for which a type of monkey that may be chosen is the white-fronted capuchin, Cebus albifrons (Humboldt). Any living material that is sent into space will have to withstand the stresses imposed upon it during the ascent phase of the spaceward flight. One of the stresses is that of acceleration greater than 1 g. Before entering into any details of planning for the use of Cebus in space laboratories, its response to increased acceleration should be studied.

As a result of subjecting three C. albifrons to varying headward-directed accelerations ($+A_z$) up to approximately 10 g, it was found that at the onset of centrifugation there was a marked tachycardia and with an increase of acceleration there was a diminishing amount of time before bradycardia occurred. In most cases the onset of bradycardia was accompanied with a squeal emitted by the monkey. Skin temperature and breathing rate did not change significantly.

ANIMAL CENTRIFUGE

In early 1965 a small, motor-driven, animal centrifuge with an arm diameter of approximately 6 feet was constructed in this laboratory. One end of the rotating arm holds a monkey chair and the other, a counterweight. Angular velocity can be varied by mechanically setting a rotating rubber tire at various distances from the center of a metal wheel that is geared to the axis of the revolving arm. A hand brake provides rapid deceleration. Calibration of the device in rpm is accomplished by comparing the voltage output of a tachometer with the number of counts per minute registered by a photocell-activated counter (see Figure 1). The maximum velocity of the centrifuge is 100 rpm,and twenty-three seconds are required to reach this speed; deceleration time to rest from this speed is the same.

METHOD

Three C. albifrons (AO1, female, 1561 grams; AO3, female, 1691 grams; and A46, male, 1476 grams) were used in the experiments. The animals had been kept in the colony at Pensacola for some time prior to the experiments under the full-time supervision of a certified veterinarian. At no time before or during the experiments were the animals given anesthesia or any other drugs. Prior to centrifugation the animal was placed in a fitted chair and restrained by fasteners of Velcro (American Velcro, Inc.) (Figure 1).

For recording the electrocardiogram small disk-shaped silver electrodes, 0.9 cm in diameter, were taped to the left and right side of the chest on the anterior axillary line at the level of the fifth intercostal space. Plastic foam soaked with electrode paste was placed between the electrode and shaved chest. A Cardiette (Sanborn Company), located near the centrifuge and connected by shielded wires through a slip-ring assembly of the centrifuge (see Figure 1) to the electrodes, recorded the tracings obtained immediately before, as well as during and after exposure to centrifugation.

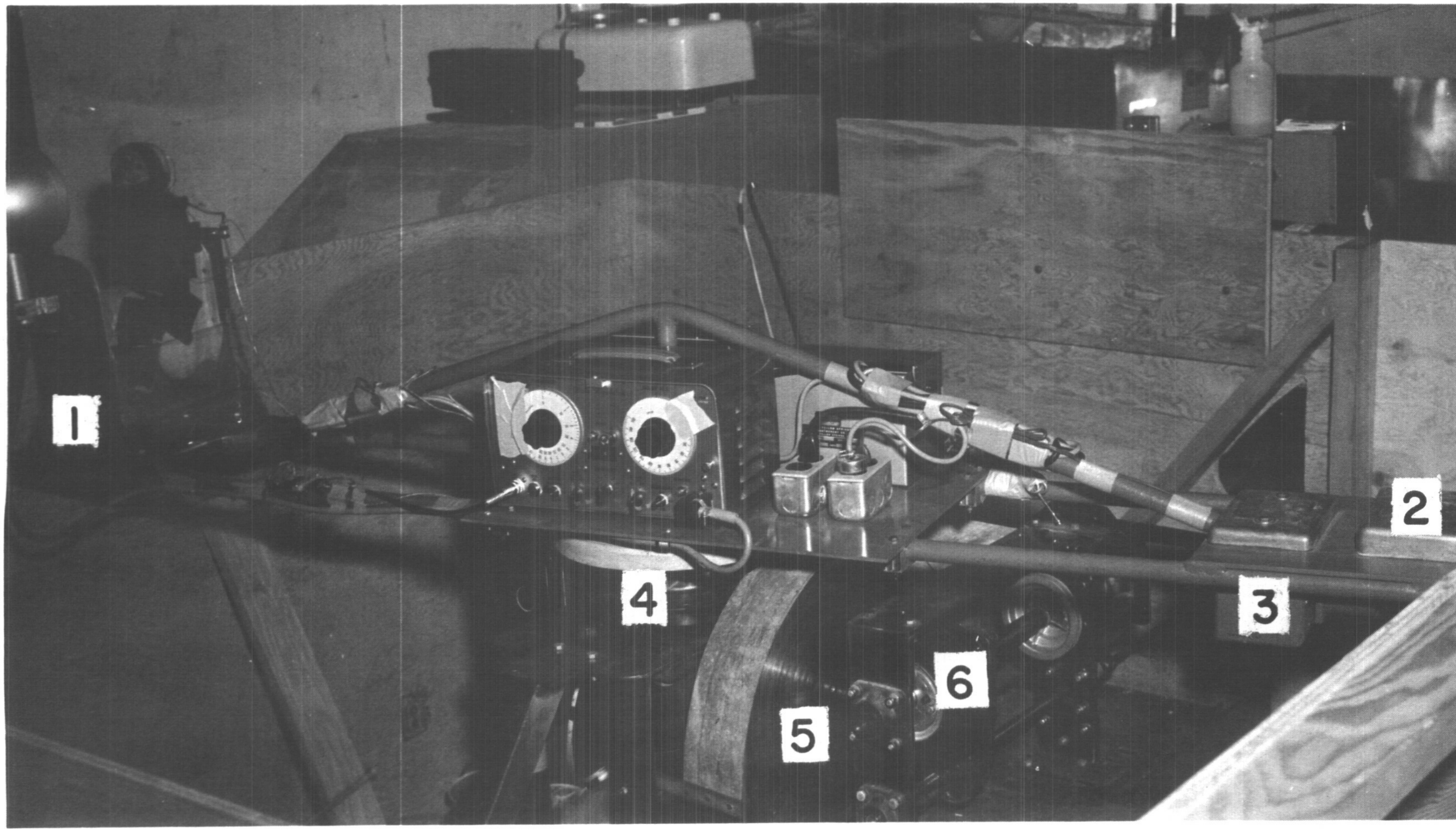

Figure 1

The small animal centrifuge installed at the Naval Aerospace Medical Institute. 1) subject holder, 2) counterweight, 3) photocell, 4) slip-ring disc, 5) metal wheel, 6) rubber drive-tire. Note skin temperature (left thigh), and electrocardiographic and electroencephalographic electrode lead wires attached to *Cebus*.

Ambient and skin temperatures were measured with a Yellow Springs Instrument Company recorder just before and after each centrifugation. The skin temperature electrode was taped to the medial side of the animal's left thigh.

An experimental schedule was established that took into consideration the desirability of exposing all three subjects during a single working day to the same acceleration level, with the increase in level being on a day-to-day basis. That is, each monkey was exposed to a single acceleration level each day which was greater than the level of the previous day. In this way the physiological endpoint was established and at the same time each individual's sensitivity was determined.

Five different resultant linear acceleration levels ($|\bar{A}|$ = 1.6, 2.8, 5.3, 7.6, and 10.3 g) were used. These were calculated using the formula

$$|\bar{A}| = \left[\left(\frac{\omega^2 R}{32.2}\right)^2 + 1\right]^{\frac{1}{2}}$$

where ω = angular velocity in radians per second; R = center of centrifuge to xiphisternum (approximately 3.032 feet). The monkey seat is pivoted so that the axis of the seat's rotation during centrifuging is perpendicular to his skeletal axis and xiphisternum with the head always moving towards the center of centrifugation. At each acceleration level, the seat was tilted so that the resultant acceleration at radius R of the monkey seat was in alignment with the z (head-foot) axis of the subject. The motion parameter of the centrifuge and the magnitude of the headward-directed linear acceleration stimulus, $+A_z$, are listed in Table I.

Table I

Headward-Directed Resultant Linear Acceleration (A_z), Centrifuge Velocity (RPM), Time (T_1) to Accelerate Centrifuge to Constant Velocity, and Time (T_2) to Decelerate Centrifuge to Rest.

	RPM			
A_z	First Minute	Remainder of Exposure	T_1 (sec.)	T_2 (sec.)
+ 1.6 g	35	35	(Promptly)	(Promptly)
+ 2.8 g	49	50	2	2
+ 5.3 g	67	71	4	4
+ 7.6 g	78	85	8	8
+ 10.3 g	83	100	23	23

Evaluation of the electrocardiogram (ECG) was made for heart rate and breathing rate. Heart rate was determined for each three-second portion of the ECG with a Viso-Cardiette Record Inserter (Sanborn Company), and breathing rate was estimated from the number of cycles of R-wave amplitude changes for each three-second recording.

RESULTS

The progressive diminution of the time for bradycardia to occur as a function of the magnitude of the resultant linear acceleration stimulus is shown in Figure 2. This graph demonstrates that all three monkeys found $A_z = +7.5$ g to be an intolerable level of acceleration for more than six to seven minutes and were physiologically normal for only a little over a minute at the $A_z = +10$ g level. Table II gives the numerical heart rate data which portray what was actually observed in the laboratory. At the beginning of centrifugation there was a change from the normal heart rate to tachycardia. At the lower accelerations tachycardia persisted for a short time, while at the higher ones this condition remained until there was a drastic drop in the heart rate. Figure 3 is typical of the type of graph obtained when a Cebus' heart rate is plotted as a function of centrifuging time at 100 rpm ($A_z = +10.3$ g). At the lower acceleration levels and depending upon the individual monkey, the bradycardia did not appear (see Figure 2 and Table II). With exception of one instance (A46 at 10.3 g), the animals let out an unusually loud squeal at the onset of bradycardia. The data in column E of Table II show that the Cebus recovered quickly from bradycardia after centrifugation ceased.

Skin temperatures recorded before and after each centrifuge run did not vary significantly (average skin temperature = 38.3°C). Ambient temperature did not vary over 3°C during a day's series of exposures and ranged during the entire experiment from 23.0° to 29.8°C.

Breathing rates could not be determined from ECG's during the episodes of bradycardia, but at the other periods of the experiment they were measured. When the centrifuge was at rest, respiratory rate was 40 to 50 per minute but with tachycardia this increased to 75-80 breaths per minute. After centrifugation, restoration of the normal breathing rate was almost immediate.

DISCUSSION

Several other investigators (1-3) have observed the same heart rate pattern of centrifugation as was evident in this experiment. First, with an onset of centrifugation there was a tachycardia which at low levels of acceleration may give way to the normal heart rate. But if the acceleration level was too great for tolerance, the tachycardia was replaced by bradycardia. Upon restoration of the animal to normal ambient conditions his heart rate soon returned to its normal value. Mehelas and Pinc (3) have observed this sequence of events in squirrel monkeys (*Saimiri sciureus* (Linnaeus)) exposed to high accelerative forces (50 to 430 g).

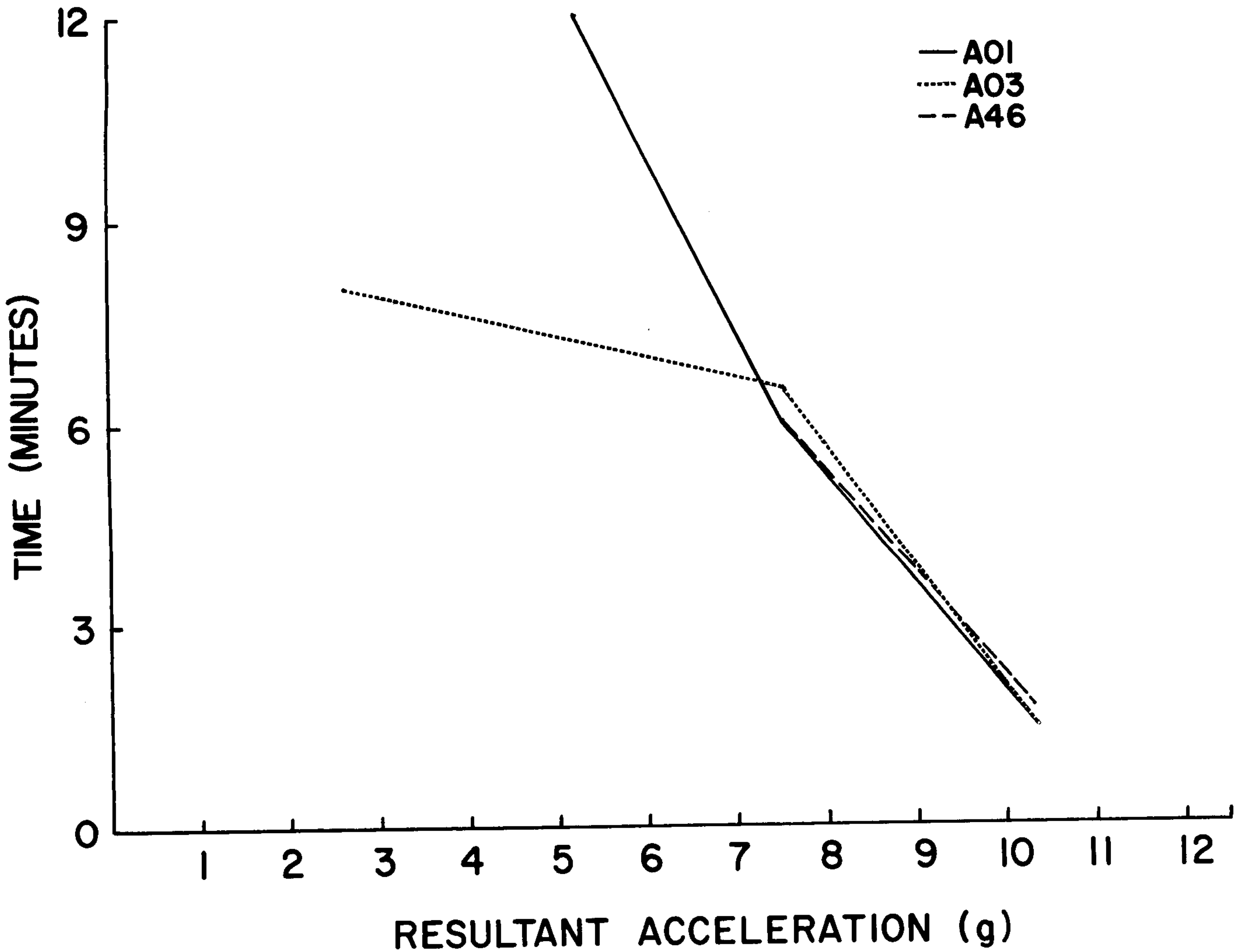

Figure 2

Time from onset of centrifugation until, at a fixed acceleration level, bradycardia and concomitant squeal occurred among three _Cebus_ monkeys.

Table II

Heart Rates of Three Cebus Monkeys During Various Phases of Exposures to Five Different Headward-Directed ($+A_z$) Acceleration Stimuli

Heart Rate (Beats Per Minute)

	1.6 g Exposure					2.8 g Exposure					5.3 g Exposure					7.6 g Exposure					10.3 g Exposure				
Subject	A*	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
A01	206	256	216	200	200	200	220	304	300	220	194	270	93‡	40	216	218	244	120‡	254	220	240	280	120‡	320	190
A03	336	324	290	270	240	286	290	80‡	180	264	254	320	--	280	220	246	250	+‡	160	222	226	298	60‡	140	238
A46	184	280	212	246	200	197	260	280	280	196	218	294	250	254	206	204	304	80‡	160	250	238	320	130	53	220

*A = Just before start of centrifuge.
B = Just after start of centrifuge.
C = Just before stopping centrifuge.
D = Just after commencing to stop centrifuge.
E = Several minutes after centrifuge stopped.
-- = ECG cannot be evaluated
+ = Abnormal ECG, immeasurable heart rate but bradycardia discernible, squeal occurred.
‡ = A loud and unusual squeal emitted from subject.

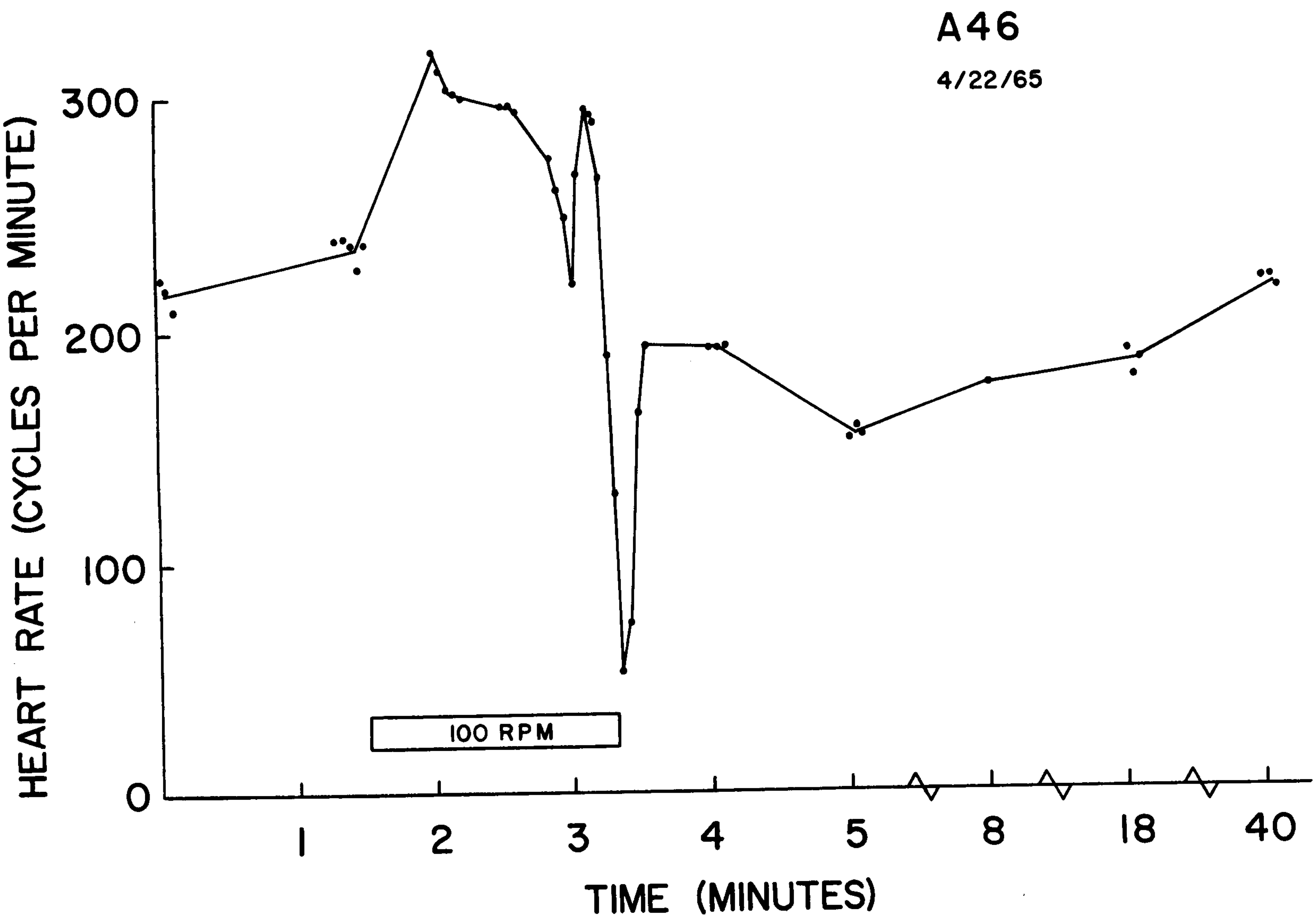

Figure 3

Heart rates of A46 (male, Cebus albifrons) before, during, and after centrifugation at 100 rpm (10.3 g).

Britton et al. (1) exposed rhesus monkeys (Macaca mulatta (Zimmerman)) to ($+A_z$) accelerations and found that acceleration of the heart rate showed a proportionality to the intensity and time of application of the stimulus. They also reported that, under prolonged exposure (5-10 minutes, 3-4 g), bradycardia set in, but recovery was rapid on stopping the centrifuge.

Kotovskaya and his co-workers (2), using M. mulatta and baboons (Papio (Müller)), exposed their subjects to "chest-back" (A_x) accelerations to determine the duration of tolerance of "12 accelerations" (units). They found that, as rotation speed increased, cardiac and respiratory rates intensified; the tolerance for 12 units was for 1 to 4½ minutes. The limits of tolerance were marked by such things as prolonged respiratory arrest or standstill, pronounced bradycardia, or disorders of automatism, and excitability.

The findings of those investigators coupled with our results seem to substantiate the electrocardiogram as an indicator of tolerance to acceleration. The tachycardia of acceleration is possibly a stress reaction involving cardiac pressor reflexes, emotions, sympathetic impulses, and hormones. Bradycardia, indicating that the acceleration is intolerable, probably shows altered sympathetic input to the myocardium which results in parasympathetic takeover of the heart's regulation and a consequent decrease of heart rate. Respiratory distress may also be involved. Taylor, Rhein, and Beers (4) have shown that bradycardia is abolished in humans injected with atropine sulphate before exposure to backward-facing impact at 15 g. They stated that this evidence supports their hypothesis that bradycardia is due to a vagal reflex from an undetermined sensor system. Further experimentation could show the same situation in Cebus. The unknown sensors might be in the aorta and carotid sinus, which are influenced by carotid artery blood volume and pressure, or in the right atrium. Findings of Kotovskaya et al. appear to implicate a neuralhormonal interaction that brings about bradycardia. They found large amounts of epinephrine and very little norepinephrine in hearts of monkeys excised thirty minutes after rotation. The adrenals showed very little epinephrine. The mechanism of bradycardia is one that could be readily studied in Cebus on a centrifuge.

At no time during centrifugation other than at the onset of bradycardia did the Cebus squeal. This occurred in every case except one (Table II). Kotovskaya et al. (2) described their monkeys as screaming when accelerations increased, but they used rhesus and baboons instead of Cebus. It would be interesting to pursue research to find if there is a relationship between the bradycardia and squealing Cebus accelerated to the point of intolerance.

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13. ABSTRACT

In preparation for biological experiments aboard orbiting laboratories three Cebus albifrons, white-fronted capuchin monkey, were exposed to five headward-directed ($+A_z$) resultant linear acceleration stimuli aboard a centrifuge and their ECG's, skin temperatures, and breathing rates recorded. Marked tachycardia was noted at the start of the centrifugation, followed by bradycardia within 6 to 7 minutes at 7.5 g and within $1\frac{1}{2}$ minutes at 10.3 g. Concomitant with the onset of bradycardia, a loud squeal was usually heard. There were no significent temperature changes, and breathing rates did not vary from normal. Normal heart rate was restored upon cessation of centrifugation. It appears that the Cebus can withstand the acceleration of space travel and therefore will be a good experimental animal in that environment.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electrocardiography- Acceleration effects						
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