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A PRELIMINARY STUDY OF THE MEASUREMENT OF HUMAN ORIENTATION ABILITY DURING ROTATION

Thesis for the Degree of M. A.

MICHIGAN STATE UNIVERSITY

Thomas N. Tillman

1964

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A PRELIMINARY STUDY OF THE MEASUREMENT OF HUMAN ORIENTATION ABILITY DURING ROTATION

By

Thomas N. Tillman

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Health, Physical Education and Recreation

1964

Approved Wayne D. Van Huss

ABSTRACT

A PRELIMINARY STUDY OF THE MEASUREMENT OF HUMAN ORIENTATION ABILITY DURING ROTATION

by Thomas N. Tillman

The objective of this study was to devise a simple, safe, reliable method for qualitatively evaluating a person's ability to orient himself in reference to a starting position while rotating about a single axis passing through his center of gravity.

To accomplish this an apparatus was conceived for rotating a person in one plane around an axis passing through his approximate center of gravity. Telemetering equipment and a recording apparatus were employed to record actual revolutions and subjectively sensed revolutions. A subject was to indicate sensing of a completed revolution by pressing a switch button.

To test the apparatus and testing methods, three subjects were particularly selected for their respective qualities. Two were highly skilled gymnasts and well experienced in multiple rotations. Of these two, one appeared to be innately skilled while the other's skill was known to be a product of training. The third subject had virtually no experience in acrobatics and very little

exposure to rotation. This third subject was highly informed as to the nature, purpose, and mechanics of the orientation test. By selecting subjects in this way it was hoped to give added emphasis to the test results.

Each subject was given two trials. A trial consisted of ten revolutions in about twenty seconds. The subjects were to orient to the starting position and indicate each time one full revolution was completed.

Supposedly, the subjects had to rely on cues originating in the semicircular canals because steps were taken to remove cues, to inhibit reception of cues, or to confuse integration of otherwise uncontrollable cues that would contribute to orientation during the rotation test as a result of peculiarities of the test apparatus.

Various mechanical problems with the apparatus were encountered so as to place reasonable doubt on the validity of the testing results. However, in comparing the three records, the subjects that were skilled were seen to register perfect records while the unskilled subject registered gross inaccuracy.

Only a few tentative conclusions were arrived at by speculative analysis because of so little data.

1. The basic design of the test seems to be good but refinements in apparatus and procedure are necessary if validity is to be realized.

2. The test appears as if it might be capable of separating skilled persons from unskilled persons.

3. The test appears as if it might be reliable; however, testing of a great many more subjects is needed to ascertain this.

4. The test appears to indicate that semicircular canal stimulation is not a major disorienting influence during simple rotation of persons skilled or trained in rotational performances.

5. The testing method appears to have possibilities for more intensive study of the phenomena associated with spatial orientation ability in humans.

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INTRODUCTION TO THE PROBLEM

Multiple aerial somersaulting tricks are among the more important kinds of tricks for gymnasts to learn in order to achieve competitive success. These tricks, however, are so difficult to perform correctly and so dangerous to misperform that they have always been especially difficult to teach. The problem is, simply, that no one has yet been able to find a really safe way to teach this type of stunt.

The potential danger of aerial somersaulting is that a performer may rotate either too far or not far enough and consequently land in such a way that serious head or spinal injuries are likely to be incurred. Furthermore, experience has shown that elimination of just such errors is the most difficult aspect of learning these tricks. Experience has also shown that, apparently, the best way of eliminating those errors is by gradual correction during repeated attempts to perform the actual stunt. Because of these factors, most attempts at finding a safe way of teaching these tricks have focused upon ways of protecting the pupil from injury while he tries to perfect his performance.

Up to the present time, it has been found that one of the easiest and most reliable of ways to protect a pupil in this situation is to employ an overhead safety belt. This belt is fastened around the performer's waist and has ropes attached to the right and left sides which pass up through an overhead pulley system and then down to a person standing on the ground. That person is then enabled to slow or completely stop the pupil's descent by merely pulling on the ropes if ever a disastrous landing appears imminent. Ultimately, the pupil gains enough experience to acquire the necessary skills so that it is safe to remove the belt for subsequent unassisted performances.

In spite of the fact that this method appears to be the most successful way of teaching aerial somersaulting tricks, even it is not entirely satisfactory because of one important factor--there is, as yet, no safe way of reliably ascertaining when a pupil has acquired sufficient skill to warrant an attempt without the security afforded by the safety belt. Usually, this is done by comparing subjective estimates by both pupil and coach as to the pupil's relative preparedness. Such estimates, however, are only educated guesses; and the writer contends that since the pupil's very life may be at stake, guesswork is definitely inadequate no matter how educated it may be.

What is needed is a simple, reliable, safe method of measuring an individual's degree of preparedness to perform a complex trick of this particular type. The problem, however, of developing such a test is exceedingly complicated due to a lack of precise knowledge concerning the exact nature of human capabilities and of the specific learning processes which are involved in this fairly unique kind of motor performance. As a consequence, development of the test must necessarily be approached on an empirical basis and cannot possibly be resolved in any single study. Moreover, since the present study cannot hope to develop anything that can be used as a practical measure at this time, it is hoped that the results will at least provide a tool which might be made practical following further investigation.

Interpretation of the Problem

Teaching experience has repeatedly shown that even though a pupil may find it relatively easy to effect aerial rotation of his body and to control the speed of that rotation, he usually experiences great difficulty learning to effect only the specific amount of rotation necessary to successful performance of the stunt being attempted. This difficulty is probably due, at least in part, to factors of human performance variability normally manifested in any complex motor act consisting of violent, gross body action. Skilled performers, however, apparently compensate for such aberrations by adjusting their rotational velocity during flight. They also appear to be capable of adjusting their performances to compensate for differences in environmental conditions such as are encountered in performing on different apparatuses or in different locales.

These observations imply that consistent success in this kind of performance ultimately depends upon an ability to discern progress of rotation regardless of differences in rotational velocity that might be achieved in these performances. In other words, in addition to learning how much effort to expend in initiating these tricks and in controlling rotational velocity, a person must learn how to orient himself either continuously or at frequent successive intervals throughout the performance in order to compensate for any deviation of conditions whether caused by human variability or by effective differences in environmental factors.

In further support of this possibility there is the peculiar phenomenon known in the vernacular of gymnastics as "getting lost." This term is applied to a situation where a gymnast begins to correctly perform a stunt (usually rotational, and most often an aerial somersaulting trick) but suddenly, for no apparent reason, commences to make seemingly uncoordinated movements that are inappropriate to the attempted trick. Questioning of a performer about these movements almost invariably invokes the response, "I got lost!" This is of especial interest because the choice of words is nearly always the same. Therefore, in spite of the fact that neither the cause nor the origin of this "lost" feeling has yet been established, the implication is clear--prior to "getting lost," the performer was (technically speaking) oriented!

If in the last analysis then, this orientation ability is actually the ultimate determinant of success or failure as it seems to be in this kind of motor performance, a test to measure the relative quality of this ability should also be a reasonably good test of a pupil's relative preparedness for unassisted performances providing other factors remain constant.

Ideally, a test for this purpose should be designed on the basis of detailed knowledge of the specific sensory processes which contribute to orientation in the particular kind of situation outlined above. A preliminary review of related literature, however, revealed that, while the phenomenon of human orientation in general has been extensively investigated by many disciplines, the specific area of concern to this study (concerning the effects of repeated exposures to purposeful rotational experiences on orientation during those experiences) has apparently been much neglected. After failing to find the specifically desired information in the literature, the writer interviewed numerous skilled performers and their coaches. Their replies plus observations drawn from the writer's own extensive experience in both teaching and performing these tricks indicated that different persons might rely on different sensations for orientation in these circumstances. Yet, the nebulous nature of the opinions expressed by these people implied very strongly that they were really unaware of the exact way in which they oriented in these performances. It is conceivable, of course, that innate differences between individuals could account for actual differences in orientation processes. It is also possible that the differences in expressed opinions merely reflects different total degrees of training. It is of special interest, nevertheless, that virtually all of the more highly skilled persons reported "feeling" the "rightness" or the "wrongness" of their performances at some stage in the actual performance.

Therefore, to make progress toward the goal it seemed most plausible to attempt to simulate as closely as possible the experience of aerial rotation in such a manner that it could be hoped the same sensations would be produced which a trained person might use for orientation in actual performances. Test conditions might then be regulated to provide orientation tasks, either roughly comparable to, or exceeding that, which exists in actual performances. If this could be achieved with a reasonable degree of reliability, subsequent studies could then be made, and would be necessary to determine the ultimate validity of the testing.

Statement of the Problem

To devise a simple, safe, reliable method for qualitatively evaluating a person's ability to orient himself in reference to a starting position while rotating about a single axis passing through his center of gravity.

Need for the Study

Little is known about the techniques of evaluating human abilities to perform complex acrobatic tricks other than by subjective estimate. Additional knowledge and objective techniques are greatly needed to reduce the risks involved in such motor performances.

Limitations of the Study

1. The orientation test results are of doubtful validity because: (a) it is not known what was really being measured; (b) it proved impossible to eliminate the possibility of auditory cues with our laboratory equipment; and (c) the testing apparatus developed a non-repairable, very audible clicking sound from which the subjects might have been either disoriented or oriented.

2. Not enough subjects to assure either reliability or validity through statistical treatment of data.

3. Due to the largely empirical nature of the orientation test design, its results cannot be considered conclusive evidence.

Definition of Terms

Multiple aerial somersaulting tricks--meant to include the variety of tricks performed by acrobats, gymnasts, or fancy divers which consist of more than one head over heels rotation of the body in the air.

Kinesthetic sense or system--the sensory system which supplies cues to the brain enabling assessment of movements and positions of the body as a whole. Some authorities include the vestibular system which although of an anatomically different structure is concerned with movements or positions of the head and thereby of the total body.

Vestibular or labyrinthine system--the sensory system with receptor argans located in the vestibule (labyrinth) of the inner ear, functionally and anatomically separated into two portions: (1) the semicircular canal portion which is known to be responsive to position or negative changes of angular acceleration, and (2) the otolith portion which is considered responsive to tilting movements or linear accelerative motion of the head.

Proprioceptive sense--used interchangeably with kinesthetic sense but identifies the sensory receptors as proprioceptors, a term originated by Sherrington.

Nystagmus--refers to reflexly caused eye movements. These movements can be thought of as purposive to preventing a blurred image on the retina. In other words the eye reflexly attempts to keep an apparently or actually moving field of vision in focus by trying to move as necessary to keep up with the motion of the visual field regardless of whether the visual field is actually moving, or whether it is still and the person is moving. The eye moves in its socket slowly in the same direction that the field is apparently moving and when anatomically stopped jumps quickly back to the other side of the socket and resumes the slow movements, once again repeating the cycle. When direction of nystagmus is referred to it indicates the direction of the fast movement of the eye and when nystagmus occurs during rotation of a person the fast movement is in the same direction as the rotation.

Post-rotatory or after nystagmus--produced when a person in rotation is decelerated or stopped abruptly.

CHAPTER II

REVIEW OF RELATED LITERATURE

Various aspects of the phenomenon of human spatial orientation ability have been extensively explored by numerous investigators in many disciplines over a considerable period of time. Unfortunately for the purposes of this study, however, there appeared to be very few instances where the line of investigation was concerned with the effects of repeated or habitual exposure to purposeful rotational experiences such as those of dancers or acrobats. Instead, attention has been focused primarily upon phenomena manifested in normal persons or in subnormal persons (clinical cases) when such people are only occasionally exposed to non-purposeful rotation experiences such as might be undergone while riding in a spinning vehicle. There is, nevertheless, much that can be logically inferred from this material in approaching the problem at hand.

According to Campbell, man orientates to his local environment through a precise cerebral integration of afferent stimuli flowing from the visual, the so-called kinesthetic, and the vestibular systems. He also notes that, on the basis of an imposing fund of experimental and clinical evidence gathered during the past century, it is generally accepted that effective orientation is possible with any two of these three systems functioning properly. It is likewise generally agreed that orientation cannot be efficient if only one of these systems is functioning. (2, p. 488)

It is important to note that there is evidently some disagreement between scientists among the disciplines concerned with these phenomena as to exactly what comprises the kinesthetic (proprioceptive) system. While many include the vestibular organs, others regard labyrinthine function as a system by itself as Campbell apparently does. These differences are perhaps due to the fact, that although all sense receptors involved are tension activated, there are some differences in the ways thay they are stimulated. The vestibular apparatus is responsive only to linear acceleration forces and gravity in the otolithic portion and only to angular acceleration forces in the semicircular canal portion. However, the kinesthetic receptors situated in skin, muscles, tendons, viscera, and connective tissues are responsive to any force which changes the tension of the tissue in which they are located. (9, 6, 13, 15)

Hanrahan and Bushnell regard the vestibular or labyinthine apparatus as the most important mechanoreceptor involved in orientation. They mention that during World War I the vestibular apparatus was looked upon as the organ of equilibration, and that sensitive vestibular reactions were considered essential for a pilot. They call attention, however, to the fact that such reactions can be a handicap as was shown when late nineteenth century scientists established a relationship between inner ear function and seasickness by observing that deaf mutes with damaged labyrinthine function were almost never seasick. (11, p. 114)

Concerning the function of the labyrinth, Walsh writes:

> In spite of its small size the labyrinth plays an important role for it supplies information to the brain about the position and movements of the head. This information is used as a basis for determining the postural adjustments which are necessary in the musculature of the limbs, trunk, and eyes. It is not the only source of information about the position of the head in space; both proprioceptive and visual sources of information also provide important cues about posture. (15, p. 129)

Ashton Graybiel, currently one of the country's foremost aerospace medical researchers, has a somewhat different opinion based on his intensive studies of orientation problems connected with flight and space travel. He points out that in man the sensory organs in the vestibular labyrinth contribute little to orientation in space if comparison is made with the otolith apparatus in fish and the semicircular canals in birds. Also of possible significance to this study, he states that the great importance of these organs rests in the fact that they are capable of causing disorientation. Since such disorientation could result from exposure to unusual patterns of stimulation which might be encountered in flight, he concludes that it might be advantageous to a space traveler if these sensory organs, especially the semicircular canals, were non-functioning. (8, p. 64)

Graybiel's comparison of man's vestibular functioning with that of birds and fish appears to have certain interesting implications. Without going into arguments over cause and effect relationships, the natural life of birds and fish involves movement patterns for which their respective vestibular functioning is particularly suitable and also probably necessary to survival. Man, however, is not restricted to the movement patterns of the fish by either his anatomy or his environment as is the fish. Also, while ordinary human individuals do not frequently effect the movement patterns of birds, they have been able to effect very similar patterns through the use of mechanical devices such as airplanes or any of the numerous devices designed for acrobatic maneuvers (springboards, trapezes, etc.). Therefore, it seems both possible and reasonable that with more frequent exposure to such patterns the functioning of man's vestibular apparatus might approach or even exceed in efficiency that of birds or fish. The fact that persons exist who have become capable of performing feats requiring a highly superior if not a superhuman sense of balance is further indication of such a possibility.

Graybiel's comment on the disorienting capability of the semicircular canals is particularly interesting because of the implications of his observation that disorientation might arise as a result of exposure to unusual patterns of stimulation. It is common knowledge that ordinary persons do not often encounter protracted rotational experiences and thus find them disorienting. Evidence, of a sort, concerning this is found in the fact that protracted rotation has been used for years in all kinds of games because of its disorienting effect. On the other hand, excessive exposures to a particular pattern of rotation would ultimately cause that pattern to become usual and thus the individual should then not be disoriented by subsequent experiences.

A possible implication of this is that the semicircular canals actually contribute to the orientation process in a negative sense which becomes diminished or less negative as the experience becomes more usual. This would seem to be in accord with what is known concerning adaptation phenomena manifested with other sensory organs.

Indirectly, it offers a possible explanation for the "lost" feeling sometimes experienced by gymnasts. It would also explain why skaters, dancers, acrobats, and the like are apparently not disoriented by rotation in their respective performances. This in turn, poses the interesting possibility that the process of learning to orientate during rotational stunts is one of eliminating the disorienting effects so that the orienting stimuli arising from the kinesthetic and the visual systems can produce orientation. However, since cerebral integration seems to be involved, it does not necessarily rule out the possibility of positive contributions from the vestibular system. In fact the negative contributions might even become less negative to the extent that they begin to become positive.

In regard to the relative importance of the three systems, visual, kinesthetic, and vestibular; Walsh, citing the work of Witkin as evidence, states that in general, visual information is used as the principal basis for orientation, and data from the labyrinth and the proprioceptive system are interpreted in this light. (15, p. 130; 16 p. 1-46)

Evidence in support of Walsh's statement is seen from the results of an underwater orientation study by Haines. In this experiment the subjects were disoriented from the vertical by means of being rotated from a starting tilt through a full circle. The subjects were then to indicate the upright vertical while remaining submerged and without visual cues. The subjects' inability to do this accurately would seem to indicate the importance of visual cues. However, attention is called to the fact that these subjects were disoriented by rotation. As a consequence, they would be forced to rely on vision because of inexperience in using vestibular senses in such a situation. (10, p. 6)

In one part of a study concerned with determining the importance of kinesthetic sensory cues to gymnastic performances, Darling obtained results which he interpreted as indicating that visual rather than kinesthetic cues are relied upon when both are possible, but that kinesthetic cues are relied upon if visual cues are inadequate or absent. Darling includes the vestibular organs as part of the kinesthetic system. (4, p. 8-9)

Still further possibilities are indicated by Campbell when he states:

> Some scientists will express an opinion as to the dominance of the visual system and its ability to perform an orientation function. However, there are in normal individuals nervous pathways with their attendant reflexes which cause eye movements to be dependent in certain degree upon stimuli emanating from the vestibular system. (2, p. 492)

The existence of these reflexive eye movements has been so well established that they have been incorporated into various clinical tests of labyrinthine function. They have also provided the basis for research in the area of concern to this study. They are therefore, important to the problem at hand because of the inferences that have been made and can be made on the basis of either their absence or presence whichever the case may be. (9, p. 680)

One type of reflexive eye movement is referred to as nystagmus. It is manifested, however, with different characteristics depending on the number of canals stimulated, on which canals are stimulated and on the manner of stimulation. A variety of this nystagmus is important here because it is known to commence when normal, ordinary persons are subjected to angular acceleration. This is called rotary or accelerative nystagmus and is known to remain so long as acceleration is maintained. If, however, angular velocity becomes constant the eye movements gradually subside and then disappear. If the nystagmus appears as the result of a sudden stop from rotation it is referred to as post-rotatory or stopping nystagmus. (6, 9, 15)

Nystagmus phenomena seem important to this study for two reasons: first, the presence of nystagmus as the result of exposure to rotation is considered normal response to such an experience; and secondly, its existence produces what is called the oculogyral illusion--apparent rotation of the environment. Since the oculogyral illusion is caused by the nystagmus movements it disappears or appears as the nystagmus does. According to Graybiel this illusion remained intact in a study where the subjects were repeatedly exposed to angular accelerations and decelerations thus giving little or no evidence that habituation or adaptation to rotation is possible. (7, p. 497)

Other investigators, however, report different results. From a cinematographic analysis of a famous male figure skater aptly nicknamed "the human bullet," McCabe found that this individual performed vertical spins that reached the incredible (calculated) rate of 420 rpm. McCabe also reported that an examination of the subject immediately following such a performance revealed absolutely no nystagmus, vertigo, or other symptoms ordinarily associated with the rotation of a normal (healthy) person at even considerably slower rates. A most likely inference from these observations is that this person had become adapted or habituated to rotational experience. (14)

In a truly classical study, and closely related to the one being attempted here, Dodge made a rather intensive investigation of the possibilities that a human might become adapted to rotation experience. In brief summary, Dodge exposed subjects to repeated, protracted rotational experiences under laboratory controlled conditions in order to observe any changes in behavior of reflexive eye movements which might indicate adaptation or habituation. Due to the completeness and extent of his study, Dodge made numerous observations of related interest to the problem at hand, in the interests of brevity, however, only those observations of apparent greatest relevance are given below in the order of their appearance throughout his report.

> If regular rotation continues long enough the hydrodynamics of the vestibule would lead one to expect a gradual decrease of effective stimulation as the fluids of the vestibule come to equilibrium. The point of equilibrium is reached when the vestibular fluids and vestibular walls have identical angular velocities. At that point one could expect the reflex compensation of closed eyes to disappear. As a matter of record, protracted, even rotation at some point always ceases to be a stimulus for the compensatory movements of closed eyes.
>
> . . . .
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> . . . It proved impossible in my laboratory to completely exclude sensory factors which arose outside the vestibule. Although reduced as far as practicable, sound and light changes still gave some clue to rotation.
>
> . . . .
>
> When the onset of rotation was first sensed by the subject he usually perceived its direction and acceleration . . . studying effects related to slow rotation . . . At no time was there any subjective appreciation of the actual speed of rotation. One subject after about fifty rotations said it seemed to him he had only gone around about three-fourths of a circle . . . .
>
> . . . .
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> . . . Under our experimental conditions it is noteworthy that at no time was the actual speed of rotation or rate of acceleration a matter of consciousness.
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> . . . .
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> . . . We tried rotating a subject in the usual manner but with the eyes open. Under such circumstances consciousness of the speed of rotation is inevitable. He sees the field of view rotating around him . . .
>
> . . . .
>
> . . . Since vestibular equilibrium indicates to a subject that he is not moving, the obvious motion is referred to the environment.
>
> . . . .

> . . .Even when the rotations were made with the eyes open there was usually no discomfort. If, however, the head was raised from the head rest during or immediately after rotation or if it were otherwise moved very distressing symptoms might appear, which in one case lasted several hours. The inference is inevitable. Uncomplicated and undisturbed slowly accelerating rotation does not cause vertigo. (5, pp. 4-15)

Concerning the effects of repetition of rotation Dodge states, . . ."This experiment disclosed the phenomenon of habituation to rotation beyond the possibility of accident." It is important to know that this conclusion was based on irrefutable evidence obtained by an ingenious, intricate method of photographing the amplitude of both accelerative and after nystagmus (post-rotatory). In regard to these records, Dodge reports . . ."There is, however, one clear difference between training of the nystagmus of stopping and training of the nystagmus of acceleration. Whereas in the former case the nystagmus completely disappeared, in the latter case, traces of it were always present at the beginning of rotation." (5, pp. 15-22)

In two supplementary portions of his study, Dodge explored (a) the possibility of transfer of training from rotation in one direction to rotation in the opposite direction, and (b) the loss of training in one week. He found that about half the training in one direction transferred to the other. As for the loss of training, a slight loss was indicated, but it was made up almost immediately. (5, pp. 20)

In conjunction with the completion of the Dodge's study it was noted that a subjective indifference to rotation developed towards the end of the training period into a striking lack of clear consciousness of rotation. One subject reported very little of the usual consciousness of motion and that the rotation felt peculiarly natural and comfortable. In respect to this Dodge states:

> . . .It can scarcely be over emphasized how completely the character of the subjective reaction to rotation changed. Instead of being a disagreeable task the rotation experiment had a soothing, soporific character both during and immediately after rotation. This peculiar pleasantness or comfortableness carried over into the post-training series. It did not carry over over into reversed rotation or accidental interference with the customary speed. (5, pp. 21)

Other than the fact that habituation to rotation is possible, and that nystagmus is reduced in the process, two factors stand out among Dodge's observations that are of special interest to this study. His mention of a reflex closure of the eyes in response to the onset of rotation would indicate an obvious inability to orient by visual means, at least initially. Unfortunately, he does not indicate whether or not this particular reflex is modifiable as is nystagmus. The other important mention, that of the subjective indifference to rotation, the feeling of comfortableness that developed after repeated exposures, seems to lend credibility to a previously stated possibility--that contributions from the vestibular system are at first negative, but become less so in a gradual adaptation so that cues from the visual and kinesthetic systems can contribute to orientation more effectively.

In assessing the above works for apparent implications to this study, it should be remembered that this material is derived from research of conditions basically different from the interest of this study in the following ways:

1. Where effects of repeated exposure to rotation have been studied it was in regard to rotations about a vertical axis instead of around a horizontal lateral axis.

2. Where studies on the effects of exposure to rotation were made the rotations were imposed on the subjects rather than being purposefully initiated and controlled by the subject.

3. Most studies have been either of normal, or sub-normal responses to rotation.

CHAPTER III

METHODOLOGY

The Problem

The problem of this study was to devise a simple, safe, reliable, method for quantitatively evaluating a person's ability to orient himself while rotating about a single axis passing through his center of gravity.

Testing Equipment

A device for rotating the subject was built by mounting a non-upholstered wooden armchair on a comparatively frictionless rotating stool base. The arm rests were appropriately modified so that a removable crosspiece could be attached to them. An adjustable curved head rest was then mounted on the crosspiece. A lever was attached to the back of the chair using a ball bearing axle to permit smooth rotation of the chair by hand. (See Plate I, Fig. 1.)

Thus modified, it was possible to place different sized subjects in a posture roughly comparable to that assumed in performing tucked somersaulting tricks. The head rest made it possible to place and maintain the subject's head in a position that was hoped would provide for stimulation of the same semicircular canals that are stimulated in performance of aerial somersaults. (See Plate I, Fig. 2.) Figure 2 illustrates the positioning of a subject for simulation of a backward somersaulting experience. By maintaining the direction of rotation (as indicated by the curved arrow) and placing the subject's head facing in the opposite direction, front somersaulting would be simulated.

An electrocardiograph apparatus was modified for use as a recording device. The modifications were made in such a way that a relayed impulse from a photo-electric cell would cause the recording needle to swing up from the base line. The photo electric cell was placed so that a flashlight attached to the chair would activate it each time the chair made one complete revolution.

In addition, a spring loaded microswitch was attached to a constant signal radio transmitter mounted on the chair. Depression of the switch transmitted a signal to a radio receiver which in turn relayed an impulse to the recording device causing a downward swing of the recording needle.

Thus, each revolution made by the chair was recorded as an upswing. Each time a subject felt he had completed the pre-designated amount of rotation set by the experimenter as an orientation task he could so indicate by depressing the transmitter switch, and this would be recorded as a downswing from the baseline. Since the recording apparatus

PLATE I

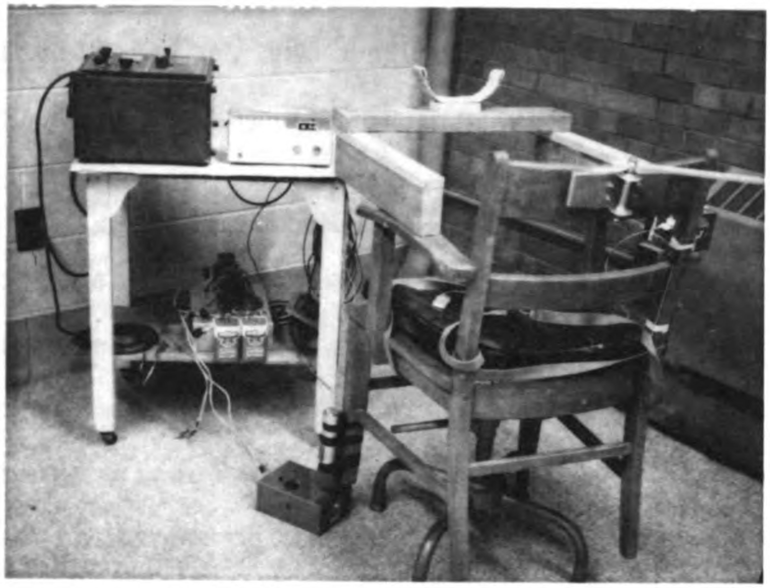


Figure 1

Figure 2

had a built in time recorder which indicated one second intervals, the total arrangement produced a record from which both actual and subjectively judged accelerations, rotational velocities, and amounts of rotation could be readily compared in any manner desired (see Appendix II)

Control of Sensory Stimulation

Since the basic purpose for designing this test was to measure orientation ability manifested during performance of aerial somersaulting tricks, it was desirable to simulate as closely as possible the sensory stimulation encountered in those performances. That goal, however, was not compatible with the goal of safety. Thus, it was decided to attempt to restrict useful orientation cues to those arising in the semicircular canal receptors-- an imposing if not an impossible task. Consequently, a number of precautionary measures were taken (see Appendix I) to block the other various possible sensory cues that might be used for orientation and particularly those which might be produced peculiar to the apparatus, procedures, and environment of the test. While not entirely satisfactory, this seemed to be the most practical first approach to the problem and it had the advantage of possibly exposing the actual importance or unimportance of the semicircular canals to rotational orientation. It was assumed that the success of these measures would play a major role in the validation of the test.

Selection of Subjects

In order to try out the apparatus and testing methods conceived in this study only three volunteer subjects were selected. One reason for selection of so few subjects was because of the possibility that the testing procedure might produce illness or other undesirable effects. The other reason is that subjects were sought on the basis of their particular suitability for testing the orientation test and only three were found who possessed the desired qualifications and who were readily available.

Two of the subjects were selected because of current highly skilled ability to perform many varieties of complex aerial somersaults under different conditions. Both of these subjects for example were capable of performing double somersaults from the ground, from a trampoline, from a one meter spring board, or from a three meter spring board. Of these two, Subject A was known to have acquired his skills from extensive training. The other, Subject B, was strongly suspected of having exceptional native ability as evidenced by his capacity to learn very complicated new tricks in relatively few trials.

The third subject, Subject C, was selected because of a definite lack of exposure to rotation experiences. This particular subject, however, possessed a highly informed understanding of the test, its procedures, and its purposes.

This was deemed desirable for purposes of exposing unforeseen weaknesses in the test.

By selecting subjects on the basis of these respective qualifications it was hoped to emphasize and give added meaning to the orientation test results. It would then be easier to make a preliminary evaluation of the test's worth and to get a better indication of any necessary refinements before proceeding with further testing.

In the first trial the subject was rotated through ten revolutions as rapidly as possible with the apparatus. These revolutions were counted soundlessly. As number ten came up the chair was stopped as abruptly as possible (within thirty to forty-five degrees), and the timer commenced the timing of after nystagmus from the moment hands grabbed the chair to stop it. The subject was told to keep his head in position, but to open his eyes. The duration of mystagmus was noted until apparent cessation at which time the timer received a signal given by the observer (experimenter) and stopped the watch.

The second trial was essentially the same. The postrotational procedure was changed slightly, however. The subject was told that he would feel like he was being stopped and would then begin to feel as though rotation were in the opposite direction. During this time he was to keep his eyes closed and keep signalling each time it seemed he made one revolution. When it finally felt as though he had stopped completely he was to say "now!" very sharply. The recording device was left on and a pencil mark was added as subject said "now!".

In the original conception of the orientation test it was hoped that the velocity of rotation would closely duplicate the rotational speed of a double somersault performed on a trampoline. Since the performer is in the air between 1.5 and 2.0 seconds his rotational velocity is between one and two revolutions per second. This could not be duplicated on this apparatus; however, it was hoped that the orientation task would still be reasonably similar.

Orientation Testing Procedure

A staff of three persons was trained to administer the test. A recorder was needed to operate and monitor the recording apparatus. A timer was needed to operate a split-time stopwatch for timing both rotation and nystagmus. The experimenter after readying the subject had to rotate, stop, and then observe the subject during the experiment.

Preparatory to the first trial the subject was seated in the rotation chair and given directions as follows: "We are going to rotate you through ten revolutions starting from the point you are now facing. Your job is to try to tell each time you come around to this position--in other words we want to know when you feel as though you have made one revolution each time you go around. Indicate this by pressing the button firmly, and quickly. Then release it. You will have to keep your eyes and your mouth closed. Your nose will also be clamped shut so you will have to hold your breath for about twenty seconds. When you feel yourself being stopped be very careful not to move any part of your body. Just open your eyes and try to look straight ahead without focusing on anything. When you feel a tap on your shoulder it means we are ready to start. You must then take a breath, close your eyes and your mouth and we will begin to rotate you. Now put the ear plugs in your ears so that you can hear nothing and we will clamp your nose shut." These instructions accompanied by appropriate demonstrations seemed to be well understood. The subject was then positioned and strapped into place.

CHAPTER IV

RESULTS AND DISCUSSION

Due to the highly theoretical nature of this study, both subjective and objective data are presented below. While all such material cannot rightly be considered experimental results in the usual sense of the term, it is important to explore all apparently possible relationships because of the great many unknowns that are involved.

Test Results

Subject A (skilled). The graphical records made by the recording apparatus illustrated in Plates II and III show that this subject was perfectly accurate in both trials which should indicate that he was successful in orienting during rotation.

Subject B (skilled). The graphical records of this subject shown in Plates IV and V indicate that he also was perfectly accurate in both trials.

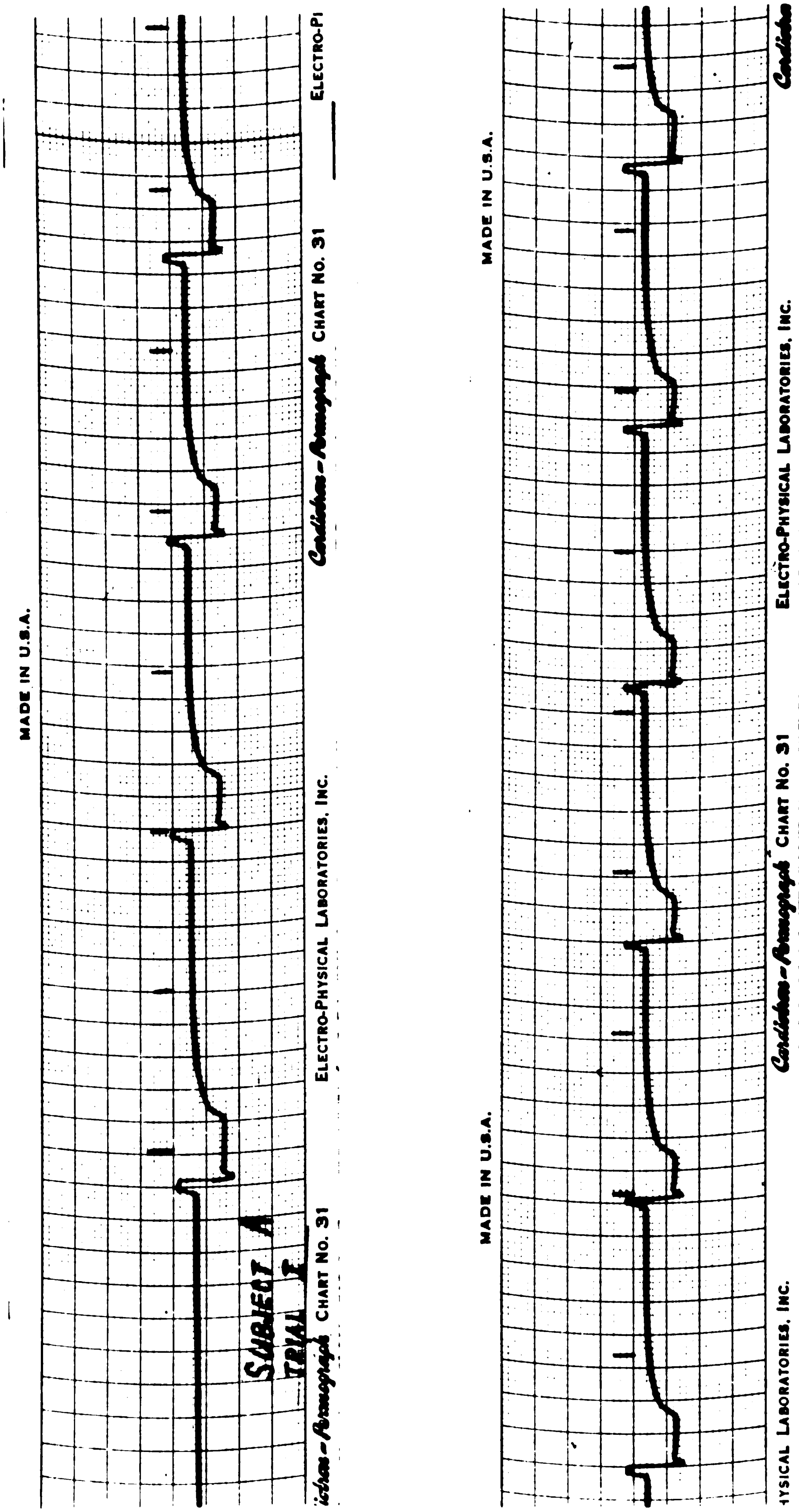
Subject C (unskilled). Due to a malfunction of the recording apparatus only one record was obtained of this subject's performance, Plate VI. It does show, however, a decided inability to discern actual revolutions accurately, and it can not be solely explained on the basis of orienting to the wrong reference point. This was evidenced by comparing these with the intervals of actual revolutions. (See Appendix II.)

Subjective Observations

Upon completion of each trial the subjects were questioned about: how they felt; what sensations they experienced during the rotation, upon being stopped, and after being stopped; and about how they thought they had sensed completion of revolutions.

Subject A reported seeing light changes through his closed eyelids but could not recall using these cues for orientatation. He added that he was surprised at the similarity of sensations derived in the test to those experienced while performing back somersaults. He also reported that he "felt" the moments to react (to indicate a revolution,) but he could not identify the source of these feelings. In regard to being stopped he mentioned feeling a reversed direction of motion, but that the motion did not distinguish itself as rotational.

Subject B also reported a feeling of when a revolution was completed, but like Subject A, he was unable to identify its source. Upon being stopped he reported that there was definitely no sense of reversed direction of motion. Instead he felt a lurch and then "a sort of hypnotic loss of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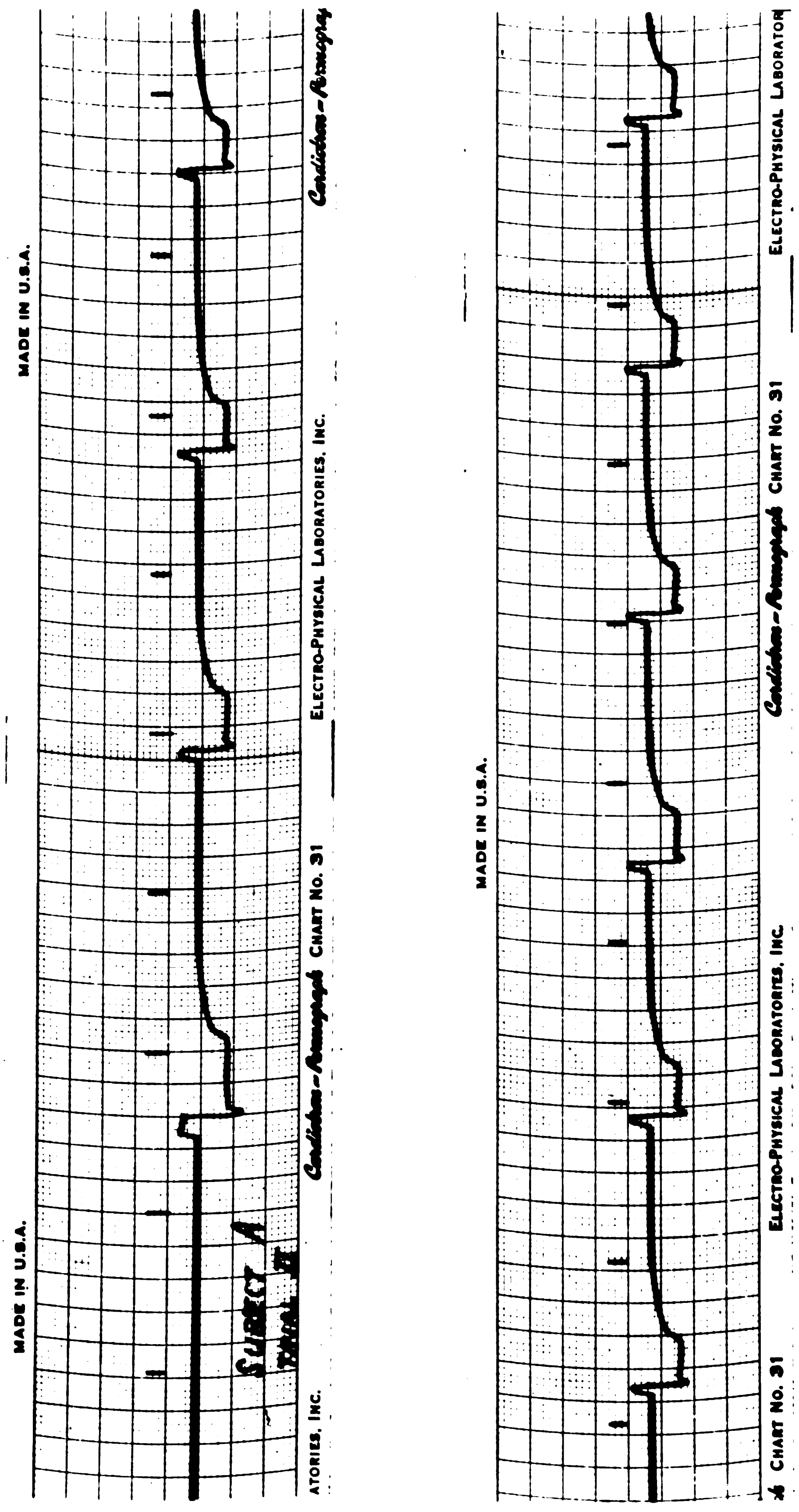
ELECTRO-PHYSICAL LABORATORIES, INC.
CHART No. 31
SUBJECT A

PLATE II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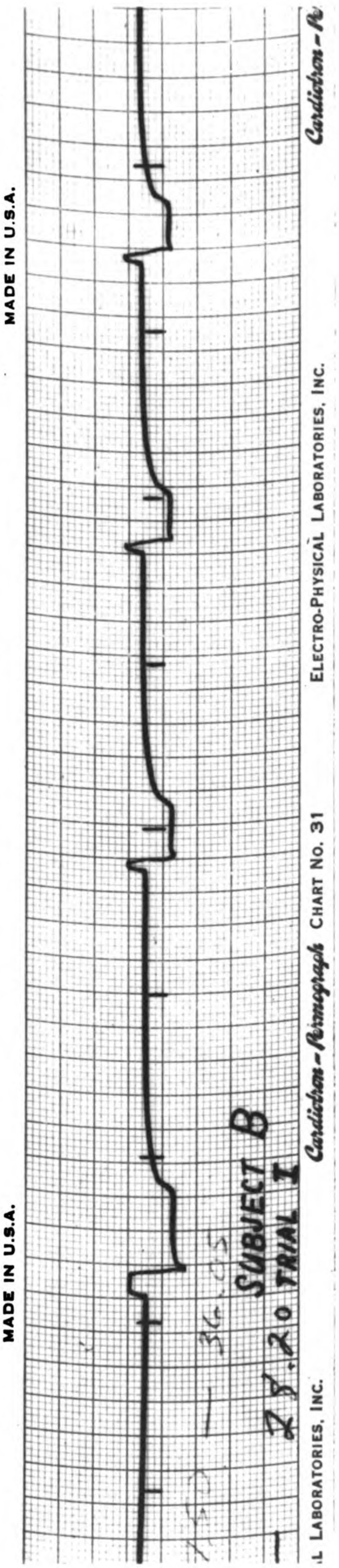
Cardiotron-Pneumograph CHART NO. 31
ELECTRO-PHYSICAL LABORATORIES, INC.
SUBJECT A

PLATE III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Cardiotron-Permograph CHART No. 31
SUBJECT B
TRIAL I
28.20

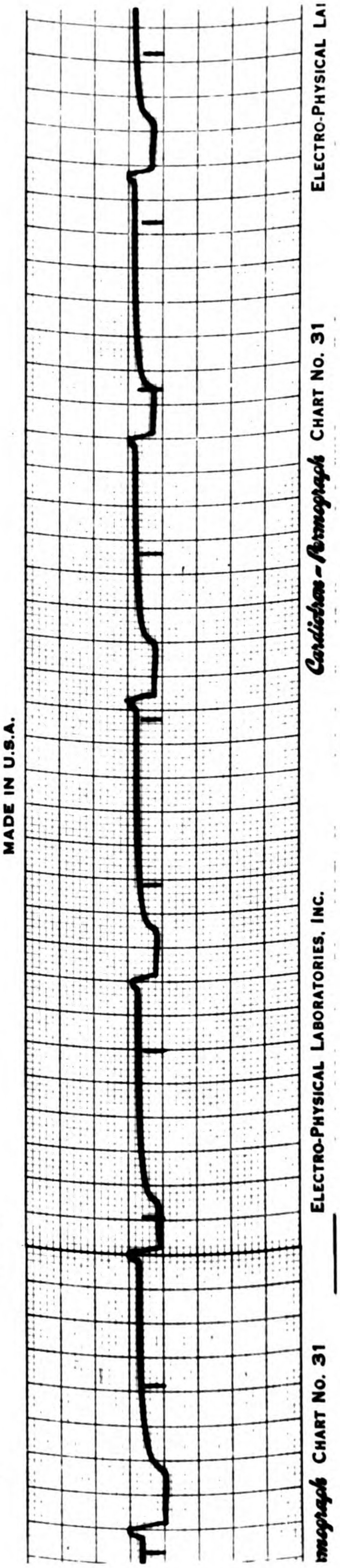
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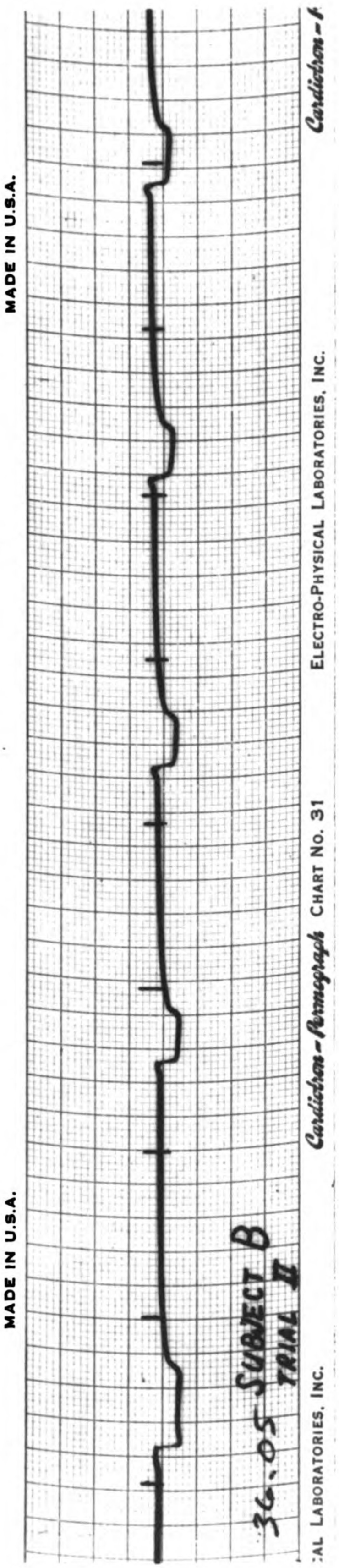
PLATE IV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36.05 SUBJECT B
TRIAL II

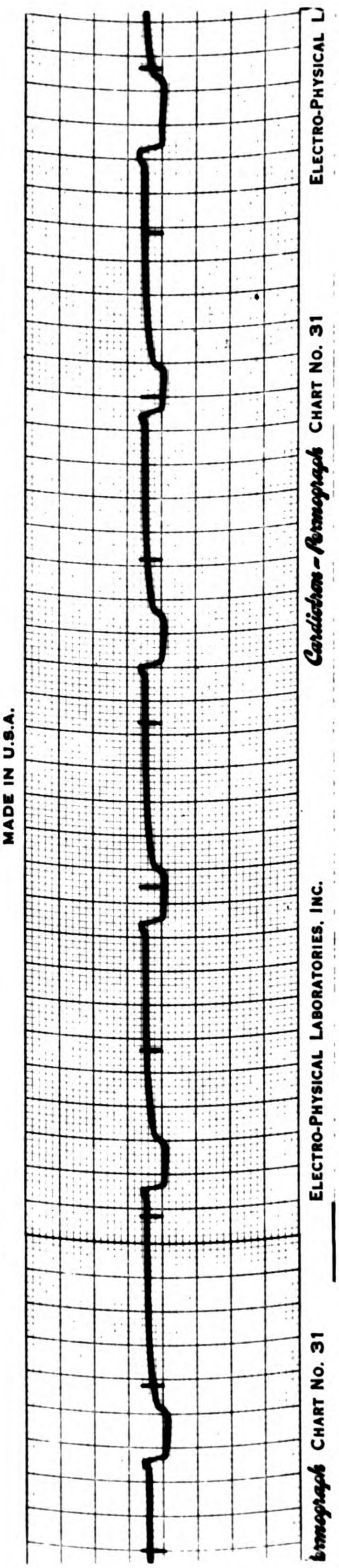
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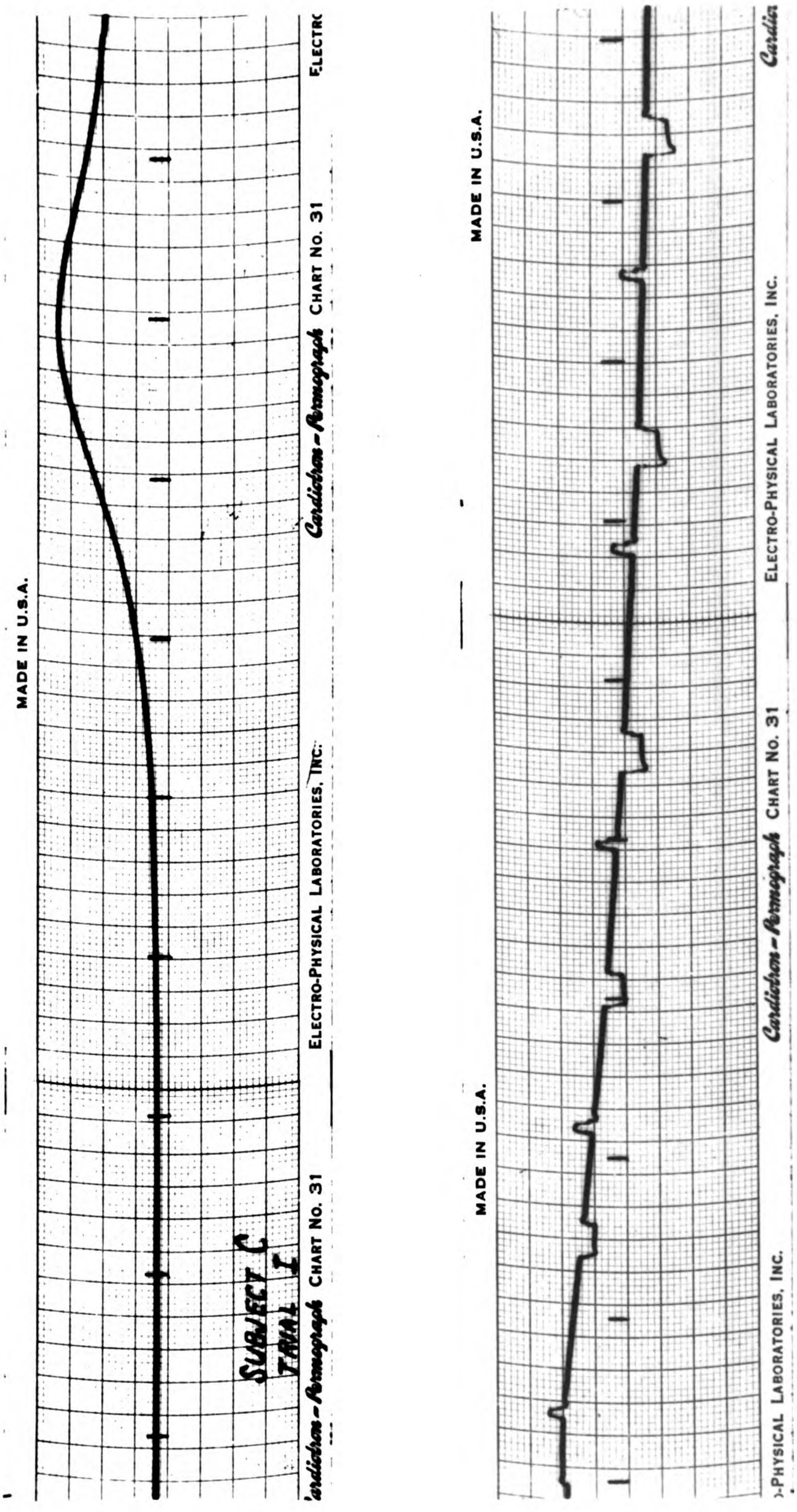
PLATE V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Cardichron-Permograph CHART NO. 31
SUBJECT C
TRIAL I

PLATE VI

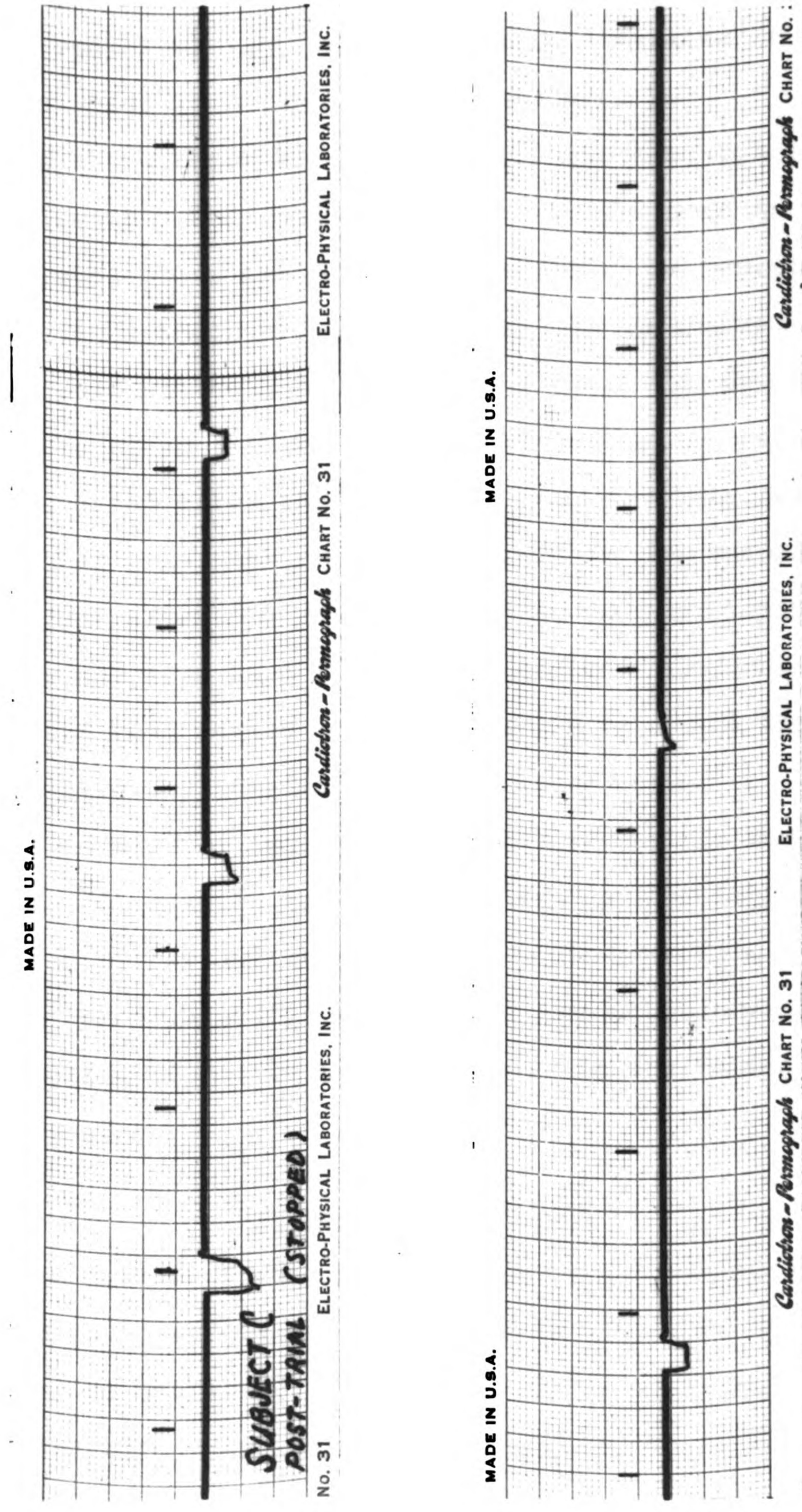

MADE IN U.S.A.
Cardiotron-Permograph CHART No. 31
ELECTRO-PHYSICAL LABORATORIES, INC.
SUBJECT C
POST-TRIAL (STOPPED)

PLATE VII

sense of body position, but rather like a feeling of being adrift in space in unfamiliar surroundings.

Subject C reported a feeling of rotation, but not of specific amounts and that his responses were more in the order of subjective estimates. In addition he reported hearing clicks which had developed in the apparatus, and that he could not help but try to use these for orientation.

It is of some interest that only Subject C reported being nauseated after the trial. It was for this reason that another trial was not run to complete the records on this subject after the recording device malfunctioned. The other subjects were directly questioned concerning nausea, but both denied any such feeling (nor did their behavior give any possible indication of nausea).

It is also of interest to note that of the three subjects, "C" was the only one to continue indicating completion of revolutions after being stopped from rotation (see Plate VII). The other two only sensed a vague feeling of motion and therefore did not indicate revolutions.

Nystagmus Observation

The method of observing and measuring nystagmus appeared to be so obviously inadequate that the results will only be mentioned in general terms. It is believed that these were very inaccurate and therefore of little analytic use (see Table I). The measurements, however, seem to take on some kind of meaning in comparing one with the other. When the eyes were watched for duration of the characteristic movements, the duration for each subject appeared about the same--approximately 11 seconds. However, when the subjects were asked to indicate duration of the sense of motion while keeping their eyes closed, the recorded times were roughly twice as long as the visually observed nystagmus. This would seem to have implications to the thought that both manifestations have their origin in the semicircular canals. It is also interesting to note that according to Gernandt, a cupula (within each canal) deflected by angular acceleration takes about 25 to 30 seconds to recover its position after cessation of rotation. It seems possible that this might indicate a way of matching test subjects on physiological bases or as a means of ascertaining normalcy of subjects on the basis of semicircular canal function.

Discussion

Since it is the method and its capability of measuring orientation ability during rotation with which this study is concerned, the individual trial records of the subjects are of importance more for what they indicate about the method rather than for what they indicate about the individuals. Moreover, due to the highly theoretical bases upon

TABLE I

POST-ROTATORY NYSTAGMUS MEASUREMENTS

	Average Duration of Rotation (10 revs.)	Observed Measure	Sensed Duration
Subject A	18.1 secs.	11.0 secs.	23.4 secs.
Subject B	17.8 secs.	10.2 secs.	18.6 secs.
Subject C	20.0 secs.	13.5 secs.	24.1 secs.

Note:

1. The time given for duration of rotation is the average time of two trials of 10 revolutions which occurred prior to nystagmus observations.

2. The observed measures represent the time interval that nystagmus eye movements were visible to the naked eye (subjectively judged by same observer).

3. The sensed duration represents the interval of time during which the subjects sensed motion after actually being stopped.

4. All measurements were taken by hand operation of a stop watch using visual cues for both starting and stopping.

which components of this study are based, it is necessary to consider all observations, both subjective and objective, each in the light of all the others. At any rate, treatment of results must be restricted to speculation.

In regards to the extreme accuracy demonstrated by the skilled subjects (A and B) as compared to the apparent great inaccuracy of the unskilled subject (C), it would appear that the test is reliable. However, Subject C did report hearing and possibly using the clicks to orient himself. Conceivably this may have caused his inaccuracy and might have caused inaccuracy of the other subjects if they had attended to the auditory clues given by the clicks. This of course would considerably change the reliability picture. It is important to add, however, that subsequent investigation of the clicks showed that they occurred at regular intervals because of defective parts of the apparatus coming together at the precise same point in the rotation cycle on each revolution. Thus the issue is truly questionable.

The fact that the clicks did occur coupled with other factors such as the inability to block auditory reception and Subject A's observance of light changes through closed eyelids is strong evidence of probably invalidity. This does not necessarily indicate inherent invalidity however.

The measurements of nystagmus duration that were taken to ascertain possibilities of habituation, while of doubtful validity, turned out to be extremely interesting. Since all measurements were taken by the same observer the errors of measurement could be constant. Therefore, it could be possible that relationships do exist even though not in an absolute sense. If this is truly the case one might reasonably postulate that Subject B has the shortest nystagmus duration due to innate ability or vice-versa. It might also be postulated that Subject A and Subject B can be considered well matched in regard to physiological function of the semicircular canals. It would then follow that the difference in exhibited orientation ability is truly a matter of training or conditioning. It might even be concluded that since the observed duration of nystagmus in Subject A is somewhat shorter than that of Subject C the conditioning or training is of the semicircular canal function.

Generally speaking, in consideration of all the data and observations, it seems that this test and method may be potentially capable of distinguishing between a trained person and an untrained person pertaining to spatial orientation ability during rotational experiences. It also appears that further testing is indicated using more subjects with more numerous variations in ability pending obviously necessary refinements of both apparatus and method. In regard to the importance of semicircular canal function to this type of orientation, techniques used here for control of sensory stimulation were too highly speculative in nature to draw any conclusions at this time.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The objective of this study was to devise a method for qualitatively evaluating a person's ability to orient himself in reference to a starting position while rotating about a single axis passing through his center of gravity.

To do this it was decided to expose a subject to continuous rotation of ten complete revolutions to see how accurately he could discern completion of each respective revolution. Testing apparatus was devised for rotating the subject using telemetering equipment to record the actual revolutions as they were completed and to record the subject's judgments of when such revolutions were completed.

Because it was foreseen that subjects might become ill from the testing procedure, it was decided to use only three specially selected subjects to try out the apparatus and the test to see if it merited further investigation. In order to emphasize test results these subjects were picked because of certain characteristics particularly suitable for purposes of evaluation. Two subjects (A and B) were selected because of relatively high degrees of skill in aerial somersaulting. The third subject (C) was selected for evident lack of skill plus a highly informed understanding of the study problem.

Each of these subjects were installed in the test apparatus in a position roughly comparable to that assumed in tucked aerial somersaulting. Efforts were made to limit orientation cues to those derived in the semicircular canals

Each subject was then given two trials of ten continuous revolutions at speeds of approximately 180 degrees per second. The data were noted, recorded, and analyzed in the light of pertinent subjective observation.

Conclusions

Use of so few subjects was restrictive of anything but speculative analysis. Nevertheless, a few tentative conclusions were reached through careful data comparisons between subjects. These conclusions obviously must be interpreted in light of the small amount of data.

1. The basic design of the test seems to be good but refinements in apparatus and procedure are necessary if validity is to be realized.
2. The test and method appears as if it might be capable of separating skilled persons from unskilled persons.

3. The test appears as if it might be reliable; however, testing of a great many more subjects is needed to ascertain this.
4. The test appears to indicate that semicircular canal stimulation is not a major disorienting influence during simple rotation of persons skilled or trained in rotational performances.
5. The testing method appears to have possibilities for more intensive study of the phenomena associated with spatial orientation ability in humans.

Recommendations

After comparing the results of this study with the results of related studies and with established facts the following recommendations are made:

1. This study should be repeated using refined apparatus and a greater number of subjects with less obvious differences in their abilities.
2. To control auditory sensations more efficiently, it became evident that masking noise applied via earphones would be more successful than blocking attempts.
3. A two channel recorder would have been more efficient and enabled better analyses of results.

4. The experiment should be repeated but should include changes in sensory controls and recording of the effects to gain more complete information concerning relative importance of the different senses to orientation.
5. Trials of each subject should include rotation in both directions.
6. If possible, the results recorded using a bent neck and vertical rotation of the body should be compared with results of actually rotating body about a horizontal axis with the neck straight.
7. Different orientation tasks should be tried with each subject such as indication of every one-half revolution and every two revolutions.
8. An efficient mechanical brake should be used to control the abruptness of stopping more efficiently.
9. Mechanical control of rotation accelerations and velocities should be employed.
10. A study similar to this of skilled subjects using neck down anaesthesia would more clearly indicate the role played by the semicircular canals of skilled persons in rotational orientation tasks.

APPENDICES

APPENDIX I

CONTROL OF SENSORY STIMULATION

For reasons that should be obvious it was impossible to duplicate exactly the sensory conditions experienced in performance of aerial somersaulting tricks. Consequently, it was necessary to attempt to control any sensory cues that might be produced peculiar to the testing apparatus, procedures, and environment which, although extraneous, could nevertheless, conceivably be used for orientation purposes and thus invalidate the test. The respective measures taken were as follows:

1. Visual--Voluntary closure of the eyes. Other precautions would have been preferable, but none was found that would not interfere with desired observance of post-rotatory nystagmus.
2. Auditory--Mouth closed voluntarily. Nose was clamped shut. Ears were plugged with commerically prepared plugs made from beeswax and foam rubber. In addition a particularly noisy electric blower was placed below the subject directly in the line with the rotational axis in an attempt to mask any sound cues not blocked out by the other precautions.

It is important to note that even the simultaneous employment of all these measures proved to be less effective than desired.

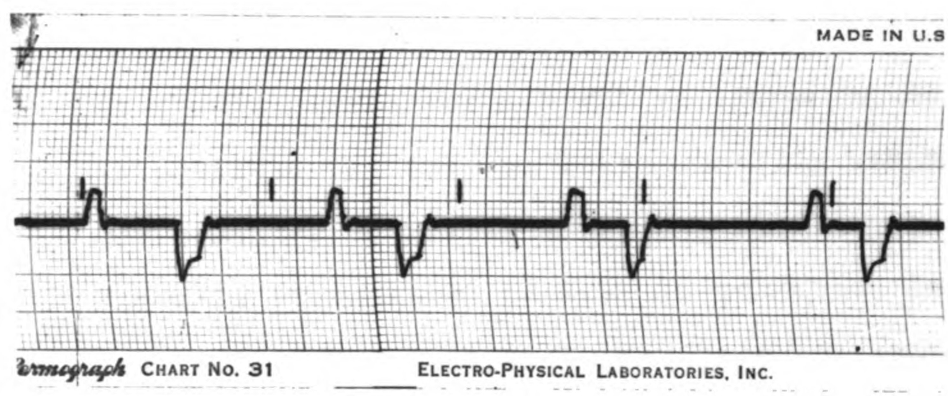
3. Tactile--To block transmission of motion produced vibrations through the apparatus, foam rubber padding was placed between subject and chair at all points of contact. In addition, subjects were strapped tightly in place to prevent any movements of the subjects that might stimulate tactile senses.
4. Kinesthetic--It was hoped to tighten the straps to such a degree that both visceral and bodily movements would be very limited if not stopped completely. It was also reasoned that by tightening the straps maximally, any kinesthetic sensations arising from contact with the straps would be so intense that minor changes of stimulus intensity such as might be wrought by centrifugal force would be imperceptible. Finally, it was hoped that the combined effects of rotating a subject in an erect, sitting, tucked up position with the neck bent sideways so that the head was positioned for stimulation of the proper semicircular canals would constitute such a totally strange experience that cerebral integration of any uncontrolled sensations for purposes of orientation would be inhibited for at least the duration of the test.

5. Mental sense of elapsed time or of rhythm--It was presumed that since this represents a cerebral function based on past experience, sufficient variations of accelerations and velocities would probably render this "sense" ineffectual.

APPENDIX II

READING THE GRAPHICAL RECORDS

1. One second intervals are indicated by the short vertical dashes appearing just above the center line of the graph paper.
2. Upswings from the base line indicate points at which actual revolutions were completed.
3. Downswings from the base line indicate points where subject judged completion of a revolution.



Sample Recording

4. An upswing should always appear just before a downswing if subject oriented to starting reference point correctly.
5. If no base line occurs between an upswing return and a downswing, subject is orienting as accurately as the device will indicate.
6. Neither the amplitude of swing nor the delay of return to base line is significant to the test.
7. Actual swings from the base line can be discerned from base line aberrations by noting abruptness of change and by comparing the length of the intervals between obvious swings.

APPENDIX III

ORIGINAL CRITERIA FOR DESIGN OF THE TESTING APPARATUS

1. It should permit simulating as nearly as possible the kinds of rotation experience encountered in aerial somersaulting tricks with respect to different combinations of angylar accelerations, decelerations, and velocities.
2. It should permit the subject to assume as nearly as possible the body position normally assumed in performances of aerial somersaulting tricks.
3. The axis of rotation should, if possible, be in the same position relative to the subject's center of gravity as it is during aerial somersaulting performances.
4. It should provide the subject with a means of making responses that will not interrupt the rotational motion or alter the subject's basic body position.
5. It should as nearly as possible allow for unitary isolation of sensory usage to determine the major contributors to spatial orientation during rotation.

6. It should include, if possible, a sufficiently accurate mechanical recording system devised to permit instant checking of the accuracy of a subject's response at any given moment while the test is being administered.
7. It should not endanger the subjects in any way.
8. It should help make the subject feel secure enough so that real or imagined fears should not interfere with ability to make responses.
9. It should, if possible, provide data records suitable for easy comparison of subjects' responses between trials and between subjects.
10. It should be fairly simple to operate.

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