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MANIPULATION OF AROUSAL AND ITS EFFECTS ON HUMAN VESTIBULAR NYSTAGMUS INDUCED BY CALORIC IRRIGATION AND ANGULAR ACCELERATIONS*

WILLIAM E. COLLINS, PH.D.

INTRODUCTION

Alterations in the nystagmic reaction of human subjects exposed to vestibular stimulation have been frequently noted in studies of drug effects, [4, 5, 25, 26, 33] "habituation", [14, 15, 16, 17, 22, 36, 37] and general features of the labyrinthine response. [1, 2, 3, 21, 27, 29, 31, 35] Wendt [36, 37] has maintained that, when visual stimuli are excluded, the primary source of intra-subject variability is the orientation of the subject. Specifically, Wendt has held that a brisk vestibular nystagmus is obtained so long as the subject remains "environment-directed" and does not lapse into a "reverie" attitude.

The present report represents a compilation of the results of several experiments in which methods of controlling the psychological attitude of the subject were evaluated. Control features were then introduced in the examination of some basic theoretical and applied aspects of the vestibular response.

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APPARATUS AND PROCEDURE

Angular Accelerations. The rotary apparatus was a turntable [30] situated in a light-proof room. Subjects were seated upright at the center of the device and a bite-board positioned their heads so that the horizontal semi-circular canals were in the plane of rotation.

In all cases, an acceleration was preceded by 30 seconds of rotation, and a deceleration was followed by 60 seconds of rotation, at a constant velocity of 1 rpm. All trials were conducted in total darkness. The various acceleration schedules employed appear in Table 1.

Caloric Stimulation. Caloric studies were conducted in a shielded, light-proof room. The testing apparatus consisted of a padded steel bed with adjustable head-section, a water bath with attached tubing terminating in a glass ear-insert, and a pan to collect the return flow from the ear. The bed was adjusted so that the head was elevated 30° from the supine position. Trials consisted of 40 seconds of irrigation with water at 30° C. Administration of the stimulus took place, in all cases, with the room illuminated. Sixteen subjects (8 "naive" and 8 "experienced") were given 5 trials each. The fifth trial, in all cases, involved room illumination and gaze-fixation on a ceiling

TABLE 1

Outline of the stimulus conditions employed. Instructions included mental arithmetic (MA), Reverie (REV), signalling subjective velocity by key presses (KP), temporal reproduction (REPRO) and attending to the sensation of rotation (ATS).

Rotatory Conditions

	Constant Velocity	Accel.	Constant Velocity	Decel.	Constant Velocity	Instructions
Value	1 rpm	4.5°/sec²	12.2 rpm	4.5°/sec²	1 rpm	MA, REV,
Duration	30 sec	15 sec	120 sec	15 sec	60 sec	KP, REPRO
Value	1 rpm	4.1°/sec²	10 rpm	4.1°/sec²	1 rpm	MA and
Duration	30 sec	13 sec	100 sec	13 sec	60 sec	REV
Value	1 rpm	1.8°/sec²	16 rpm	1.8°/sec²	1 rpm	MA and
Duration	30 sec	50 sec	120 sec	50 sec	60 sec	ATS
Value	1 rpm	1.0°/sec²	15 rpm	1.0°/sec²	1 rpm	MA and
Duration	30 sec	84 sec	120 sec	84 sec	60 sec	ATS
Value	1 rpm	0.5°/sec²	10.2 rpm	0.5°/sec²	1 rpm	MA and
Duration	30 sec	110 sec	120 sec	110 sec	60 sec	ATS

Caloric Conditions

Four subjects were tested according to each trial sequence.

Trial Identification	*Fixation Distance*	*Environment*	*Instruction*	*Sequence of Trials*
1	30.5 cm	Illumination	REV	A-1, 2, 3, 4, 5
2	- - - -	Darkness	REV	B-2, 1, 4, 3, 5
3	30.5 cm	Illumination	MA	C-3, 4, 1, 2, 5
4	- - - -	Darkness	MA	D-4, 3, 2, 1, 5
5	1.63 m	Illumination	MA	

mark. A counterbalanced order of presentation was established for the first 4 trials, such that 2 subjects from each group were tested according to each sequence. Two of these trials were in room illumination with fixation on a small target 30.5 cm from the subject. For the remaining two trials, all lights were extinguished at the moment of stimulus termination. An outline of the caloric test conditions appears in Table 1.

In addition to the recording of nystagmus tracings, the duration of response in illumination was timed by the investigator by direct observation. A qualitative rating on a 0-4 scale of the observed regularity, frequency, and amplitude of response was also made. The timer-rater was never aware of the instructions given to the subjects.

Nystagmus Recordings. Horizontal components of nystagmus and periods of stimulation were recorded on an Offner Type-T Electroencephalograph. Electrodes were taped at the outer canthus of each eye and an indifferent electrode was taped on the mastoid process. Prior to each trial, calibration data relating degrees of eye movement to pen deflection were obtained.

Instructions. In all cases, subjects were told to keep their eyes open and, in darkness, to stare "straight ahead." Several sets of instructions were designed in an effort to influence the states of alertness or arousal of the subjects throughout a given trial, and thereby provide some control of the subject's "orientation." Two of these, mental arithmetic and reverie, proved

particularly effective and were employed in most of the experiments conducted. The instructions included:

1) *Mental Arithmetic (MA)*—Subjects were given a starting dividend and a constant divisor. They were told to divide silently and continuously throughout a given trial, using each successive quotient as the next dividend. It was emphasized that the arithmetic process should begin promptly at a given signal (10 seconds prior to acceleration and 30 seconds prior to termination of calorization) and should continue with a maximum effort at speed and accuracy until the conclusion of the trial. The task assumed the nature of a challenge and subjects expressed interest in their speed and accuracy as compared with others. All answers were recorded at the conclusion of a trial.

2) *Reverie (REV)*—Subjects were instructed to ignore the stimulus environment, to relax and daydream, but to keep their eyes open. They were requested not to pursue any particular line of thought.

3) *Key Pressing (KP)*—A telegraph key, connected to the recorder, was secured to the arm of the turntable chair. Each subject was instructed to attend to the sensation of rotation and to indicate, by pressing the key, the onset, cessation, and each experience of 90° of subjective rotation.

4) *Temporal Reproduction (REPRO)*—A buzzer was connected to the telegraph key and to an outside control. Sound stimuli were systematically presented throughout a given trial for durations varying between 0.5 and 6.5 seconds. Subjects were instructed to attend carefully to the onset of the sound and, at its conclusion, to reproduce its duration by pressing the telegraph key.

5) *Attend to Sensation (ATS)*—Subjects were instructed to attend carefully to the rotatory sensations produced by acceleration. They were to report verbally on intensity, duration, and direction of experienced rotation at the conclusion of a trial.

RESULTS AND DISCUSSION

Angular Accelerations

A. General Effects of Assigned Task.

The effects of four assigned tasks (MA, REV, KP, and REPRO) on nystagmus responses to a 4.5°/sec² angular acceleration (see Table 1) were examined.[6] Data were recorded from 8 subjects. Each subject was given 6 trials per day for 4 consecutive days. A single task was assigned to a subject on a given day, but the order of task-presentation differed systematically among subjects. The following results were obtained:

1. Both amplitude and duration of the nystagmic response were affected by instructions.
2. Mental arithmetic was the most efficacious means of maintaining a brisk, long-duration nystagmus.
3. Reverie states produced the most variable nystagmus responses. In some cases, no nystagmic beats were detected.

Table 2

The average slow-phase velocity of nystagmus for 30-second periods beginning with the onset of the stimulus and the average total duration of response under 4 instruction-conditions (mental arithmetic, key pressing, temporal reproduction, and reverie). Data are averages of 6 accelerations, 6 decelerations, and 8 subjects (stimulus: 4.5°/sec² for 15 seconds).

Task	Average Slow-Phase Velocity (Deg/Sec) for first 30 Sec	Average Total Nystagmus Duration (Sec)
MA	18.7	47.0
KP	16.3	41.0
REPRO	14.5	38.6
REV	8.1	26.7

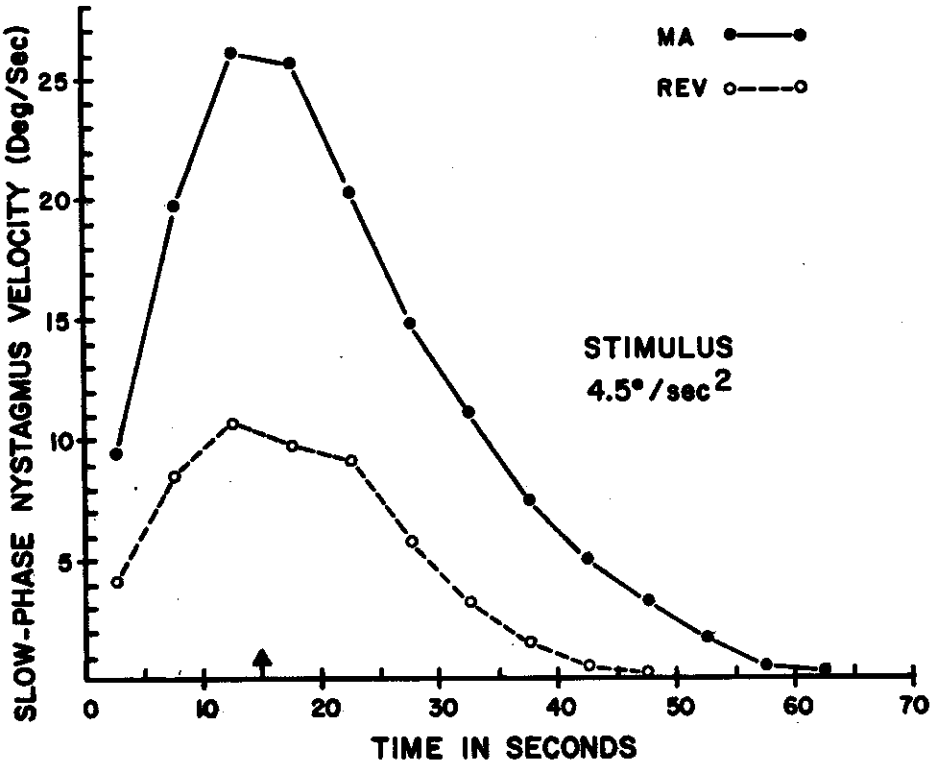

FIGURE 1. Average slow-phase eye velocity (deg/sec) for 5-second intervals under conditions of mental arithmetic (MA) and reverie (REV). Data are averages for 8 subjects, each given 6 accelerations and 6 decelerations under each condition. Arrow indicates point of stimulus termination (4.5°/sec² for 15 seconds).

The average duration of nystagmus for the group and the average slow-phase velocity for 30-second periods beginning with stimulus onset appear in Table 2. The importance of arousal or alertness level in the evaluation of vestibular responses is clearly evident. As Wendt [26, 27] has noted, reverie states result in a decline or abolishment of nystagmus (see Figs. 1 and 2). The maintenance of an alert state, by simple instructions outlining subject-tasks, tends to prevent such declines and probably permits a more accurate evaluation of the vestibular response.

The tasks, however, differ in efficiency in maintaining nystagmus. Mental arithmetic consistently yielded brisk, long-duration responses. The key-pressing condition, a measure of subjective velocity,[19] appeared reasonably effective but, since the subjective experience of rotation tends to decline with repeated stimulation,[18] a consequent reduction of nystagmus also probably occurs as the subject's attention is less and less required.[21] The REPRO instructions were generally effective especially in early trials. However, in later trials for some subjects, nystagmus occasionally became less well-defined. It is known that timing behavior can become quite automatic (subjects can be conditioned to respond with timing behavior during sleep) and, as mental effort declines, nystagmus is similarly affected. Reverie states probably differ little from those of uninstructed subjects or of subjects who are assigned somewhat vague tasks.

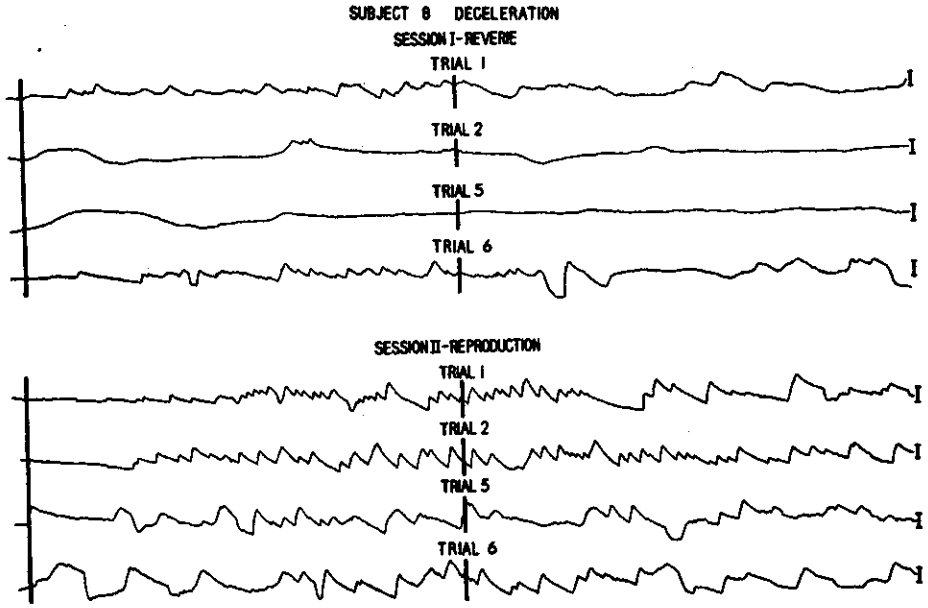

FIGURE 2. Nystagmus recordings from deceleration trials for a single subject under conditions of reverie and temporal reproduction. Vertical bars through the records denote the stimulus periods (4.5°/sec² for 15 seconds). Calibration markers at the right of each record indicate 20° eye excursions. Note the less well-defined eye movements in Reproduction trials 5 and 6. Mental arithmetic trials (not depicted here) consistently yielded vigorous, well-defined nystagmus as in Reproduction trial 2.

B. SPECIAL EFFECTS OF ASSIGNED TASKS.

1. Responses after administration of an analeptic. Many early reports noted the fact that something like alertness exerted an influence on nystagmus production. Mowrer[30] with pigeons, Griffith[17] and Pearcy and Hayden[31] with normal humans, and Angyal and Blackman[2] with schizophrenics noted effects due to "excitement" or levels of physical tension. More recently, Crampton[11] and Crampton and Schwam[12] have employed sensory and chemical means of influencing the arousal-levels of cats. They indicate a positive relationship between nystagmus output and increased levels of the animals' activity.

In order to evaluate further the effect of instructions on nystagmus production, a study was conducted using an analeptic to influence the physiological arousal-level of subjects.[11] Normal clinical doses of amphetamine and a placebo were administered subcutaneously to groups of "rotation-naive" and "rotation-experienced" subjects according to a counterbalanced design. Subjects were used as their own controls. Mental arithmetic and reverie instructions were utilized. Although significant increases in cardiovascular activity occurred as a result of drug administration, the influence of the analeptic on nystagmus output was statistically negligible. However, the instructions again produced highly significant effects. Men-

TABLE 3

Mean total nystagmus output (degrees of slow-phase activity) and duration in seconds of the primary nystagmus for 6 "naive" and 6 "experienced" subjects exposed to a normal clinical dosage of amphetamine and to a placebo. Data were calculated from averages of two trials per subject under each condition. MA and REV refer to mental arithmetic and reverie instructions, respectively (stimulus: 4.1°/sec² for 13 seconds).

		ACCELERATION				*DECELERATION*			
		DRUG		NO DRUG		DRUG		NO DRUG	
		MA	REV	MA	REV	MA	REV	MA	REV
"Naive" Subjects	DEGREES SLOW-PHASE	380	228	376	268	510	360	577	337
	SECONDS DURATION	49.8	43.8	47.5	42.2	58.7	50.0	57.6	43.0
"Experienced" Subjects	DEGREES SLOW-PHASE	365	263	280	173	275	249	309	155
	SECONDS DURATION	46.4	42.2	42.5	36.0	42.2	41.5	44.4	34.0

tal arithmetic tasks resulted in significantly greater output of slow-phase nystagmus than did the reverie state. (See Table 3; Fig. 3.)

These results indicate that the arousal variable in nystagmus output is less intimately related to the analeptic-produced changes in activity than to the kind of alertness influenced by instructions. They also point out the need for a caution in the evaluation of drug effects on nystagmus. Most such studies have employed tranquilizing or depressant-type drugs and have related resultant deterioration or absence of nystagmus to those areas of the brain on which the drug exerts a primary influence. In many cases, the main vestibular significance of the drug may be more general i.e., simply that the subject becomes relaxed and less mentally active. Studies of sedative compounds used in conjunction with instructions influencing mental activity would be of interest.

2. Low-magnitude, prolonged constant angular acceleration. The effects of instructions on the nystagmic response to accelerations of 1.8° and 1.0°/sec² were examined.[9] Aschan[3] has presented evidence indicating that the nystagmic response terminates abruptly at the moment of stimulus cessation when stimuli of 1.0°/sec² are employed, and that a 50 per cent reduction in response appears in the second following cessation when higher levels of stimulation are used. Neither of these findings were verified when subjects were engaged in mental arithmetic (See Table 4). The data indicated that:

(a) Under the arithmetic condition clear nystagmus appeared for all subjects throughout stimulation and never ended prior to, or

TABLE 4

Average total slow-phase nystagmus and average duration of the response in seconds. Data are averages of two accelerations and two decelerations for each of 6 subjects. MA and ATS refer, respectively, to mental arithmetic and attending to the rotatory sensations (stimuli were 1.0°/sec² for 84 seconds and 1.8°/sec² for 50 seconds).

Stimulus	Task	Degrees Slow-Phase Nystagmus	Nystagmus Duration in Seconds
1.0°/sec²	MA	671.4	94.8
	ATS	298.1	57.2
1.8°/sec²	MA	854.3	68.3
	ATS	159.9	27.3

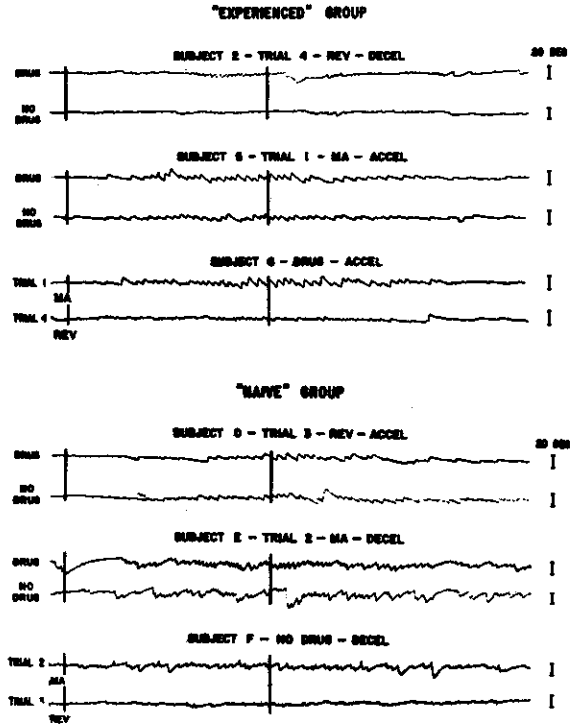

FIGURE 3. Nystagmus recordings obtained from rotation-experienced and rotation-naive subjects under conditions of mental arithmetic (MA) and reverie (REV). Data were obtained under both conditions with a placebo and with a normal clinical dosage of amphetamine. Stimulus periods (4.1°/sec² for 13 seconds) are denoted by the vertical bars through the records. Calibration markers at the right of each record indicate 20° eye excursions.

at the moment of, stimulus termination.

(b) When simply attending to the rather weak rotatory sensations elicited by these low-level accelerations, 58 per cent of the records showed either "zero" response or ended prior to, or at the moment of, stimulus termination.

(c) A 50 per cent drop in slow-phase nystagmus velocity (1.8°/sec² stimulus) appeared 4-6 seconds after stimulus termination during arithmetic trials.

In addition, two subjects who had demonstrated a high vestibular output in other experiments were tested under the mental arithmetic condition with a 0.5°/sec² stimulus applied for 84 seconds in one case and 110 seconds in the other. Results were similar to those obtained at 1.0° and 1.8°/sec² (see Fig. 4). The data demonstrate that, when subjects are kept mentally alert, nystagmus does not cease abruptly with the termination of low-level accelerations (see Fig. 5).

Caloric Stimulation

In order to determine whether the significant effects due to instructions could be generalized to other methods of nystagmus elicitation, a study of clinical procedures was conducted (see Table 1). Four variables were manipulated: instructions (MA and REV), fixation distance (30.5 cm and 1.63 m), subject experience, and the presence or absence of vision.[16] Average data appear in Table 5 and the results may be summarized as follows:

1) The "naive" and "experienced" groups did not differ significantly.

2) In both light and darkness, nystagmus was of greater amplitude and longer duration while subjects were engaged in mental arithmetic than when they were instructed to relax.

3) Unlike responses to rotation, the caloric reaction was always present during reverie states.

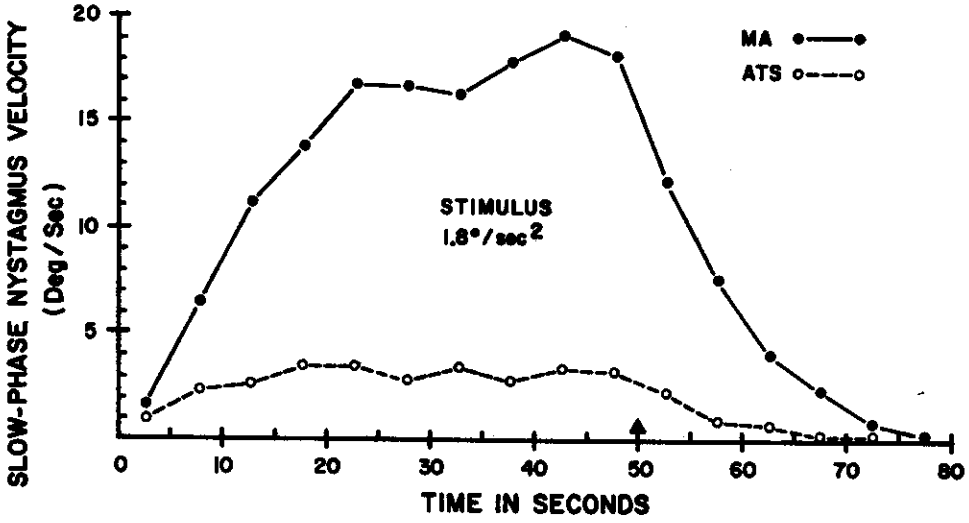

FIGURE 4. Average slow-phase eye velocity (deg/sec) for 5-second intervals under conditions of mental arithmetic (MA) and attending to the direction and intensity of the rotatory sensation (ATS). Data are averages for 6 subjects each given 2 accelerations and 2 decelerations under each condition. Arrow indicates point of stimulus termination (1.8°/sec² for 50 seconds).

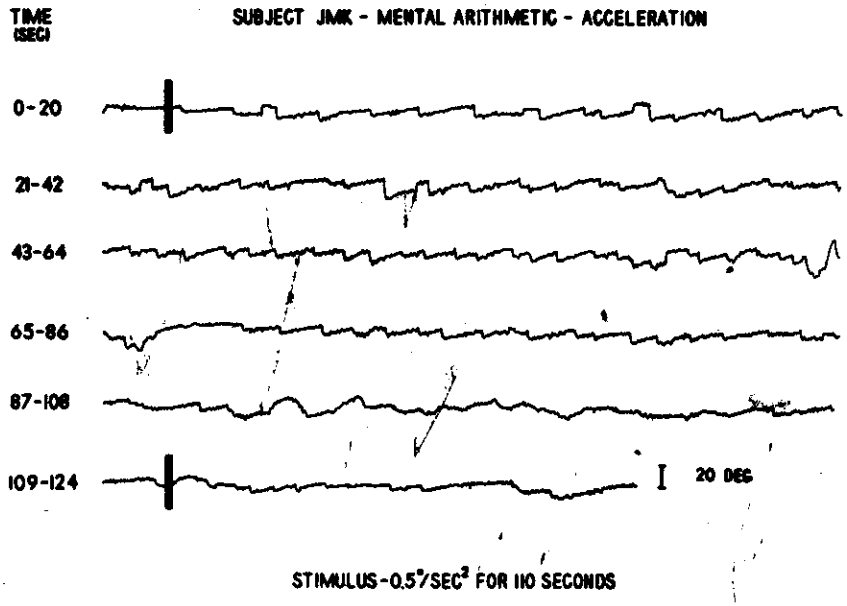

FIGURE 5. Nystagmus recording from a subject exposed to an acceleration of 0.5°/sec² for 110 seconds while engaged in mental arithmetic. Vertical bars through the record indicate the stimulus period and an eye-excursion calibration appears at the end of the record. Note the beats occurring after stimulus termination.

TABLE 5

The average duration of caloric nystagmus, average slow-phase nystagmus output (total darkness), and average nystagmus rating in illumination (a 0-4 scale considering frequency, amplitude, and regularity of response) under conditions of mental arithmetic and reverie. Fixation distance in illumination was 30.5 cm or 1.63 m (ceiling fixation). Data are averages for 16 subjects tested with water at 30° C applied for 40 seconds.

Total Darkness

Task	Average Nystagmus Duration (Sec.)	Average Total Slow-Phase Nystagmus Output (Deg.)
MA	230.9	2310°
REV	194.5	1520°

Illumination

Task	Average Nystagmus Duration (Sec.)	Examiner's Average Rating (0-4 Scale)
MA	139.9	2.1
REV	124.8	1.5
MA (cf)*	104.3	1.3

* indicates ceiling fixation (1.63 m)

4) Ratings of the nystagmus response in illumination favored MA over REV trials.

5) Near-fixation (30.5 cm) yielded greater amplitude and duration of nystagmus than far-fixation (1.63 m).

6) Two of 8 subjects demonstrated no response during far-fixation.

These data demonstrate that the nystagmic reaction to calorization is affected by instructions, although less markedly so than during rotatory stimulation (see Fig. 6). This is probably due to a combination of greater intensity of the caloric stimulus and increased apprehensiveness on the part of subjects in the caloric situation. Furthermore, the distance of the fixation point from the subject during aural irrigation in illumination is a critical variable. Not only is nystagmus reduced with far-fixation, but also, with 2 experimental subjects and 2 others used in preliminary trials, no nystagmus was observed.

General Discussion

The series of studies outlined above has: (1) confirmed and expanded notions regarding arousal-level and its effect on human vestibular nystagmus, (2) evaluated the efficacy of several techniques for providing some control of arousal-level, and (3) pointed to a possible explanation for conflicting or unusual results in theoretical or applied vestibular investigations.

The early studies which noted changes in nystagmus as some function of "excitement" or physical tension pointed to the need for control over subjective states. Wendt[36, 37] was probably the first to establish some basis of reducing the variability which results from subjective changes by his notion of an "environment-directed orientation." One of the means he employed to maintain alertness was to have subjects imagine and attend to "a ship on the horizon."[33] Apparently some subjects could use this technique and remain alert throughout a number of trials.

It would appear, however, that the underlying factor in subjective orientation may be more accurately defined as some degree of mental activity or, perhaps, as a psychological state of alertness or concerted attending. The direction of a subject's orientation seems to matter little, i.e., whether he is "inward-directed" or not, so long as he is mentally active. Further, at least for a relatively short series of repeated vestibular stimulations, the mental arithmetic task seems to provide the least amount of trial-to-trial intra-subject variability and results in a vigorous, long-duration nystagmus. Other recent studies have employed arithmetic tasks to demonstrate changes in caloric nystagmus. Mahoney, Harlan and Bickford[30] and, later, Lidvall,[27] used short arithmetic problems during nystagmus dysrhythmia to elicit a burst of regular nystagmus. However,

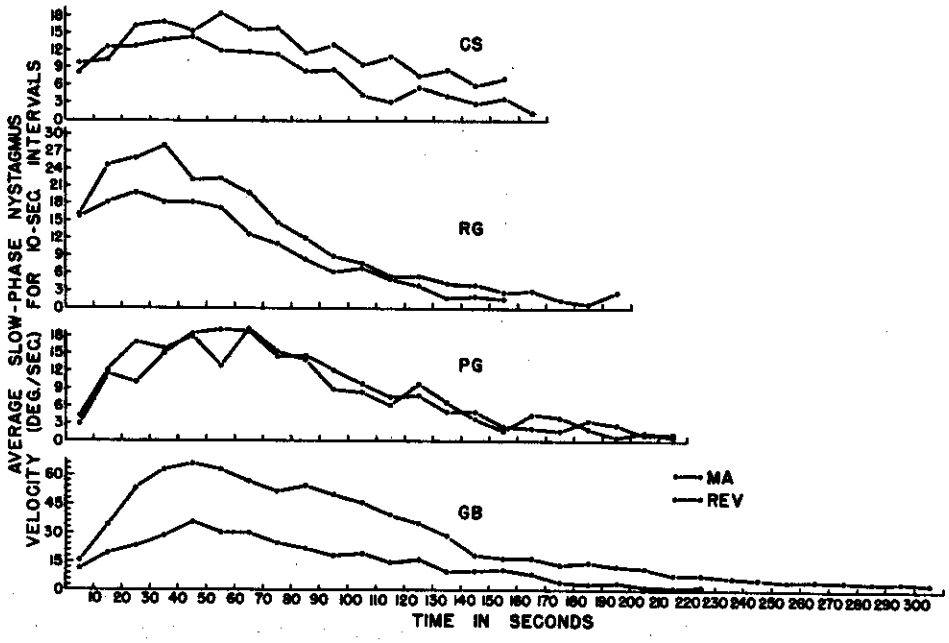

FIGURE 6. Average slow-phase eye velocity for 4 subjects under conditions of mental arithmetic (MA) and reverie (REV). Stimuli were 40 seconds of aural irrigation with water at 30° C administered in illumination. "Zero" time indicates moment of stimulus termination and onset of total darkness.

these investigators do not appear to have employed the task as a means of stabilizing subjective states throughout successive trials.

Wendt[26] has pointed out one of the main areas in which failure to control the alertness factor can result in possibly erroneous conclusions, i.e., habituation of nystagmus. Wendt claims that habituation in total darkness does not take place unless the subject is allowed to assume a "reverie attitude." Early studies, such as those by Dodge,[14] Dorcus,[15] and Griffith,[16, 17] showed a markedly reduced response with repeated angular accelerations. Wendt, however, accredits these findings to a failure to control alertness. The same explanation probably accounts for at least some of the nystagmus decline recently reported for repeated caloric stimulations.[28]

Two other studies may be cited as examples where a lack of control of the arousal states of subjects probably produced results at variance with actual vestibular functioning. Thus, the report of Aschan[3] indicates no nystagmic response from some subjects and an immediate cessation of nystagmus with stimulus termination from others, when acceleration values of 1.0°/sec² are employed. He relates this to the notion that, at such a low level of acceleration, only a torsion of the cupula occurs, since the stimulus is too weak to cause the end-organ to slide along the crista. His findings, however, are not confirmed when subjects are kept mentally active. Further, the rapid decline of nystagmus after stimulus cessation reported for higher-level accelerations also does not appear when appropriate subject-tasks are assigned. Only during conditions of reduced mental activity have subjects used in the present reports demonstrated examples of Aschan's findings.

The second investigation, by Suzuki and Totsuka,[35] made note of inconsistent nystagmus responses from some subjects during a series of repeated accelerations and, from others, "a temporary reduction in response followed by a complete and lasting restoration of nystagmus." It is almost certain that the reported fluctua-

tions were due to changes in the subjects' states of alertness.

For any given series of repeated stimulation of the vestibular system, some task-control of the subject's mental activity level appears necessary. Further, two other factors must be considered: (a) if subjects are permitted to close their eyes, arousal is probably affected[24] and, it has been demonstrated that, even if subjects are in total darkness, eye-closure results in a reduced nystagmus response when the corneo-retinal-potential method of recording is employed;[22] (b) with prolonged or repeated exposure to a given set of conditions, the various stimuli involved probably lose their arousal value. This has been demonstrated for auditory stimuli.[24]

Thus, it is suggested that, for short series of stimulations, arithmetic tasks be assigned to subjects to provide some control over their mental activity. For long stimulus series, a variety of tasks is probably necessary to maintain arousal level. The use of simple tasks which require sustained mental activity should reduce variability of the nystagmic response not due directly to vestibular function and permit a more adequate evaluation of vestibular processes, *per se*. This approach does not contradict the possibility that the normal course of events may be for both the subjective and nystagmic aspects of vestibular function to rise and decline at comparable rates in the absence of extraneous stimuli.[9]

Some notion of the subject's mental activity appears to be a prerequisite for proper evaluation of vestibular responses in practical situations, e.g. in clinical diagnosis, maneuvers of air or space vehicles, etc. With respect to the latter, it is of interest that, although evidence is conflicting, several studies[7, 8, 23] have indicated that gross qualitative and quantitative changes in nystagmus may occur as a function of alertness without a significant change in EEG pattern. That is, in the evaluation of the effects of certain maneuvers or environmental conditions, the absence of nystagmus in a subject may be a signal of reduced mental activity which it too subtle to be detected by EEG tracings, rather than a lack of vestibular stimulation. If the nystagmograms show the wandering, autogenous eye movements mentioned by Wendt,[26] this is almost certainly the case.[9]

A point of more general application should also be made. The data reviewed in the present report indicate the importance of the subject's state of arousal on the reactions elicited through stimulation of what has been frequently regarded as a "reflexive system." It is possible that much "reflex activity" is significantly influenced by the subject's state of alertness. Further, this "psychological tonus" may have implications for the evaluation of clinical cases.

SUMMARY

Investigations concerned with the effects of subjective states on vestibular nystagmus were reviewed. Methods of controlling such states were discussed. Data indicate that the significant factor in subject-orientation is a state of arousal, defined in terms of mental activity. Continuous, concerted attending to a task yields a brisk, long-duration nystagmus. If responses to a task require less attention with repetition, or if subjects are not kept alert, a significant reduction in nystagmus output may occur. A sudden alerting stimulus may then occasion a burst of nystagmic activity in an apparently "adapted" individual. Knowledge of subjectives states is a pre-requisite for proper evaluation of vestibular responses in theoretical formulations, in many clinical situations, and in ascertaining vestibular components associated with air- or space vehicle maneuvers.

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