Observations of Canal Sickness and Adaptation in Chimpanzees and Squirrel Monkeys in a "Slow Rotation Room"

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IN AN EARLIER experiment[2] in which human subjects were exposed to bizarre patterns of angular acceleration in the "slow rotation room" (SRR), the syndrome of "canal sickness" was defined. The main symptoms characterizing this syndrome were headache, malaise, nausea, and apathy, associated with pallor, sweating, and often vomiting. Since these symptoms are believed to result indirectly from stimulation of the semicircular canals, the term "canal sickness" was coined to cover this particular type of motion sickness. In the human, adaptation generally occurred after a period of hours or days of constant rotation, the symptoms either gradually decreasing in severity or disappearing.[1,3] After cessation of rotation, symptoms reappeared (post rotation effects), but recovery was relatively rapid.

To complement the studies on man, a variety of animals (monkeys, mice, rats, ground squirrels, racoon and possum) were subjected to rotation, and it was found that the squirrel monkey was particularly susceptible to canal sickness. Systematic investigations were carried out on these monkeys and on chimpanzees.[4] The objectives of the present study were to measure the susceptibility of the animals to canal sickness at different levels of Coriolis acceleration, to study the capacity of the animal for adaptation to slow rotation, and to correlate the manifestations of canal sickness with labyrinthine function.

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APPARATUS AND PROCEDURE

Subjects:—Five chimpanzees, two female (No. 176 and 178) and three male, were obtained from Yerkes Laboratories of Primate Biology, Orange Park, Florida. Their ages ranged from 3.5 to 4.5 years, and their weight varied from 14.5 to 18.6 kg with an average weight of 16.4 kg (36 lbs). The animals were raised in captivity and appeared to be in excellent general health. There was no past history of ear disease or trauma. During their stay in Pensacola the animals were kept singly or in pairs in large cages.

Eleven squirrel monkeys, six female and five male were also studied. These monkeys had been obtained from Peru, South America, and were among a colony kept in large cages in the animal quarters at Pensacola. These animals were approximately two years old, and their weights varied from 500 to 740 grams. They had been given anthelmintic treatment tuberculin skin tests and a chest x-ray.

Slow Rotation Room:—As described in earlier reports,[2] this room, 15 feet in diameter and 7 feet high, has been constructed around the center post of the Pensacola human centrifuge. A large animal cage was placed against one wall of the room about six feet from the center post of rotation, and each animal was placed individually

in the cage which allowed it freedom of movement. Voice intercommunication between the experimenters within the SRR and those in the control room was possible. Because of the great inertia of the flywheel and the superstructure, the centrifuge ran very smoothly throughout extended periods of time. The rates of rotation varied between 1.9 and 10.0 rpm. Even at maximal velocity the centripetal force was small, the resultant G at the center of the cage being 0.1.

The Stimulus:—The effective stimulus, a Coriolis acceleration, was generated whenever the animal rotated its head out of the plane of rotation of the room. This resulted in a pattern of stimulation of the semicircular canals not in accord with other sensory inputs. Variations in stimulus were produced by changes of the angular speed of the centrifuge, which was under precise control. In addition, the stimulation pattern was affected by changes in the number and rapidity of the head movements of the animals. The number of head movements was under partial control of the experimenter who could attract the animal's attention through the use of colored objects. Rapidity of head movements tended to be characteristic for the animal.

Symptomatology:—The chimpanzees and the squirrel monkeys initially were exposed to rotational velocities of 5.4 and 10.0 rpm. The animals were observed individually by the experimenter riding with the animal during the total period of exposure; with the exception of attracting their attention to induce head movements, they were not disturbed. The manifestations of illness exhibited by the susceptible animals were graded as follows:

Grade 0: Normal activity with usual inquisitiveness and alertness.

Grade I: Reduction in activity and alertness. Chimpanzee assumes prone position in cage with to and fro movements of head; squirrel monkey huddles or crouches quietly and drowsiness is frequently observed.

Grade II: Yawning, salivation, chewing and smacking of the lips.

Grade III: Retching and vomiting.

Threshold and Adaptation Studies:—The critical rotational speeds at which Grade III symptoms appeared were determined for each of the susceptible animals. After establishment of this critical speed for vomiting, an attempt was made to adapt one chimpanzee and three squirrel monkeys to tolerate stronger stimulation by initial prolonged exposure to low angular velocities.

Caloric Tests:—In the chimpanzee, the function of the semicircular canals was tested by irrigating the external auditory canals with cold (10° C.) water. For this purpose each animal was sedated with Nembutal injected intramuscularly (22 mg/kg) and placed on a restraining table in an upright position. The external canal of each ear was syringed for one minute or until nystagmus appeared.

The caloric testing of the semicircular canals of the squirrel monkeys was modified in that an arrangement was made whereby the water bath temperature could be varied from 9° to 37° C. Initially, the ears of the nonsedated animals were syringed for thirty seconds with water at body temperature (37° C.), and the syringing was then repeated at progressively lower temperatures until nystagmus appeared. In this manner a threshold for appearance of nystagmus following cold water stimulation was established for each monkey.

RESULTS WITH CHIMPANZEES

Symptomatology:—Marked differences were observed in the response of the chimpanzees to speeds of 5.4 and 10.0 rpm (Table I). The symptomatology of canal sickness could clearly be observed in chimpanzee 176 at 5.4 and higher speeds (Figs. 1 A, B, C). This animal would consistently exhibit the varying degrees of illness in which copious vomiting represented the final stage (Grade III), often accompanied by

urination which seemed involuntary. The final stage of vomiting developed in chimpanzee 178 on one occasion at 10.0 rpm (Figs. 2 A, B). Several episodes of Grade II illness were noted and II symptoms but rarely Grade III; at 5.4 rpm vomiting was observed during all exposures of the nonadapted animal (Figs. 1, D, E). These experiments established the threshold for the first

TABLE I. RESPONSE OF CHIMPANZEES TO ROTATION AND CALORIZATION

CHIMPANZEE	RESPONSE TO ROTATION	CALORIC TEST	
		RIGHT EAR	LEFT EAR
176 ♀	VOMITING AT 5.4 to 10 RPM	HORIZONTAL NYSTAGMUS 15 SEC. DURATION	HORIZONTAL NYSTAGMUS 15 SEC. DURATION
178 ♀	VOMITING AT 10 RPM ON ONE OCCASION ONLY	HORIZONTAL NYSTAGMUS* 10 SEC. DURATION	NO RESPONSE*
163 ♂	NO SIGN OF ILLNESS AT 10 RPM	NO RESPONSE*	NO RESPONSE*
RIC ♂	NO SIGN OF ILLNESS AT 10 RPM	NO RESPONSE*	NO RESPONSE*
PIX ♂	NO SIGN OF ILLNESS AT 10 RPM	NO RESPONSE	NO RESPONSE

*RESULTS OF TWO CALORIC TESTS

on exposure to 5.4 rpm, and the signs of illness were identical to those exhibited by chimpanzee 176.

In contrast to animals 176 and 178 the three male chimpanzees remained active and well when exposed to an angular velocity of 10.0 rpm, and this response was verified on three separate occasions for a duration of twenty minutes. Any signs of sickness in the male animals failed to develop despite frequent head and body movements.

Threshold Studies:—Gradations of illness were observed in the two susceptible chimpanzees when they were exposed to increasingly higher angular velocities. At 1.9 rpm, animal 176 continued its normal activity without sickness; at 3.8 rpm the animal experienced Grade I stage of canal sickness in chimpanzee 176 at about 2 rpm and for the third stage at 5 rpm. Chimpanzee 178 also developed a progressive increase in severity of symptoms but at higher angular velocities (Figs. 2 C, D, E) Grade II symptoms were observed at 5.4 rpm and above; the third stage of canal sickness was noted only on the initial exposure to 10.0 rpm.

Adaptation Studies:—Chimpanzee 176 was rotated at 3.8 rpm for one, two, and three hours on separate trials which were immediately followed by exposure to 5.4 rpm (Figs. 1, F, G, H). As in previous experiments at 5.4 rpm, the animal vomited. It was concluded that if adaptation were to occur, longer periods of exposure to sub-threshold velocities were necessary.

Consequently, the animal was subjected to

constant rotation for two days. The first thirty hours of this period were spent at 3.8 rpm; the next eighteen hours at 5.4 rpm (Fig. 3A). At no time during this period was vomiting observed, and throughout this extended run the animal was normally active during the daytime when the room was lighted. The animal ate well at the usual feeding times. After this forty-eight-hour period of constant rotation, the animal was subjected to rotation for one hour at 7.2 rpm, immediately followed by three hours at 10.0 rpm. During the first hour at 10.0 rpm, the animal exhibited symptoms Grade I and II. Thereafter, the condition of the animal improved gradually, and during most of the run at 10.0 rpm the chimpanzee showed no sign of illness despite frequent head and body movements. Adaptation was clearly demonstrated.

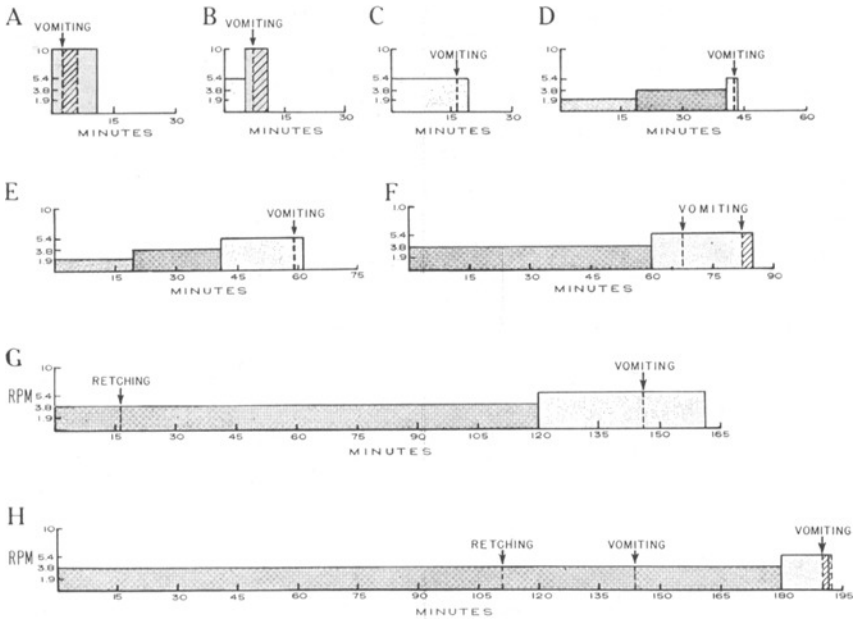

Fig. 1. Response of Chimpanzee 176 to Slow Rotation.

The persistence of the adaptation was studied in experiments performed one and five days later. In the first experiment the animal was rotated for a period of sixty minutes at 5.4 rpm (Fig. 3 B). The speed was then increased at fifteen-minute intervals to 7.2 and 10.0 rpm, respectively. After an exposure of twelve minutes duration at 10.0 rpm, Grade I manifestations appeared and Grades II and III shortly thereafter.

In the second experiment five days after adaptation, the animal was again rotated at 5.4 rpm for sixty minutes (Fig. 3 C). When the speed was increased to 7.2 rpm, the animal vomited after a twelve-minute exposure. These experiments indicated a gradual loss of adaptation over a five-day period of time.

Caloric and Hearing Tests:—When the external canal of each ear of chimpanzee 176 was syringed with cold water, nystagmus developed which was primarily horizontal with the quick component to the opposite side of the irrigated ear (Table I). The nystagmus was of equal intensity following stimulation of either ear and persisted for approximately fifteen seconds. Syringing the ears of animal 178 for one minute produced nystagmus of brief duration in the right ear only. Despite repeated syringing of

both ears with cold water for five minutes, nystagmus failed to develop in the three male chimpanzees. The caloric tests were repeated two months later on three of the animals with results identical to the first test.

In order to exclude the possibility of deafness, all five chimpanzees were exposed to sounds of moderate intensity coming from an adjoining room. The animals reacted by moving towards the sound source. In addition, a recording of the sounds of the preparation of the food for the daily feeding of the chimpanzees was made and played to three of the chimpanzees individually in a soundproof room. All three animals responded to sound levels which were fifteen to twenty decibels higher than the auditory threshold of a normal human. It was concluded that the chimpanzees could hear most sounds to which they were exposed.

RESULTS WITH SQUIRREL MONKEYS

Symptomatology:—The eleven squirrel monkeys studied, with one exception, were highly sensitive to rotational velocities of 5.4 rpm or greater. Retching and vomiting developed in the animals generally within fifteen minutes of exposure, and vomiting continued at five- to ten-minute intervals throughout the exposure. The one exception (monkey EN) failed to show signs of illness despite repeated exposure to speeds of 10.0 rpm.

The signs of illness exhibited by the squirrel monkeys were similar among the susceptible animals and correlated well with those observed in the chimpanzee. The first sign of illness consisted of a reduction of the animal's usual quick and vigorous movement, and the animal would frequently sit quietly in a crouched position and hold to the side of the cage (Grade I). Shortly thereafter salivation and swallowing could be observed (Grade II) which progressed to retching and vomiting (Grade III). The vomiting episodes would generally last two to three

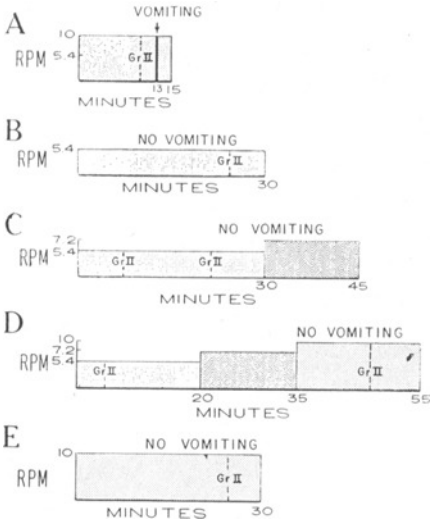

Fig. 2. Response of Chimpanzee 178 to Slow Rotation.

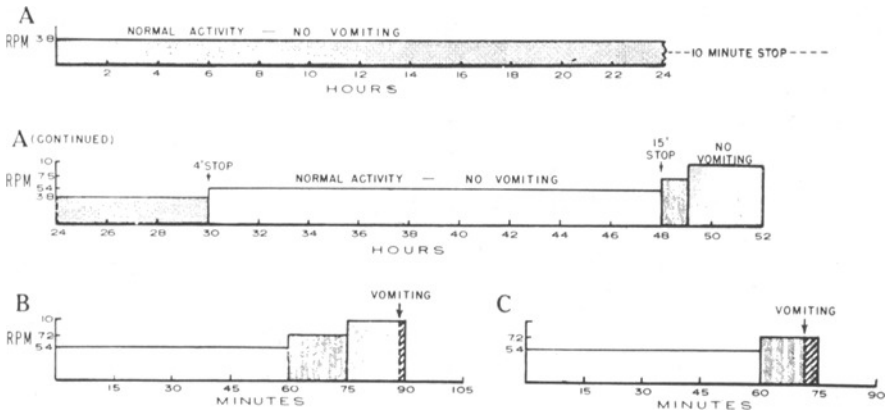

Fig. 3. Adaptation of Chimpanzee 176 to Slow Rotation

minutes, followed by apparent relief of symptoms and a resumption of body movements. Invariably a return of illness would then occur and lead to a second period of vomiting. Between vomiting spells the animal frequently would appear drowsy and would huddle quietly with its eyes closed.

TABLE II. THRESHOLD RESPONSE OF SQUIRREL MONKEYS TO ROTATION AND CALORIZATION

SQUIRREL MONKEY	THRESHOLD RESPONSE		
	SLOW ROTATION (RPM)	CALORIC TEST (C°)	
		RIGHT EAR	LEFT EAR
E B	1.9	26	24
E C	2.6	29	29
E D	1.9	26	25
E E	1.9	27	26
E G	1.9	23	26
E H	1.9	28	30
E I	3.8	19	20
E K	1.9	27	26
E L	1.9	30	30
E M	1.9	30	30
E N	None at 10 RPM	15	None at 9°

Threshold Studies:—The rotational speed at which Grade III illness developed was determined for each of the eleven monkeys (Table II). Initially, the animals were exposed for twenty minutes at a low velocity (1.9 rpm). If no vomiting occurred during this time the speed was increased to 2.6 rpm. At these speeds retching and vomiting developed in nine of the eleven monkeys. Monkey EI did not vomit until the speed was increased to 3.8 rpm, and as previously noted monkey EN showed no signs of illness at the maximum velocity of 10.0 rpm.

Adaptation Study and Aftereffects:—Three squirrel monkeys (EE, EG, EH) which were highly susceptible to angular acceleration were subjected to increasing velocities over a four-hour period of time (Fig. 4). The first two hours of this period were spent at 2.6 rpm which was slightly above the threshold response of each animal. After ten minutes at this speed all three monkeys became ill, and the vomiting persisted at ten- to fifteen-minute intervals for ninety minutes. After this initial period of illness the animals appeared well, and their activity increased. The angular velocity was then increased gradually until it reached 10.0 rpm. During this time the animals appeared well although their activity was reduced, and no vomiting was observed. After ten minutes of exposure to 10.0 rpm, however, all three animals vomited for a brief interval and then remained well until the conclusion of the exposure.

After a total duration of four and one-half hours at increasing angular velocities, the centrifuge was stopped. Within five minutes all of the animals showed signs of illness by reduction of activity, salivation, and in one instance a two-minute episode of vomiting. These signs of illness exhibited by the squirrel monkeys after

the room had stopped lasted for ten minutes and were interpreted as manifestations of post rotation effects.

Caloric Tests:—The results of the caloric tests for the squirrel monkeys are listed in Table II. The water temperatures in the table are those at which nystagmus first appeared. Horizontal nystagmus was observed in nine of the eleven monkeys at 23° to 30° C. There was no appearance of nystagmus in monkey EI until the water temperature had been reduced to 19 to 20° C. A few nystagmic eye movements were noted when the right ear of monkey EN was syringed at 15° C., and no response could be produced by syringing the left ear at 9° C.

DISCUSSION

Although only two chimpanzees exhibited signs of canal sickness when subjected to the stress of angular acceleration, there was a striking correlation of the manifestations of illness between the chimpanzee and the squirrel monkey. The latter animal, however, was more susceptible to the effect of rotation, and perhaps this is because of the squirrel monkey's keenly developed sense of balance and frequent irregular head movements. These results are of interest especially in comparison with human behavior under similar conditions.

The absence of canal sickness in the three male chimpanzees and squirrel monkey EN has its counterpart in the insignificant changes in performance in a human subject with bilateral destruction of the inner ears.[2] The negative caloric tests in these four animals indicate a loss of vestibular function, although no etiology for the diminished labyrinthine function in these animals could be found. In addition, chimpanzee 178 and squirrel monkey EI, in which the results of the caloric test indicate a diminished response, were less sensitive to rotation than the animals with more normal labyrinths. The experiments point to the conclusion that in the animals as in man, the canal sickness experienced on the slow rotation room depends upon normal vestibular function.

The signs of illness exhibited by the animals are similar to those seen in man and include expressions of drowsiness, reduction in activity, and the sequence of salivation, retching, and

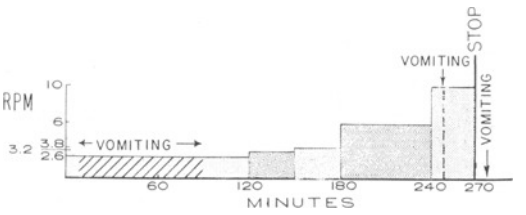

Fig. 4. Adaptation of Three Squirrel Monkeys to Slow Rotation.

vomiting. Such symptoms as headache, dizziness, sweating, and visual illusions experienced by humans cannot be verified in animals; however, the animal's prone or crouched position, the expression of the eyes, and the occasional passage of urine were probably manifestations of anxiety.

There is much similarity in the rate and degree of adaptation between the chimpanzee and man. At 5.4 rpm adaptation occurs far more readily than at 10.0 rpm. These results suggest that the neurophysiological mechanisms leading to adaptation are likely to be similar for man and chimpanzee. The state of adaptation in the chimpanzee diminishes rapidly in a five-day period of time; similar information on human subjects is not yet available. The three squirrel monkeys likewise demonstrated the ability to adapt to slow rotation and at a much faster rate than man or the chimpanzee. Although adaptation was not complete, the animals showed a significant tolerance to high angular velocities after four hours of exposure.

In studies involving humans, post rotation effects were frequently observed on cessation of rotation. These included fatigue, difficulty in walking and nausea. Post rotation effects were observed in the three squirrel monkeys, although they were not seen in the chimpanzee.

The results of these preliminary studies indicate that the main mechanisms underlying canal sickness in man and in the chimpanzee and

squirrel monkey are likely to be very similar. The latter animal in particular is highly sensitive to the stimulus of slow rotation and must be regarded as an animal of choice for experiments which cannot be carried out on man. In this way the squirrel monkey may contribute considerably to a clarification of the etiology and the final control of canal sickness. In addition, the sensitivity of these animals to canal sickness and the possibility of adaptation should also be considered in space flight experiments.

SUMMARY

Five chimpanzees and eleven squirrel monkeys were exposed to rotations varying from 1.9 to 10.0 rpm in the Pensacola slow rotation room. Two of the chimpanzees and ten of the squirrel monkeys manifested signs of canal sickness similar to that experienced by normal humans. Those animals that failed to manifest canal sickness exhibited evidence of impaired vestibular function as demonstrated by cold water caloric testing. The symptomatology of canal sickness was similar in the susceptible animals and could be graded as to severity.

Adaptation to the unusual stimulus during constant rotation could be demonstrated with both the chimpanzee and the squirrel monkey. This adaptation appears to be of short duration. These findings are highly encouraging for the use of monkeys and higher apes in studies of the manifestations and etiology of motion sickness of all types.

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