NAMI-1079

N69-38276
NASA CR-105972

# DIRECTIONAL DIFFERENCES IN VISUAL ACUITY DURING VERTICAL NYSTAGMUS

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**JOINT REPORT**

NAVAL AEROSPACE MEDICAL INSTITUTE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

16 July 1969

# DIRECTIONAL DIFFERENCES IN VISUAL ACUITY DURING VERTICAL NYSTAGMUS *

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Bureau of Medicine and Surgery
MR005.01.01-0021B
NASA Order No. R-93

| Approved by | Released by |
|---|---|
| Ashton Graybiel, M.D.<br>Head, Research Department | Captain M. D. Courtney, MC USN<br>Commanding Officer |

16 July 1969

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* This study was supported in part by the United States Army Aeromedical Research Laboratory.

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# SUMMARY PAGE

## THE PROBLEM

Investigation of the loss of visual acuity in the vertical dimension as a result of the vertical nystagmus elicited by angular acceleration of the head about the pitch axis.

## FINDINGS

Twenty naval aviator candidates were exposed to four ramp velocity test profiles generated by the Human Disorientation Device. The head orientation was such that the $y$ (left-right) axis was on the Earth-vertical rotational center of the device, with the resulting $\alpha_y$ pitch stimulation eliciting vertical nystagmus which was recorded on all four profiles. During two of the profiles, the subjects were required to observe a visual target consisting of a vertically aligned series of dots and to report the duration of the period where dot fusion or target blur occurred as a result of the vertical nystagmus. It was found that during pitch forward angular acceleration ($+\alpha_y$) resulting in nystagmus with a slow component upward, the loss of visual acuity was of a significantly longer duration than that present during stimulation in the opposite direction. Directional differences in the vertical nystagmus response were also observed.

## ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. A. Thomas and Mr. A. N. Dennis for their help in performing the experiment and analysing the data.

# INTRODUCTION

There arose in the planning stages of the Apollo series of spaceflights a question as to potential disorientation hazards in the event of an abort at 80,000 to 120,000 feet. In such a case, the escape tower would fire to separate the manned capsule from the main body of the vehicle. To ensure clearance between the escape tower and the booster, the procedure called for an eccentrically applied escape tower thrust which would result in the capsule being angularly accelerated at a relatively high level for a brief period of time. A typical set of motion parameters after activation of the escape system was a 2-second angular acceleration of the capsule from rest to a constant angular velocity of 200 deg/sec. This velocity would be maintained for about 12 seconds, followed by a deceleration to rest in approximately 20 seconds. The orientation of the capsule spin during this entire period was such that the piloting astronaut would be rotated about his $y$ (left-right) head axis; i.e., he would in effect be subjected to a pitching angular motion. The operational importance of this rotational stimulus arose from the fact that the astronauts had only some 40 seconds following its cessation to visually reorient themselves and manually adjust the capsule attitude to the proper return orientation.

The authors, using the Human Disorientation Device to simulate the angular motion component of the over-all stimulus and a series of visual targets, observed a marked increase in the amount and duration of visual blurring that occurs during pitch forward angular accelerations as compared to pitch backward stimulation. This directional difference effect was observed for all subjects. From the operational viewpoint, these findings indicated a preferred direction of capsule rotation during escape if the duration of visual blurring following cessation of capsule rotation was to be minimized. Because of the potential implications for the success of the escape mission, these preliminary observations were transmitted to NASA by letter report*, together with the recommendation that the direction of capsule rotation during escape be such that the terminal deceleration would be in the pitch backward direction to produce minimal blur at the end of the profile. The experiment to be described was performed to formalize the preliminary observations.

# PROCEDURE

## SUBJECTS

The subjects were twenty male volunteers from the naval aviation training program. All were in good health and had no apparent abnormalities of vestibular function.

## APPARATUS

The angular acceleration stimuli used in this study were generated by the Human Disorientation Device (HDD), a two-axis, velocity-controlled servorotator, Earth-

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*Niven, J. I. and Hixson, W. C. Letter report to Manned Spacecraft Center, NASA, 16 April 1964.

vertical rotation of each subject about his $y$(left-right) head axis was accomplished in the following manner. A movable subject chair installed at the center of the HDD capsule was first rotated 90 deg from its normal position so that the subject's $x$ (front-back) head axis was aligned with the Earth-horizontal rotational axis of the device. Second, the entire capsule was rotated 90 deg about this latter axis so that the sagittal $xz$ head plane was placed in an Earth-horizontal plane. By controlling the direction of the second static 90-deg rotation of the chair, the subject could be placed on either his right or left side with his $y$ head axis being aligned with and centered upon the Earth-vertical rotating axis of the device. The desired $y$ axis angular acceleration stimulation could then be accomplished by energizing the HDD Earth-vertical drive system. The control signal used to produce the desired ramp velocity profile was provided by an operational-amplifier type drive-system programmer.

The visual target used to investigate the observed directional differences in vertical acuity was a small back-illuminated slide holder for 5-cm square photographic film transparencies. The pattern selected for this test was a series of eight vertically arranged 0.38-mm square dots equally spaced approximately 3.0 mm apart. When vertical nystagmus was elicited by angular acceleration about the $y$ head axis, the series of dots subjectively appeared to form a single continuous vertical line; i.e., the dots would blur together and form a continuous line rather than a discrete dot image. The subject signalled the onset and duration of this loss of resolution by activating a pistol-grip response switch.

For measurement of the vertical nystagmus response, conventional AC corneo-retinal potential technique was used with electrodes placed immediately above and beneath the vertical centerline of the right eye. Sensitivity of the recording system was established by means of calibrated 20-deg eye motions of the subject above and below the normal dead-ahead position. The nystagmus data were displayed on a direct-writing recorder and stored on magnetic tape for later computer analysis.

## METHOD

The basic rotational stimulus was a ramp angular velocity profile defined by acceleration from rest to 30 rpm in 6 seconds, followed by constant velocity rotation for 120 seconds, and terminated by a 6-second deceleration to rest. This ramp profile could be programmed to rotate the HDD either counterclockwise (CCW) or clockwise (CW), as viewed from above by a fixed observer, about the Earth-vertical rotational axis. Stimulus patterns A and D were obtained by CW ramps and patterns B and C by CCW rotation (see Table I). By positioning the subject so that his left ear was down in patterns A and C and the right ear down in B and D, four different stimulus patterns resulted. Since the direction of the slow component of nystagmic eye velocity is opposite the direction of the driving angular acceleration stimulus, vertical nystagmus with an upward directed slow component occurred during the initial acceleration of stimulus conditions A and B and the final deceleration of C and D. Conversely, slow components in the downward direction occurred during the deceleration phase of A and B and the acceleration phase of C and D.

## Table I

## Summary of Basic Stimulus/Response Conditions

| | Stimulus A | Stimulus B | Stimulus C | Stimulus D |
|---|---|---|---|---|
| Head orientation (ear down) | Left | Right | Left | Right |
| Direction of HDD rotation | CW | CCW | CCW | CW |
| Direction of acceleration stimulus * | $+\alpha_y$ | $+\alpha_y$ | $-\alpha_y$ | $-\alpha_y$ |
| Direction of deceleration stimulus | $-\alpha_y$ | $-\alpha_y$ | $+\alpha_y$ | $+\alpha_y$ |
| Direction of nystagmus (slow component) during acceleration | up | up | down | down |
| Direction of nystagmus (slow component) during deceleration | down | down | up | up |

* $+\alpha_y$ = pitch forward angular acceleration
$-\alpha_y$ = pitch backward angular acceleration

The twenty subjects were divided into four groups of five, with each group receiving a different sequence of the four ramp stimulus patterns. The four sequences were ABCD, DCBA, CDAB, and BADC. On the second and fourth pattern of each sequence, the visual target lamp was illuminated and the subjects required to signal the duration of the visual blur. During all sequences nystagmus was recorded for at least 45 seconds after the beginning of each acceleration or deceleration interval.

The duration of the blurring sensation was determined through the straightforward measurement of the time interval in which the subject depressed the response switch. The duration of the nystagmus response was measured by an experienced record scorer who estimated the time following onset of a given acceleration or deceleration at which the nystagmus response had, for all practical purposes, decayed to a near zero level. The limitations of this method are well known. However, since a single individual scored all records, a common measurement reference is involved for all these data.

An analysis of the magnitude of the nystagmus response was also performed using hybrid computer techniques. The nystagmus eye displacement data stored on magnetic tape were directed to the input of an operational-amplifier type electronic differentiator which produced an output signal analog to the instantaneous velocity of the eyes. This signal, describing the velocity of the eyes during the fast as well as slow components of nystagmus, was then fed to the input of a precision absolute-value circuit which, in essence, performed a full-wave rectification of the velocity signal. The output was then parallel routed to the input stages of six clock-controlled operational-amplifier type integrators, each of which could be independently programmed to operate in one of three modes: reset, integrate, and hold. Initially, all integrators were placed in the reset position. At time $t = 0$, defined by the onset of the stimulus, the first integrator was placed in the integrate mode and a continuous integration made of the unidirectional polarity eye velocity signal. At $t = 5$ seconds, the digital clock placed this circuit in the hold condition and switched the second integrator to the integrate mode which was maintained until $t = 10$ seconds. At this time the second integrator was placed in the hold mode. The process was continued for 30 seconds, thus resulting in six sequential integrated eye velocity measures of the nystagmus response. The magnitude of the output signal from each integrator then described the summed total eye displacement occurring in both directions over the 5-second measurement period.

## RESULTS AND DISCUSSION

The expectation of a bias in favor of the pitch backward condition which produces a vertical nystagmus with a downward directed slow component was borne out by the experimental results. As may be seen in the bar graphs in Figure 1, the visual target blurred for a mean duration of about 15 seconds during the $+\alpha_y$ pitch forward angular acceleration stimulus conditions as compared to slightly less than 9 seconds for the oppositely directed $-\alpha_y$ stimulus conditions. In effect, the duration of target blur with the slow component of nystagmus directed upward is almost twice as long as that when the slow component is down.

In the case of the nystagmus duration data collected while the subject was viewing the target, the same form of directional difference was observed to a lesser degree. The duration of the slow component up nystagmus produced by pitch forward angular acceleration ($+\alpha_y$) was slightly more than 17 seconds, while the downward directed nystagmus lasted only 13 seconds.

This directional difference in nystagmus duration did not occur, however, for the without-target test condition. As may be seen to the right in Figure 1, both $+\alpha_y$ and $-\alpha_y$ stimulation produced nearly equal nystagmus durations of approximately 21 seconds. In effect, there seems to be no directional difference in vertical nystagmus duration when the subject is in complete darkness without any visual reference to fixate. A further observation is that the duration of nystagmus measured without the visual target is longer than that occurring with the target. This follows since any visual aid given to a subject which facilitates the point fixation of his eyes reduces the amplitude of nystagmus compared to that which would be measured without this reference.

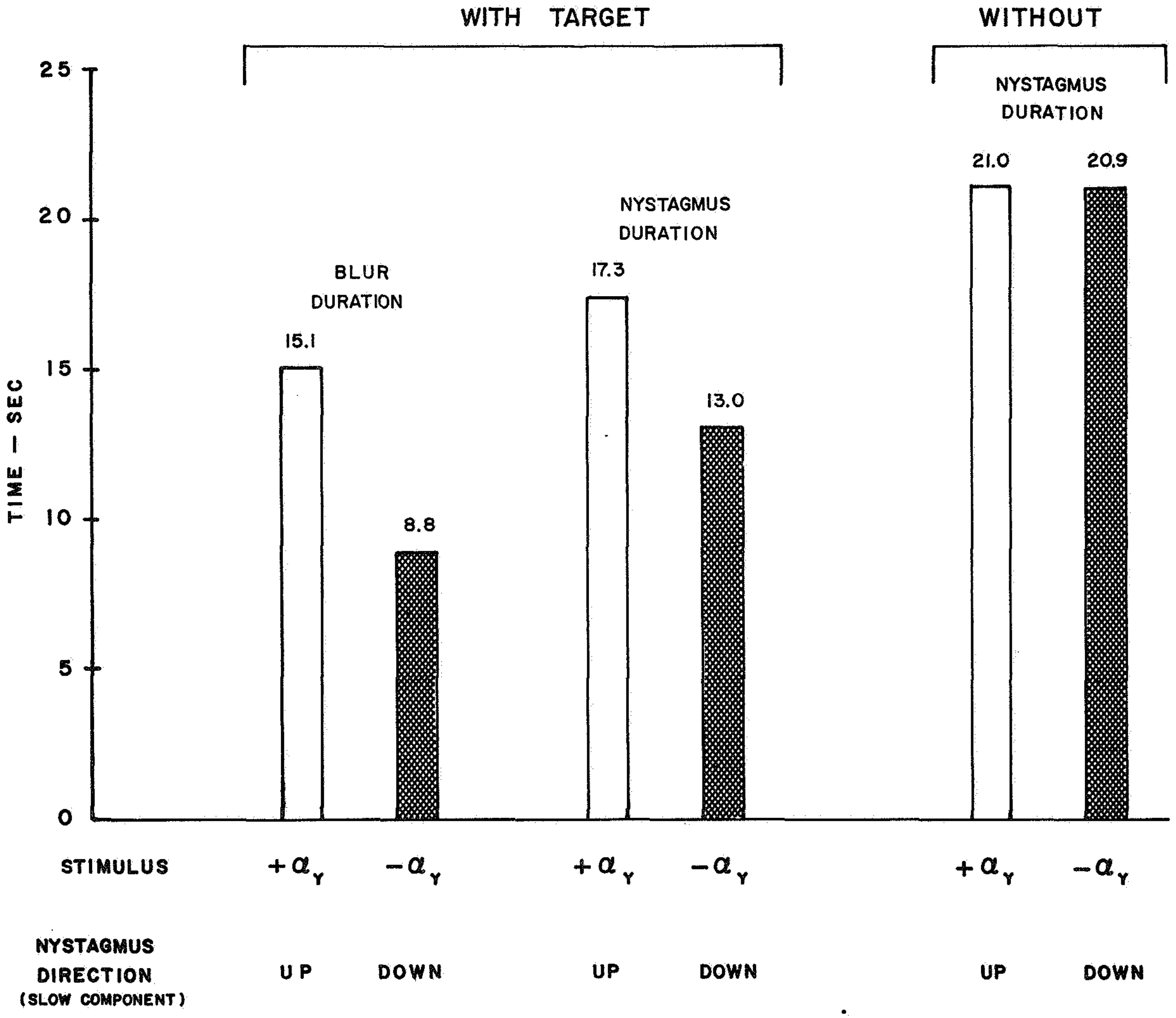

Figure 1. The directional differences in the mean duration of the visual blur interval and the mean duration of the associated vertical nystagmus as a function of the direction of the pitch angular acceleration stimulus may be observed from the bar graphs at the left. During pitch downward $(+\alpha_y)$ stimulation, which elicits nystagmus with an upward directed slow component, the duration of nystagmus as well as the duration of the period where visual acuity is lost is significantly greater than that for stimulation in the opposite direction $(-\alpha_y)$. However, as shown at the right, directional differences in nystagmus diration are negligible when nystagmus is recorded in total darkness without a visual fixation target.

The results of the computer analysis of the relative magnitude of these same nystagmus data over the first 30 seconds following application of the stimulus are presented in Figures 2 and 3. Each plotted data point represents the total eye displacement in degrees measured during the preceding 5-second period as described earlier. It should be observed that the output is not zero during the late stimulus intervals when nystagmus is decaying toward a zero level since the instantaneous eye velocity is always greater than zero due to the continual presence of tremor, saccades, et cetera. The data show that nystagmus amplitude begins to increase soon after application of the angular acceleration stimulus, and reaches a peak some 5 to 10 seconds later, and then declines to a more or less constant level representing the basic "electrophysiological noise" in the system.

NYSTAGMUS AMPLITUDE VS. TIME

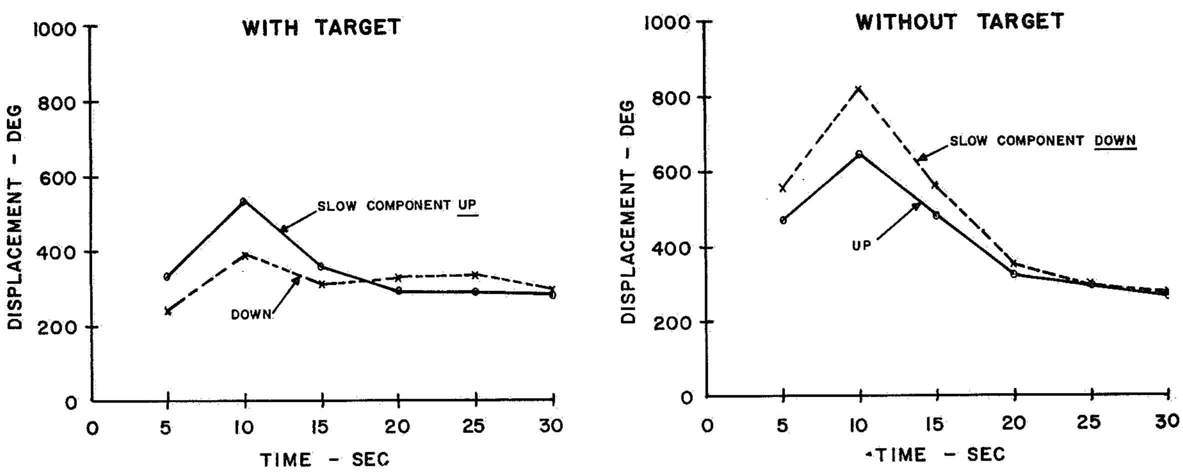

Figure 2. A comparison of amplitude-time relationships for the vertical nystagmus data of Figure 1. Since the visual target serves as an eye fixation reference, the peak amplitude of the nystagmus response occurring when viewing the target is less than that when in the dark. These data show also a marked directional asymmetry in the nystagmus amplitude response both with and without the target. The most striking effect of this asymmetry, however, is that with the target, the peak magnitude of the upward directed component of nystagmus is greater than that of the slow component; without the target, the opposite effect occurs.

NYSTAGMUS AMPLITUDE VS. TIME

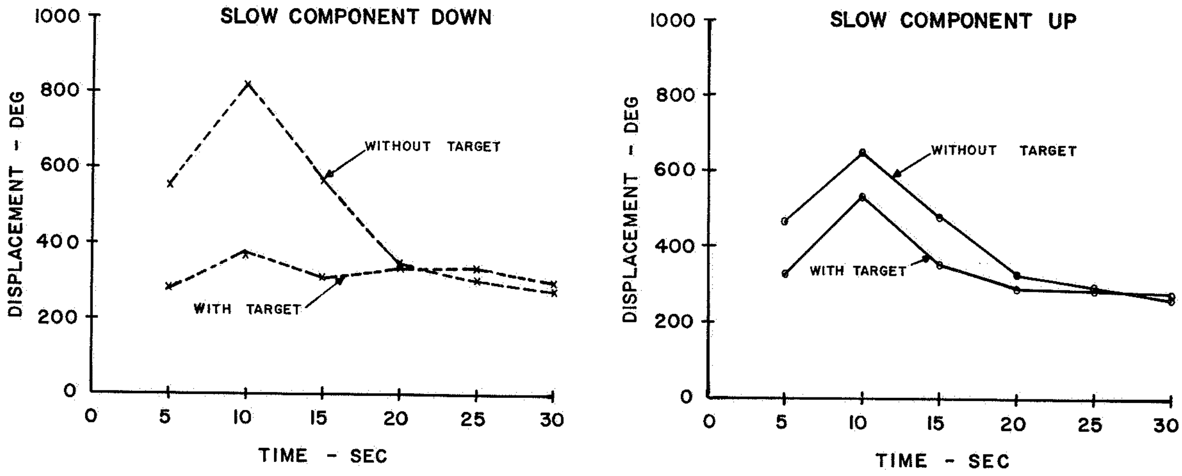

Figure 3. The data of Figure 2 rearranged to allow a comparison of the magnitude of the nystagmus response in a given direction with and without the visual target. The resulting greater decline in nystagmus amplitude when its slow component is directed downward is presumable accounted for by a better capability to fixate the eyes under these conditions. The inability to fixate as well when the slow component is directed upward would account for the greater amount of blurring associated with it as shown in Figure 1.

As may be seen at the left in Figure 2, when the subject views the visual target, the peak magnitude of the upward directed (solid line) slow component of nystagmus is somewhat greater than the downward (dashed line) component in correspondence with the directional difference observed with both the duration of these same nystagmus data and the duration of the target blur. There is also a directional difference in the peak magnitude of nystagmus measured without a visual target as shown at the right in Figure 2. However, in this case, the directional difference is reversed in that the magnitude of the downward directed slow component somewhat exceeds that of the upward component.

A more significant interpretation results, however, when a comparison is made between the nystagmus magnitude observed with a target to that observed without the target, holding constant the direction of the nystagmus response. This comparison is facilitated by Figure 3 where, except for physical location, all data points are in exact correspondence with those presented in Figure 2. As may be seen at the left in Figure 3, the peak magnitude of the downward directed nystagmus response is quite considerably reduced in the presence of the visual target. As with past observations of horizontal nystagmus under similar test conditions, this reflects the capability of a subject to reduce significantly nystagmus amplitude if he is presented a visual reference which affords even a minimal degree of eye fixation; the greater the fixation characteristics of the visual target, the greater the reduction in nystagmus.

For nystagmus magnitude with an upward directed slow component, however, little decrease in magnitude occurs as a result of presentation of the visual target, as shown by the data at the right in Figure 3. Though there is some decrease in magnitude, the difference does not begin to approach that achieved with the presentation of a fixation source during nystagmus with a downward directed slow component. From these nystagmus magnitude data then, it may be inferred that during the production of nystagmus with an upward directed slow component, the ability of a normal subject to fixate a stationary target is considerably reduced as compared to the same ability during nystagmus with a downward directed component.

These results may be compared to past observations of horizontal nystagmus data collected with and without visual target references. When a normal subject is placed at the center of an Earth-vertical rotator and oriented so that he is turned about his $z$ (head-foot) axis, the duration of the resulting horizontal nystagmus is approximately the same for either direction of angular acceleration stimulation, that is, either yaw leftward $(+\alpha_z)$ acceleration producing nystagmus with a rightward slow component or yaw rightward $(-\alpha_z)$ stimulation producing a leftward slow component. Correspondingly, the magnitude of the right or left directed slow component of horizontal nystagmus is about the same for oppositely directed stimuli of equal magnitude. The above applies to a subject in total darkness with eyes open. When an illuminated target or field which affords a good degree of eye fixation is presented, the duration and magnitude of the horizontal nystagmus response are considerably decreased compared to those observed in total darkness; however, there are no left-right directional differences in either the duration or the magnitude of the nystagmus response. Similarly, the loss of visual acuity produced by horizontal nystagmus is the same for either direction of rotation. In effect, the horizontal nystagmus response, the ability to fixate in the horizontal dimension, and the loss of visual acuity, all appear to have complete symmetry of response to Earth-vertical $\alpha_z$ stimulation.

When normal subjects are placed on the same type of Earth-vertical rotator but oriented so that they turn about their $y$ (left-right) head axis, the duration of the resulting vertical nystagmus when the subject is in total darkness is approximately the same for either direction of angular acceleration stimulation, that is, either pitch forward ($+\alpha_y$) acceleration producing nystagmus with an upward slow component or pitch backward ($-\alpha_y$) stimulation producing a downward slow component. Such symmetry does not apply for the magnitude of the nystagmus response; the magnitude of the downward directed slow component is slightly greater than that of the upward directed slow component. When a fixation target is presented, the duration and magnitude of the vertical nystagmus response are decreased compared to those observed in total darkness. However, the reduction is greatest for nystagmus with a slow component directed downward. This asymmetry is present also in terms of the loss of visual acuity produced by the vertical nystagmus. The duration of target blur during nystagmus with a downward directed slow component is about one half of that during nystagmus in the opposite direction. It would appear then that the ability to fixate on a visual target during the occurrence of vertical nystagmus is considerably greater when the slow component is directed downward rather than upward.

## DOCUMENT CONTROL DATA - R&D

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

1. ORIGINATING ACTIVITY *(Corporate author)*
Naval Aerospace Medical Institute
Pensacola, Florida 32512

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
N/A

3. REPORT TITLE
DIRECTIONAL DIFFERENCES IN VISUAL ACUITY DURING VERTICAL NYSTAGMUS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
N/A

5. AUTHOR(S) *(Last name, first name, initial)*
W. Carroll Hixson and Jorma I. Niven

6. REPORT DATE
16 July 1969

7a. TOTAL NO. OF PAGES
11

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.
NASA Order No. R-93

b. PROJECT NO.
MR005.01.01-0021B

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
NAMI-1079

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
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11. SUPPLEMENTARY NOTES
Study supported in part by U. S. Army Aeromedical Research Laboratory

12. SPONSORING MILITARY ACTIVITY

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Twenty naval aviator candidates were exposed to four ramp velocity test profiles generated by the Human Disorientation Device. The head orientation was such that the $y$ (left-right) axis was on the Earth-vertical rotational center of the device, with the resulting $\alpha_y$ pitch stimulation eliciting vertical nystagmus which was recorded on all four profiles. During two of the profiles, the subjects were required to observe a visual target consisting of a vertically aligned series of dots and to report the duration of the period where dot fusion or target blur occurred as a result of the vertical nystagmus. It was found that during pitch forward angular acceleration ($+\alpha_y$) resulting in nystagmus with a slow component upward, the loss of visual acuity was of a significantly longer duration than that present during stimulation in the opposite direction. Directional differences in the vertical nystagmus response were also observed.

DD FORM 1 JAN 64 1473

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|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Vestibular apparatus | | | | | | |
| Angular acceleration | | | | | | |
| Pitch axis rotation | | | | | | |
| Vertical nystagmus | | | | | | |
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