

**Distribution of this document is unlimited.**

**LACK OF RESPONSE TO THERMAL STIMULATION OF THE SEMICIRCULAR  
CANALS IN THE WEIGHTLESSNESS PHASE OF PARABOLIC FLIGHT\***

**Robert S. Kellogg and Ashton Graybiel**

**Bureau of Medicine and Surgery  
MR005.04-0021.136**

**NASA Order R-93**

**Released by**

**Captain H. C. Hunley, MC USN  
Commanding Officer**

**9 August 1966**

**\*This research was conducted under the sponsorship of the Office of Advanced Research  
and Technology, National Aeronautics and Space Administration.**

**U. S. NAVAL AEROSPACE MEDICAL INSTITUTE  
U. S. NAVAL AVIATION MEDICAL CENTER  
PENSACOLA, FLORIDA**

## SUMMARY PAGE

### THE PROBLEM

The objective of this study was to clarify the mechanism of caloric nystagmus in man by conducting the test in weightlessness. Eight subjects were selected on the basis of a strong nystagmus response to irrigation with ice water. Nystagmus was determined by oscillograph tracings and direct observation, and, in addition, subjective responses of the subject were obtained.

### FINDINGS

The experimental evidence indicated that, under the conditions of this experiment, zero gravity completely suppressed caloric nystagmus. This supported Bárány's original hypothesis that caloric nystagmus was dependent on difference in specific weight of the endolymph in the horizontal canal.

## INTRODUCTION

In 1906, Bárány (1) described caloric nystagmus and also advanced an hypothesis to explain the response. He wrote, "Heat is conducted via the temporal bone to the semi-circular canals, affecting first the horizontal canal. The result is a change in specific gravity of the endolymph in the canal's most lateral part relative to its innermost part. If the canal is not horizontal, this sets up a current in the endolymph which affects the cupula and leads to nystagmus." Bárány's hypothesis has been widely but not universally accepted. The following is a summary of the leading theories which have been advanced to explain the reaction:

1. Bartels (2) in 1911 suggested that the caloric reaction is due to a direct effect on the nerves, heat having a stimulating and cold a depressing effect.

2. Kobrak (3) in 1918 theorized that the caloric response is caused by vascular reactions in which the vessels in the periphery of the labyrinth are constricted by a cold stimulus and the central vessels react with dilation. This, according to Kobrak, sets up a flow of endolymph and a consequent deviation of the cupula.

3. Borries in 1920 and in 1925 (4,5) pointed out the importance of both the labyrinth as a whole and of the otolith specifically. He stressed experiments in which subjects whose semicircular canals were damaged or extirpated still showed clear caloric reactions.

4. Brunner (6) in 1921 put forth the notion that the caloric reaction is not the result of deviation of the cupula but is of central origin.

5. van Caneghem (7) in 1946 suggested that a hot caloric stimulus might cause an increase of the intralabyrinthine pressure and a cold stimulus might cause a decrease. He felt that the increase of the intralabyrinthine pressure has its effect at the utricle.

In weightlessness heating or cooling the endolymph cannot cause a change in specific weight; hence, endolymph flow for this reason would be an impossibility. On the other hand, conduction of heat would occur, and heat and cold would lead to expansion and contraction, respectively. Hence, conducting the caloric procedure in weightlessness would test many of the above-mentioned theories, which was the purpose of the experiment.

## PROCEDURE

### SUBJECTS

Eight subjects, ranging in age from 20 to 41 years, were used in the study. All eight were on flight status, implying they had met the USAF medical standards. One subject, G, manifested a 40 db hearing loss in the high frequency range. None had experienced any spontaneous labyrinthine disturbances. All subjects had had extensive experience in military aircraft.

## THE FORCE ENVIRONMENT

A report by Weiss (8) describes in detail the force environment of the zero-gravity airplane in parabolic flight. The flight profile for each subject consisted of three consecutive zero-gravity maneuvers flown in the modified KC-135 (Boeing 707) (Figure 1). In each maneuver the aircraft was placed in a shallow dive followed first by a pullup generating 2.0 G units and then a pushover into a ballistic trajectory with approximately twenty-five to thirty seconds of weightlessness or near-weightlessness. Recovery involved a second pullup generating 2.0 G units followed by a brief period of level flight. The second and third maneuvers followed seriatim, the intervals ranging from one to several minutes.

## INSTRUMENTATION

Standard corneoretinal extraocular electrodes were applied as shown in Figure 2. Vertical and horizontal eye movements were recorded separately. Two Kaiser EEG miniature solid-state pre-amplifiers were used to provide voltage amplification. The units were temperature compensated and had differential input circuitry such that, when the eye ceased moving, the tracing returned to the baseline; the response time was 1.2 seconds. The outputs of these amplifiers were passed directly to a CEC 5-124 oscillograph recorder equipped with CEC type 7-325 galvanometers. Sensitivity of the galvanometers was 2.92 mv/inch deflection. Movement of the eye in an upward direction produced an upward deflection on one graph, and movements of the eye to the right produced an upward deflection on the second graph. A third galvanometer was used to record aircraft normal acceleration (G level) as sensed by a Statham 2 G strain gauge accelerometer.

## METHOD

The subjects were selected partly on the basis of a good nystagmic response to irrigation of the ear with ice water. Two or more baseline caloric tests were performed on each subject before flight tests were carried out. Since ice water was used for irrigation, the first ground-based test served to familiarize the subject with the experimental procedure. The subject, inclined backward 60 degrees, was instructed to fixate on a convenient spot on the ceiling and note all of his subjective sensations. Thirty cubic centimeters of ice water were injected with a syringe directly into the external canal in approximately three seconds. One subject, H, had a remarkably short lag time, nine seconds, before the appearance of nystagmus, while in the others it varied between sixteen and twenty-one seconds. Inflight, the subject was inclined 60 degrees backward from the visual vertical with respect to the aircraft, which approximated the gravito-inertial vertical when this force was acting. The first maneuver served as a control. In the second maneuver, ice water was injected during the transition period from 2.1 to 4.5 seconds prior to the onset of weightlessness at which times the G loading was about 0.5 G unit or greater; this minimized or prevented the tendency toward "airlock" due to the minimum energy configuration of fluid in zero G. Visual observation and sometimes recordings were continued throughout the third parabola. Immediately thereafter the subject was interrogated. Recordings obtained from subjects C and D were not wholly satisfactory, and chief reliance was placed on visual observation of eye movements.

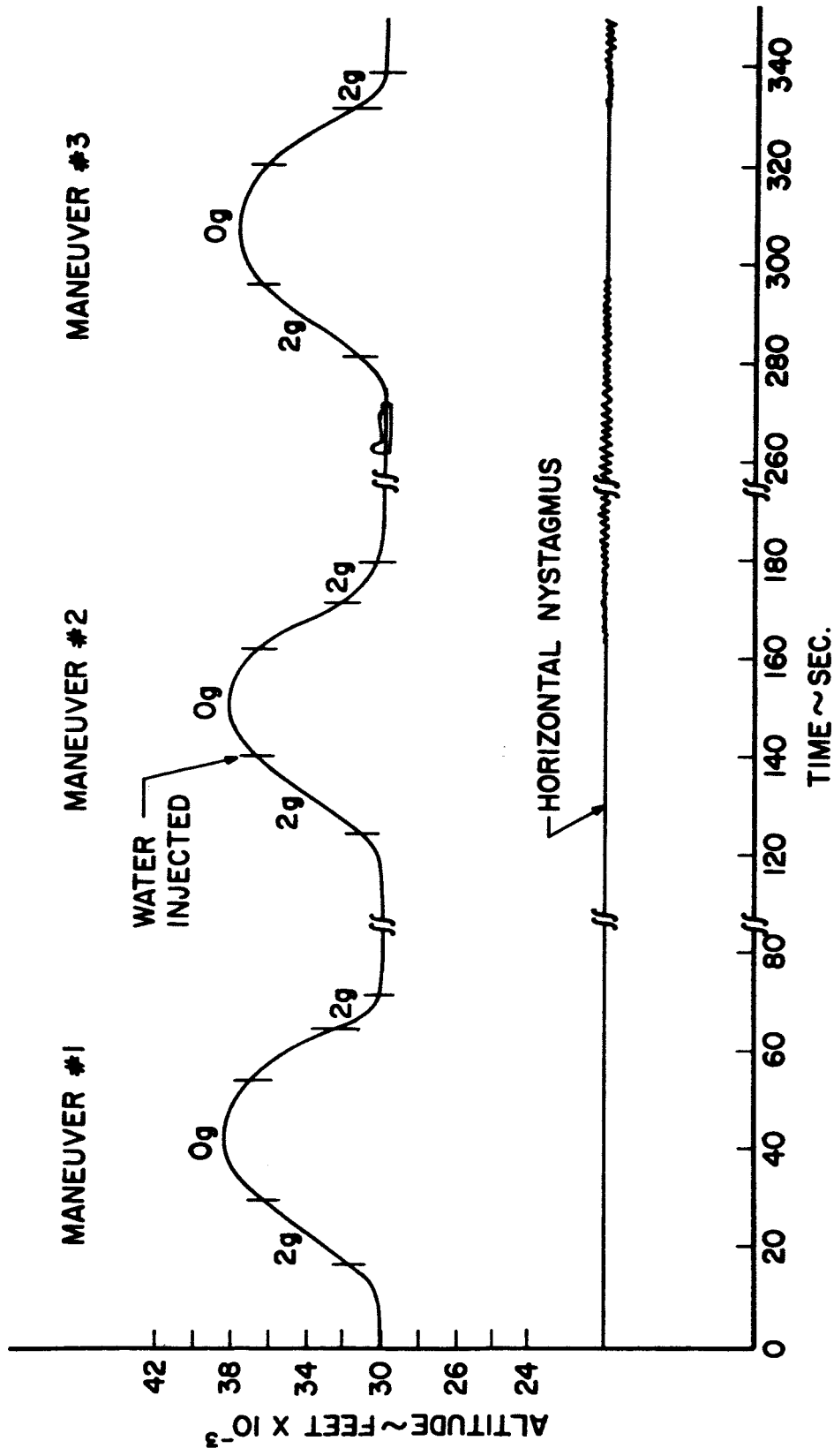


Figure 1

Caloric Nystagmus Aircraft Maneuvers

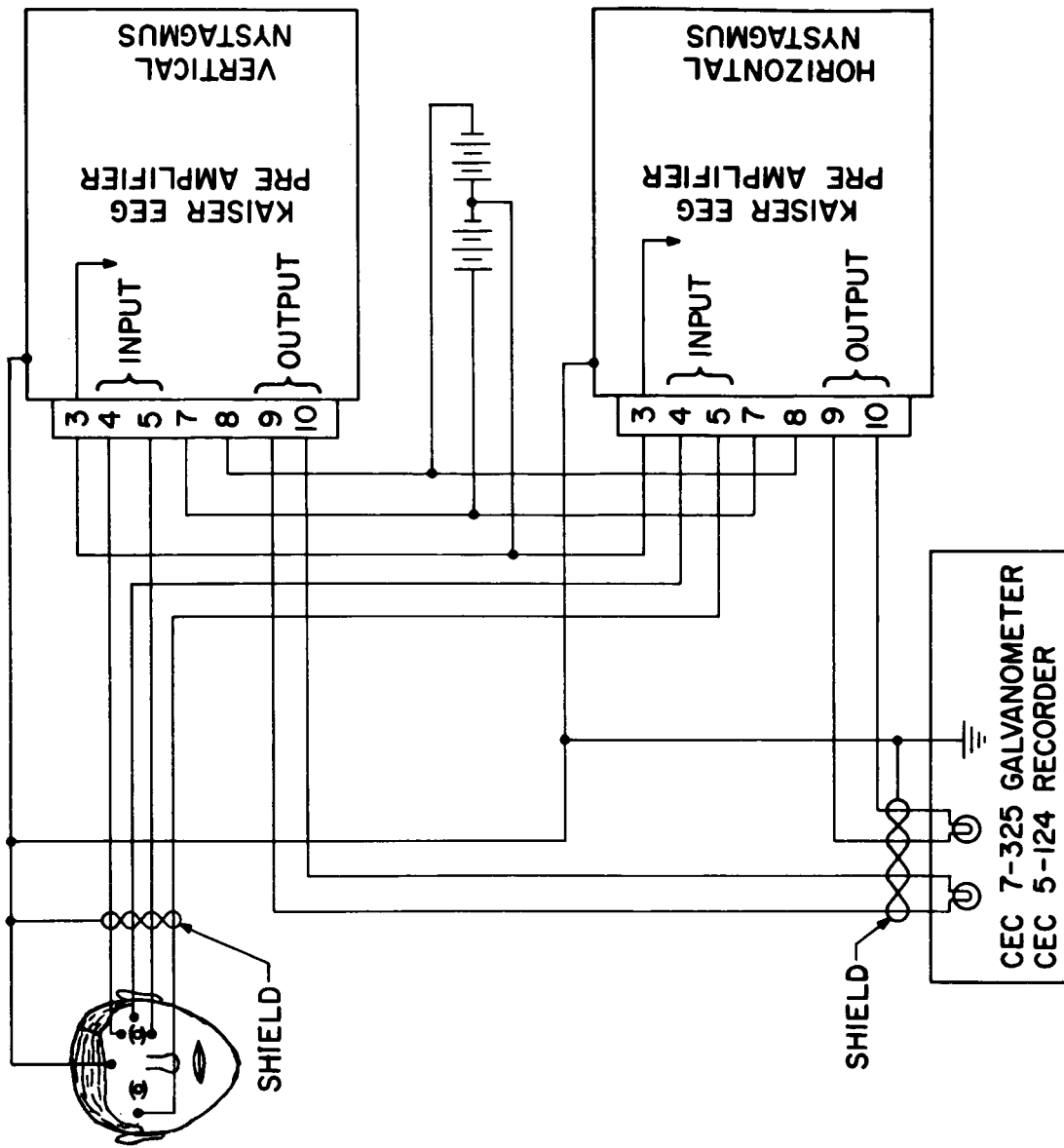


Figure 2  
Caloric Nystagmus Instrumentation

## RESULTS

The important findings are summarized in Table 1. A nystagmic response was not manifested during the control parabolic maneuver. In the second maneuver, nystagmus was not observed during the weightless phase although the total response period available, i.e., from the onset of irrigation to the end of the weightless phase, exceeded the ground-based nystagmus delay time by 0.1 to 16.5 seconds. On pullout, at approximately 1.5 G (four to eight seconds after the end of weightlessness), horizontal nystagmus appeared in every instance. During the zero G phase of the third parabola, nystagmus disappeared in the few instances it was present in the pullup. The nystagmus always beat in the anticipated direction.

Subject H was an exceptionally good producer of nystagmus and some details of the findings in his case are summarized in Figure 3. During the first maneuver there was little eye movement aside from blinking. During the second maneuver nystagmus first appeared during pullout about five seconds after the end of the weightless phase and at which time the G loading was approximately 1.5 G unit. Nystagmus continued during level flight after the second maneuver (Figure 3,3) and during pullup in the third maneuver (Figure 3,4) but disappeared in the weightless phase. On pullout a few beats appeared but thereafter none appeared on the record.

There was a tendency for the subjects to be aware of the nystagmic beats during increased G loadings, and the impression was gained that spontaneous eye movements, aside from blinking, were reduced in weightlessness.

## DISCUSSION

Although the observations just reported must be regarded as an experimental probe, yet they were clear-cut. With eyes open and fixating a target, subjects did not manifest nystagmus during control parabolas; hence, any complicating positional nystagmus and nystagmus due to increased G loadings were avoided. Carrying out the irrigation prior to the onset of weightlessness, for the most part, not only had the effect of extending the zero G phase but also of ensuring good contact between water and skin interface. The adequacy of the stimulus was demonstrated by the long lasting nystagmus once the weightless phase had ended. The supranormal G loadings acted as an activator which not only served to extend the time during which nystagmus might be observed but also emphasized the dramatic effect of weightlessness in abolishing caloric nystagmus.

Little attempt has been made to quantify the results inasmuch as improvements in procedure will make the task simpler. The short delay in appearance of nystagmus on transition out and into zero G suggests 1) that under ordinary conditions much of the delay following irrigation is due to conductance of the thermal stimulus from ear to canal and 2) that little displacement of the cupula occurs; otherwise elastic restoration would continue well into the weightless phase with nystagmus a manifestation. By using a modified parabolic maneuver, it should be possible to determine the level of G required to

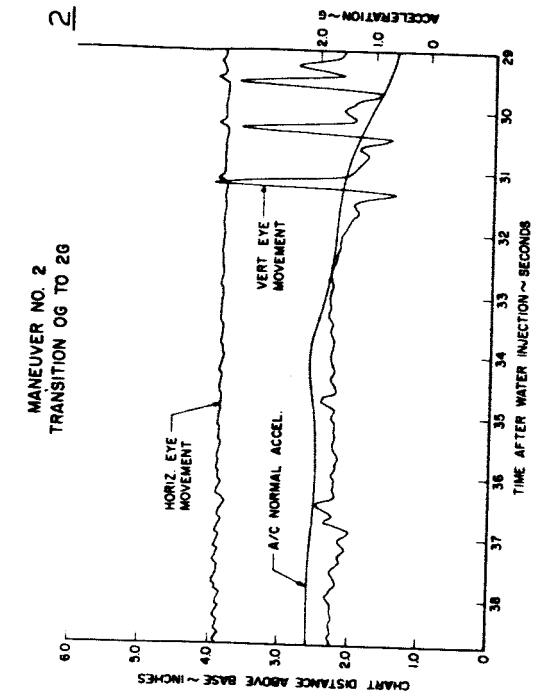
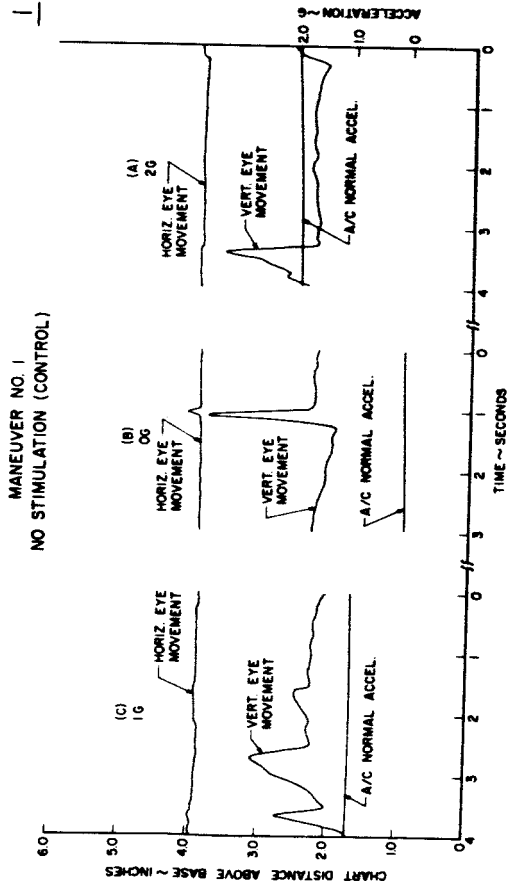
Table I  
Caloric Nystagmus Responses in Eight Subjects Under Laboratory and Parabolic Flight Conditions

Subj.	Age	Ground-Based Observations Nystagmus Delay Time (NDT)*	Parabola I		Parabola II			Parabola III			
			Nystagmus Response Pullup	Control Nystagmus Response Zero G Pullout	Onset Irrig. Prior Zero G Sec	Onset Irrig. Zero G Phase	Duration Zero G Phase	Time Onset Irrig. to End Zero G Minus NDT	Nystagmus Response Zero G Pullout	Nystagmus Response Zero G Phase	
A	22	16 sec	0	0	2.3	0.31	25 sec	8.3 sec	0	Positive	0
B	23	18	0	0	2.9	0.58	26	7.9	0	Positive	0
C	20	19	0	0	2.2	0.48	26	6.2	0	Positive	0
D	39	21	0	0	2.1	0.45	22	0.1	0	Positive	0
E	36	18	0	0	4.5	2.00	24	7.5	0	Positive	0
F	23	19	0	0	-	-	24	2.0+	0	Positive	0
G	41	20	0	0	2.6	0.62	23	2.6	0	Positive	0
H	33	9	0	0	4.5	1.25	24	16.5	0	Positive	0

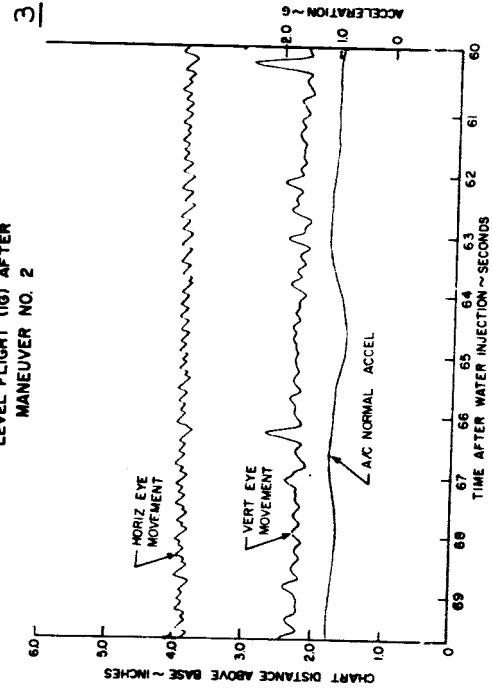
\*NDT - nystagmus delay time; irrigation 30 cc ice water in approximately 3 sec.



MANEUVER NO. 1  
NO STIMULATION (CONTROL)



LEVEL FLIGHT (1G) AFTER  
MANEUVER NO. 2



ENTRY (2G) INTO  
MANEUVER NO. 3

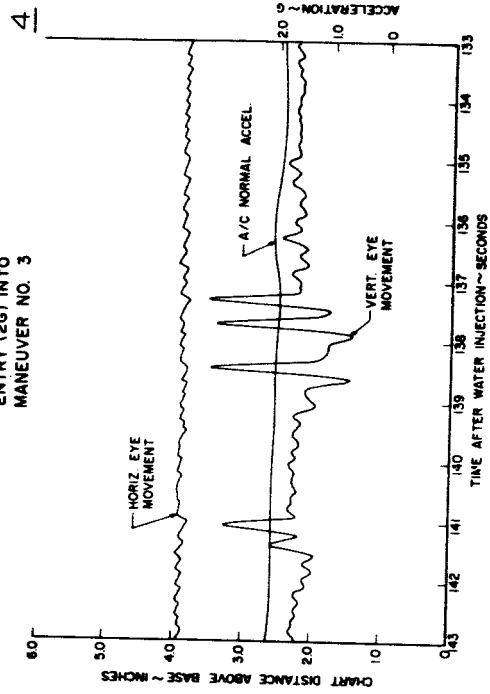


Figure 3

Oscillogram tracings from subject H. Read R to L. Nystagmograms in Fig. 3, 3 photographed; the others traced and photographed.

evoke caloric nystagmus. Extrapolating the curve drawn from similar observations under supragravity conditions led Bergstedt (9) to predict that caloric stimulation in zero G would not evoke nystagmus. The present study indicates that his prediction was quite correct.

Direct stimulation of the nerve, as suggested by Bartels (2), does not seem tenable inasmuch as the reaction should have taken place regardless of the G level. The theory advanced by Kobrak (3) concerning vascular reactions seems equally untenable since the vascular responses could not operate as fast as the eye movement changes indicated in the changing acceleration fields.

Borries' position (4,5) is more difficult to counter, since the otolith is essentially deafferented (10) during zero G. What effect this may have is still an open question. It is further difficult to explain the occurrence of caloric nystagmus in subjects with ablation of the canals. The theory put forth by van Caneghem (7) is also difficult to dismiss since it would seem that a change in the intralabyrinthine pressure would take place regardless of acceleration level.

The position taken by Brunner (6) (that of central origin) seems unlikely since such a response would not seem to have a causal relationship with gravity changes. Gemandt, Igarashi, and Ades (11) moreover have demonstrated in the squirrel monkey that very prolonged irrigation with ice water is required to evoke nystagmus which is of central origin.

## REFERENCES

1. Bárány, R., Untersuchungen über den vom Vestibularapparat des Ohres reflektorisch ausgelösten rhythmischen Nystagmus und seine Begleiterscheinungen. Mtschr. Ohrenheilk., 40:193-297, 1906.
2. Bartels, M., cited in Bárány, R., and Wittmack, K., Funktionelle Prüfung des Vestibularapparates. Verh. dtsh. otol. Ges., 20:37-184, 1911.
3. Kobrak, F., Beiträge zum experimentellen Nystagmus. Beit. z. Anat., Physiol. Path. Therap. Ohr., 10:214-220, 1918.
4. Borries, G. V. T., Studier over Vestibular Nystagmus. Thesis, Copenhagen, 1920.
5. Borries, G. V. T., Theorie des kalorischen Nystagmus. Arch. Ohr.-Nas.-, u. KehlkHeilk, 113:117-155, 1925.
6. Brunner, H., In: Alexander G., and Marburg, O. (Eds.), Handbuch der Neurologie des Ohres. Vol. I. Berlin: Urban Schwarzenberg, 1921. P 239.
7. van Caneghem, D., Application du Romberg amplifié et de la réaction vestibulaire sonore sur diagnostique différentiel entre la tympanosklerose et l'otoskongiose. Bull. Soc. Belge d'otol., rhinol., laryng., 88, 1946.
8. Weiss, R., Display systems for sub- and zero-gravity flight. AMRL-TDR-63-11. Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratories, 1963.
9. Bergstedt, M., The effect of gravitational force on the vestibular caloric test. Acta otolaryng., Stockh., 53:551-562, 1961.
10. Miller, E. F., II, and Graybiel, A., Otolith function as measured by ocular counterrolling. In: The Role of the Vestibular Organs in the Exploration of Space. NASA SP-77. Washington, D. C.: National Aeronautics and Space Administration, 1965. Pp 121-131.
11. Gemandt, B. E., Igarashi, M., and Ades, H. W., Effects of prolonged stimulation upon oculomotor, vestibulospinal, and segmental spinal activity. Exp. Neurol., 14:249-263, 1966.

DOCUMENT CONTROL DATA - R&D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author)  U. S. Naval Aerospace Medical Institute Pensacola, Florida		2a. REPORT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>
		2b. GROUP N/A
3. REPORT TITLE <b>LACK OF RESPONSE TO THERMAL STIMULATION OF THE SEMICIRCULAR CANALS IN THE WEIGHTLESS PHASE OF PARABOLIC FLIGHT</b>		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) N/A		
5. AUTHOR(S) (Last name, first name, initial) <b>Kellogg, Robert S., Captain USAF, and Graybiel, Ashton, M. D.</b>		
6. REPORT DATE <b>9 August 1966</b>	7a. TOTAL NO. OF PAGES <b>9</b>	7b. NO. OF REFS <b>11</b>
8a. CONTRACT OR GRANT NO. <b>NASA ORDER R-93</b>	9a. ORIGINATOR'S REPORT NUMBER(S) <b>NAMI-977</b>	
b. PROJECT NO. <b>MR005.04-0021</b>	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) <b>136</b>	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES  <b>Distribution of this document is unlimited.</b>		
11. SUPPLEMENTARY NOTES <b>Joint Report of 6570th Aerospace Medical Research Laboratories Naval Aerospace Medical Institute, and NASA.</b>		12. SPONSORING MILITARY ACTIVITY
13. ABSTRACT  The objective of this study was to clarify the mechanism of caloric nystagmus in man by conducting the test in weightlessness. Eight subjects were selected on the basis of a strong nystagmus response to irrigation with ice water. Nystagmus was determined by oscillograph tracings and direct observation, and in addition, subjective responses of the subject were obtained. The experimental evidence indicated that, under the conditions of this experiment, zero gravity completely suppressed caloric nystagmus. This supported Bárány's original hypothesis that caloric nystagmus was dependent on difference in specific weight of the endolymph in the horizontal canal.		

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Caloric nystagmus						
Parabolic flight						
Oscillograph tracings						
Semicircular canal stimulation						
Weightlessness effects						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through \_\_\_\_\_."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through \_\_\_\_\_."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through \_\_\_\_\_."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.