Hand-Eye Coordination in Weightlessness

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Hand-eye coordination is a skill which is learned from infancy and in which one is dependent on intact pathways of vision, kinaesthetic sense from the limb, and muscle control. If the aiming point is observed and the eyes are then closed, a normal individual can still touch the target accurately. This is still hand-eye coordination but the hand movement is now coordinated with the memory of the target—a visual memory which is stabilized by labyrinthine reflexes so that, although the head may be moved after the eyes have closed, it is still possible to locate the target.

Where this task does differ from that performed with the eyes open, is in the visual information on performance. Since this is absent when the eyes are closed, monitoring of performance has to be carried out by kinaesthetic information alone. The technique of performing hand-eye coordination tests with eyes open and eyes closed is therefore employed by the clinician as one method of differentiating between ataxias of sensory and of cerebellar origin. In an ataxia associated with sensory loss, inaccuracies in pointing may be manifest when the eyes are closed. With adequate visual information, however, the patient may correct his performance so well that no abnormality may be evident. On the other hand in cerebellar ataxia, the performance of a test of hand-eye coordination is little better with eyes open than it is with eyes closed because it is the coordination of muscle activity which is affected. Typical tests employed clinically are the heel to knee and the finger-nose tests.

An aiming test such as that employed by von Beckh[6] falls into the same category as those clinical tests. He employed his test to determine the ability of subjects to point at a target under zero g in flight, both with eyes open and with eyes closed.

In 1957, Gerathewohl, Strughold and Stallings[2] reported on a similar task carried out under zero g, 1 g, and 3 g but only with the eyes open and observing performance. It is evident that even though the speed of pointing in their experiment may have been fast, one can still not eliminate the variable of visual monitoring of performance.

It was therefore decided to repeat some of these experiments but without visual information on performance yet with a visual fixation point so that eye movement might be controlled. The intention was to plot results on a time scale by taking the Cartesian coordinates of each point made by the subject and plotting "X" against time and "Y" against time. In this way it was thought to demonstrate the presence of any adaptation times or recovery trends. None were shown in this investigation but other interesting observations were made.

MATERIALS AND METHODS

The subject was given the task of pointing at graph paper which was situated some 20 to 25 inches from the chest and at chest level. He pointed at this with the index finger, usually of the right hand, and wearing a thimble with a point so that accurate measurement of the coordinates could be made. After pointing, the arm was returned to the lap and the next point was usually made 2 to 5 seconds later.

The recording of results was effected either by a camera which photographed the finger on the graph paper, or by the experimenter reading the coordinates directly from the target. The "X values" seen on the ordinate of the graphs in this paper, refer to positions in the horizontal axis and the convention adopted is that X increases from left to right of the target. "Y val-

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ues" also shown on the ordinate of the graphs, refer to positions in the vertical axis, the convention being that Y increases from the lower edge of the target to the top.

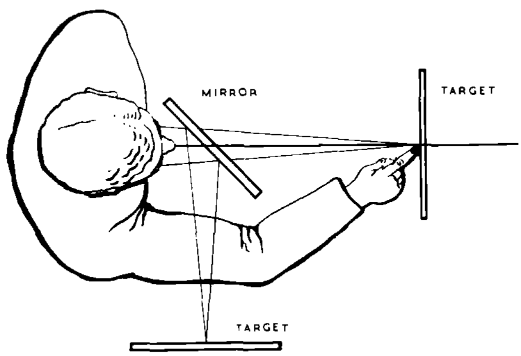

Fig. 1. Apparatus which prevented subject from seeing the target at which he was pointing.

With direct vision of the target it would be possible by sufficiently slow pointing to correct small errors which might be reduced as the time for the corrective movement became too short. To control this variable, therefore, and also to control eye movement, the subject was prevented from seeing the target at which he was pointing by means of the apparatus shown in Figure 1. This quite simply consisted of a mirror into which the subject looked and in which he saw the virtual image of a target situated to one side. He could thus look and point to the target, although he could not see his arm or hand touching it.

In addition to the performance of the task in the laboratory under stable conditions, sitting upright and without any unusual forces acting on him, the subject also carried out the task in three other situations.

Simulation of subgravity was effected by immersing the subject in water up to the neck so that he carried out his pointing task onto a target which was below the surface of the water. This had the virtue of subjecting the trunk and limbs to near zero gravity while the head and of course the labyrinth was still subject to 1 g.

In a Meteor Mk 7 aircraft by flying the now well known parabola, ten to twenty seconds of zero g were obtained during which time of course the entire subject was weightless. A steel nut suspended on a piece of string served admirably as the instrument for the measurement of zero g, since even small departures from zero would cause the nut to fly in one direction or another. Thus, for example, even 0.1 g would cause the nut to move with an acceleration of 3 ft./sec./sec. The period of zero g was usually preceded by a pullout of 1.5 g to 2.5 g. The third environment to which the subject was exposed was produced by the human centrifuge at Farnborough whose radius is 30 feet. In this, the subject experienced 2 g for two or three minutes, this period being chosen so that when the head was kept still, effects due to angular acceleration were minimized.

In a previous series of experiments on the effects of weightlessness on tendon jerks, the weightless state was obtained by dropping the subject in a chair a distance of three or four feet, decelerating the chair on a hydraulic ramp. This gave a period of about 300 milliseconds during which experiments were carried out on tapping the tendon and recording the electromyographic activity in the calf muscle.

RESULTS

In all these experiments the subject was tightly strapped into the seat by a seat harness such as that used in aircraft. Having determined that reasonably consistent results could be obtained over a period of several minutes, the experiment was then transferred to the water tank and repeated. The results shown in Figure 2 are the mean of three experiments. It will be seen that there was a small though significant change in the X values, that is, in the deviation from side to side, but that there was a more marked change in the height of pointing as shown in the Y axis. These data and those obtained in the other experiment were subjected to an analysis of variance of the X and Y coordinates separately. It was found in this particular experiment which comprised three trials, that both X and Y values differed significantly from the controls ($P = .001$). The results of this analysis are summarized in Table I. This means that the subject when immersed in water pointed too high by some 3 inches (equivalent to an error of about 6 degrees). He was not aware of his error and, in fact, the impression was very strong that he was pointing very much lower—actually, at the datum line. It was therefore a great surprise when on one occasion the hand actually broke through the surface, thereby informing the subject that he was pointing much higher than he thought.

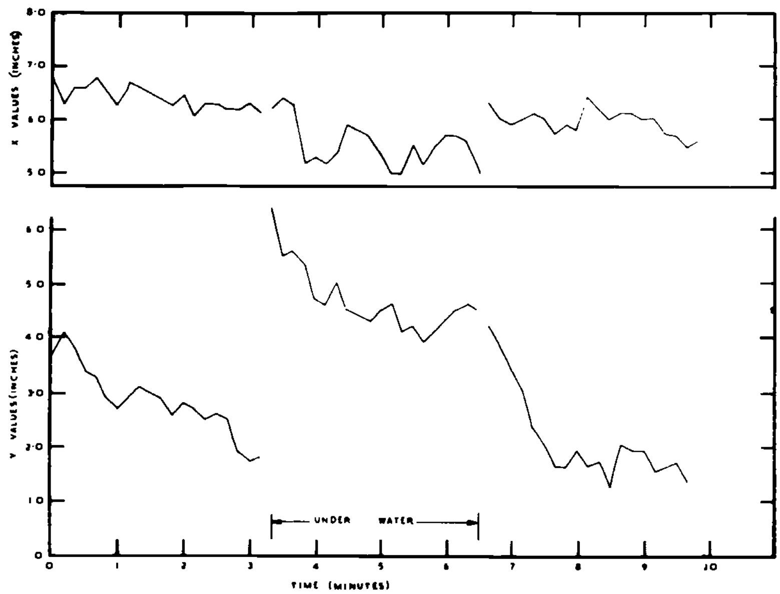

Fig. 2. Pointing under water—indirect vision. (Each point represents the mean of three trials).

TABLE I. SUMMARY OF RESULTS UNDER WATER

Coordinate	Control	Under Water	Control	Significance	P
X	6.43	5.58	6.01	Under Water<Control	0.001
Y	2.99	4.69	2.14	Under Water>Control	0.001

Since all that had happened in this experiment was that the subject was immersed in water to the neck, the changes which had taken place in the direction of pointing could be attributed only to changes in the periphery, such as a change in the information from the kinaesthetic sense of the arm.

The experiment was repeated in flight where the subject was weightless for periods up to twenty seconds—a condition which differed from the underwater experiment only in that the head was now also weightless. Surprisingly, it was now found that the subject, during the zero g phase, pointed consistently low. It is improbable that these findings could be associated with the previous period of angular acceleration associated with the 2 g pull-out, because this would have caused a past pointing error upwards and not down as was found experimentally. The results of this experiment are seen in Figure 3. The zero g period being preceded and followed by a control test carried out in level flight. In this experiment, X differed from control ($P = .01$) whereas Y differed from control at a higher level ($P = .001$) as shown in Table II.

In the human centrifuge, results were obtained from this same test when carried out under 2 g for a period of two minutes. This was preceded by a control period with the centrifuge at rest. Under 2 g it was found (Fig. 4) that the subject tended to point high; and, in this case, the level of high pointing differed significantly from the controls, as shown in Table III. The increased value of X showed a tendency to point too far to the right under 2 g. (The right hand was used in all these experiments.)

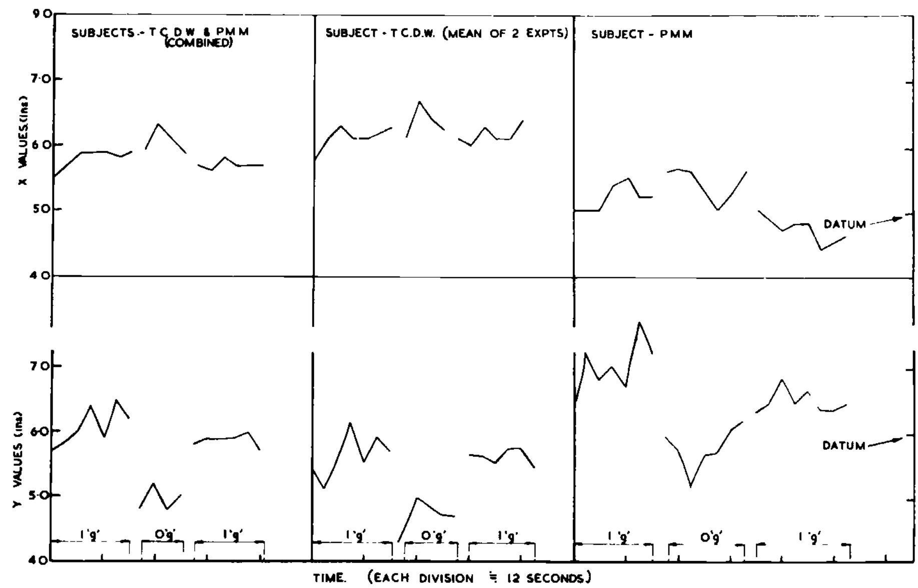

Fig. 3. Pointing under zero g (no direct vision).

TABLE II. SUMMARY OF RESULTS ZERO g

Coordinate	Control	Zero g	Control	Significance	P
X	5.80	6.06	5.70	0 g>control	0.01
Y	6.07	4.95	5.87	0 g<control	0.001

DISCUSSION

The change in information from the kinaesthetic sense which resulted in the subject pointing high when he was immersed in water was accompanied subjectively by a sensation that the arm was orientated in the correct direction. One must therefore conclude that the position sense, under the conditions of this experiment, was grossly misleading. Under normal conditions, there is no doubt that position sense is much more accurate as evidenced by the "static runs" carried out over several minutes and of which Figure 5 is an example. In these, 1 inch corresponds to about 2 degrees so that the error of static runs is about $\pm$ 1 degree. This has also been confirmed by experiments of a similar nature by Cohen.[1]

It is not necessary for the present experiment to embark upon speculation and experiment as to the neural mechanisms involved in this disorientation under water. It merely suffices to conclude that when the arm alone is subjected to weightlessness there is a consistent tendency to point upwards if there is no visual monitoring of performance.

When, in addition, the head is weightless as in the flight experiments, the fact that the subject now pointed downwards must find its origin in the only changed factor, namely, weightlessness of the head and of the labyrinth.

From an investigation of the effects of free found, leads one to suspect that there are no purely reflex changes occurring independently of the changes at the periphery. One must therefore look for secondary effects for the ex-

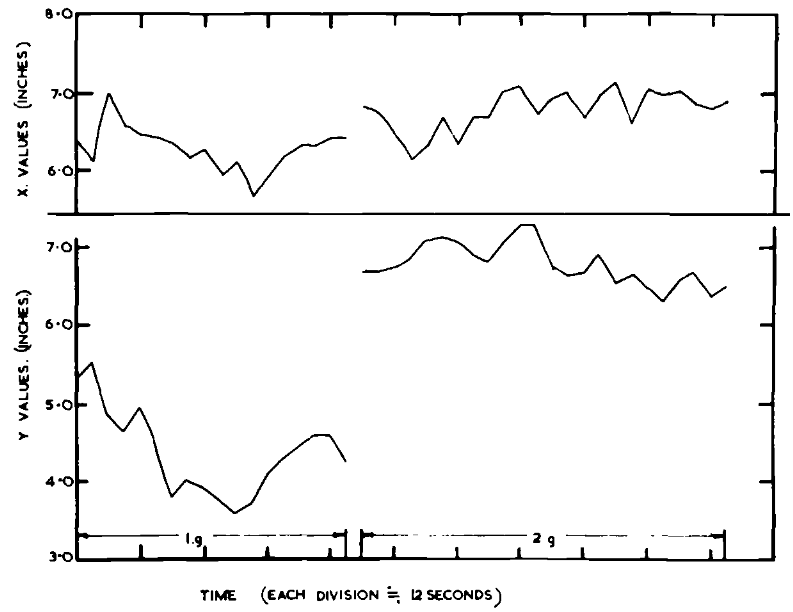

Fig. 4. Pointing under 2 g (no direct vision).

fall on tendon reflexes, in particular the ankle jerk, it was found that the myotatic reflex elicited by tapping the Achilles tendon disappeared shortly after the onset of zero g, reappearing about 100 msec. later.[4] This was probably associated with the steplike change from 1 to zero g, and it seems that the responsible factor was the resultant passive movement of the calf muscle with consequent shortening of some of the muscle spindles. There was no evidence of any change in reflex activity in the lower limb which could be associated temporally with weightlessness affecting the head. Furthermore, knee and tendon jerks elicited during the zero g parabola revealed no abnormality.[5]

It is to be expected that if there were reflex effects in muscle activity occurring directly as a result of zero g affecting either the utricular otoliths or affecting the tonic neck reflexes, these effects would have appeared within the first 300 msecs. of weightlessness. That nothing was

TABLE III. SUMMARY OF RESULTS 2 g

Coordinate	Control	2 g	Significance	P
X	6.23	6.75	2 g>control	0.001
Y	4.38	6.80	2 g>control	0.001

planation of low pointing in zero g and of the high pointing under water.

As one begins an ascent in an elevator, the surrounding walls, floor and ceiling appear to rise about one and, conversely, on beginning a descent there is an impression that the walls are descending more rapidly. This is an illusion, as can easily be demonstrated—even if the head is fixed. It is not associated with a change in the direction of the resultant acceleration but with a change in the amount of the accelerative force. This illusion is therefore not quite the same as the oculogravic illusion described by Graybiel since that is usually referred to in connection with a changing direction of resultant acceleration This "elevator illusion" however goes in the same sense as the effect described by Graybiel with regard to the apparent rise and fall of a real target observed during flight maneuvers which resulted in increases and in decreases in g forces, and is undoubtedly the same phenomenon. An after-image, however, which is placed on the retina immediately before these changes in force of acceleration, will be seen to go up as the g diminishes and to go down as the g increases. Similar changes in position of after-images have been observed in flight by Gerathewohl and Stallings.[3]

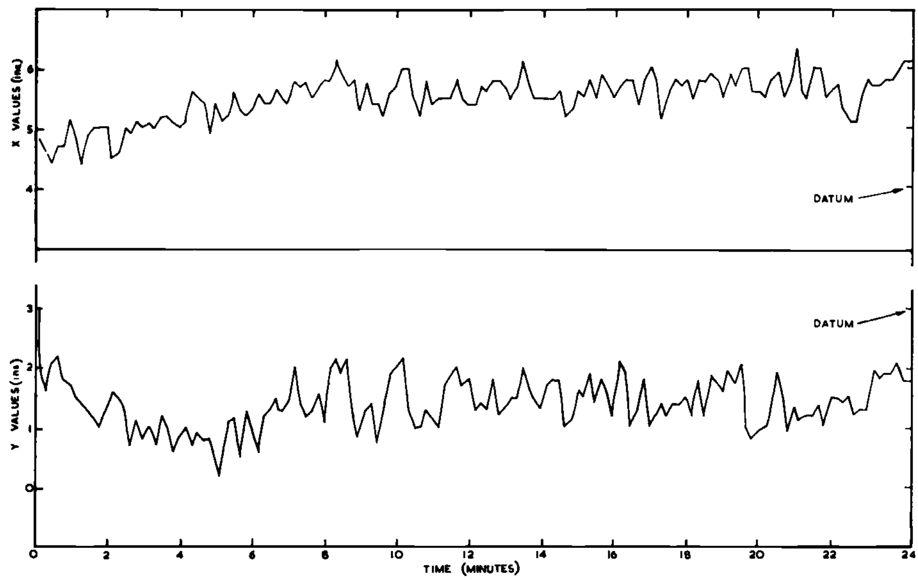

Fig. 5. Point—static test (no direct vision).

In experiments carried out on the human centrifuge at Farnborough it was found that this downward movement of the after-image under increasing g can be controlled voluntarily and is therefore apparently caused by eye movements. Certainly, with eyes open, it is possible to keep the after-image superimposed upon a real target; in which case, as g increases, there is no downward movement of the after-image. On the contrary, it remains superimposed on the real target and, like it, appears to move upwards during the onset of increasing g remaining fixed for the duration of the g run (up to two minutes). At the end of the g run it appears to go down very far since there is angular acceleration producing tumbling sensations. After some ten to fifteen seconds, when these sensations have passed off, the real target and its after-image assume a position which once again coincides with their real position relative to the observer.

For want of a better word, and to differentiate this illusion from the oculogravic, with its usual connotation of change in direction of resultant force, one might here refer to this as the "elevator" illusion.

In the zero g flights, as the g was reduced from 1 to zero, there was the illusion of the target moving downwards. The subject pointed to the apparent position of the target and, since there was no visual information on performance, the error in pointing remained uncorrected and the subject did in fact point too low.

Conversely, in the course of the 2-g runs in the centrifuge, the illusion was that the environment and of course the target, moved upwards with respect to the subject, so that he pointed deliberately to their apparently higher position and again, since there was no information on performance, the subject was not aware of the error and no correction was made.

CONCLUSIONS

There are indications that the opposite results observed by Gerathewohl and Stallings[2] and confirmed by this author, may be due to overcorrection when the eyes can see the hand moving towards the target.

The most immediate practical conclusion to be drawn from this small investigation is that if a pilot is in the cabin of an aircraft which has "ditched" and filled with water, he will be unable to locate without difficulty such a familiar emergency control as a hood jettison handle if he cannot see it.

That observation is not new, and this investigation merely explains the causal psychophysiologic mechanism.

ACKNOWLEDGMENT

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Early Fruits

Nigeria achieved its long awaited independence on October 1, 1960, and scarcely three months later the Pharmaceutical Society of the new nation issued the first number of Volume 1 of its official publication. Produced in Lagos under the direction of a publication committee of the organization and the editorship of its secretary, A. A. Egboh, the *Journal of the Pharmaceutical Society of Nigeria* has also a London office in Stafford House, Norfolk Street, and is printed in England. It is to be published quarterly.

The contents of the first issue—in addition to a welcoming editorial, an introduction as first patron of the Society of Dr. Nnamdi Azikiwe, first African governor-general and commander-in-chief of the Federation of Nigeria, and amiable greetings from persons of importance—include several practical and scientific articles. Among them appear such titles as "Recent Researches on Pyrogens and Fever" and "Pharmacy in a New Nigeria."

Such a sign of orderly and intelligent initiative coming from a leading nation of the world's second largest continent, wakening to a consciousness of its own destiny, is doubly welcome.—*The New England Journal of Medicine.*