Effects of Weightlessness as Simulated by Total Body Immersion Upon Human Response To Positive Acceleration

CAPTAIN VICTOR G. BENSON, MC, USN, CAPTAIN EDW. L. BECKMAN, MC, USN, LCDR KENNETH R. COBURN, MSC, USN and RANDALL M. CHAMBERS, PH.D.

IT IS now well known that human beings can withstand the launch and reentry accelerations which will be experienced in either orbital or space flights, however, weightlessness and its possible effect upon reentry acceleration tolerance remains the enigma of space flight.

Previous studies into the effects of simulated weightlessness by means of total or partial immersion of subjects in water have yielded inconclusive results.[1,2,4] Results of studies in which the subjects were immersed in water to neck level were obscured because of an accompanying water diuresis.[1,4] One previous study utilized total immersion[2] and was equivocal because most of the subjects terminated the period of water immersion within such a short period of time that no comparison of pre-immersion and post-immersion blackout levels was possible. It was felt by the investigators that the premature terminations were largely due to the unfamiliar stress of the underwater environment. For this reason in this series of experiments, arrangements were made for professional divers from U. S. Navy Underwater Demolition Team 21 to act as subjects.

METHOD

Following a complete physical examination, each of the twelve subjects was repeatedly exposed to various levels of positive acceleration in order to familiarize them with the human centrifuge and to allay any fears or anxieties which might have been present. The subjects were positioned in a swinging carriage at the 37-foot radius of the centrifuge (Fig. 1). During this familiarization, the subjects' responses to positive G were determined by utilizing the limitation of ocular motility under acceleration (LOMA) as an objective end point.[3] The LOMA end point occurs at approximately the same G level as when loss of peripheral vision or greyout occurs in subjects exposed to positive acceleration. The subjects were instructed to fix alternately their gaze upon one of two lights, each of which was located on the horizontal plane 23 degrees on either side of the central visual axis. As the subjects fixed their gaze upon one of the lights they activated a microswitch to indicate that the light was visible.

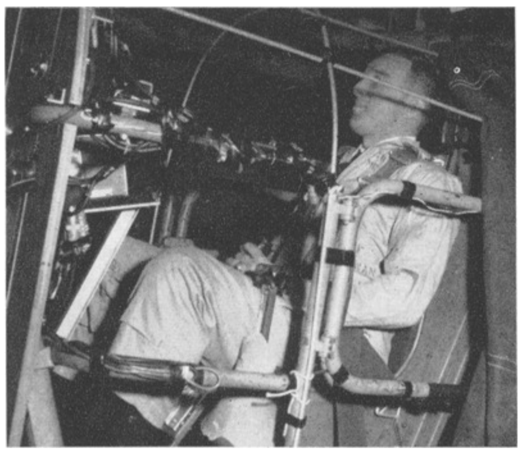

Fig. 1. Subject seated in swinging carriage during pre-immersion G-tolerance determinations.

From the Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

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The light on that side was then extinguished and the contra-lateral light turned on. The magnitude of positive acceleration was increased in 0.25 G increments on successive runs until the subject was no longer capable of alternating his gaze, and his eyes involuntarily came to rest on the central visual axis. This condition is termed LOMA. This objective physiological end point is easily discernible by monitoring the subject on the closed circuit television screen.

A circular plastic swimming pool, 28 feet in diameter, was filled with water to a depth of 4 feet (Fig. 2). Four subjects entered the pool at hourly intervals to make a group of four. They remained totally immersed in water for a period of approximately 18 hours. This procedure was repeated daily until all 12 subjects were tested. Circulating pumps and immersion heaters maintained adequate circulation of water and comfortable water temperatures (94.0-95.0° F). The subjects were equipped with diving face-masks and underwater breathing regulators. The regulators were supplied with compressed breathing air either from a deep-sea diving compressor or from 200-cubic-inch compressed air tanks. The subjects passed their time while immersed watching television, reading or playing checkers. Communication between the subjects and the observers was satisfactorily maintained by writing messages on metal plates and passing them in and out of the tank.

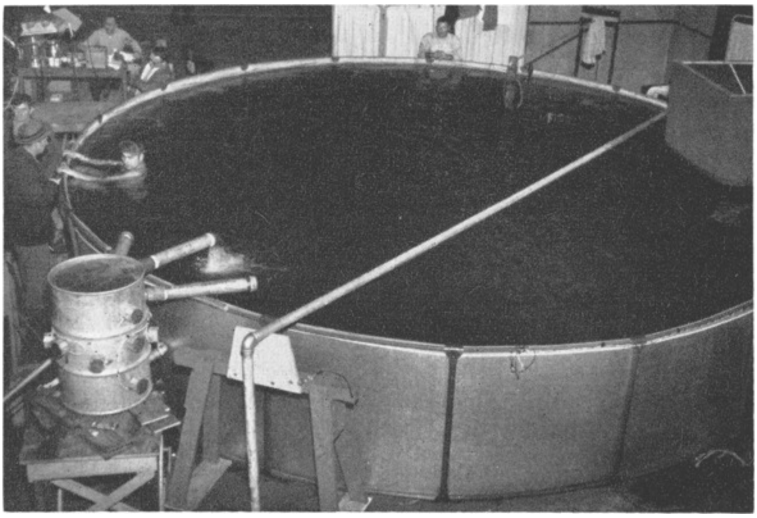

Fig. 2. View of swimming pool and heating unit.

At the completion of the 18-hour immersion a small tank was lowered by crane into the swimming pool (Fig. 3), and the subject swam under water into the tank. The air supply was switched to a portable bottle and the subject was transported, still immersed in water, to the centrifuge. The subject then came to the surface and climbed out of the tank onto a stand located at the side of the swinging carriage attached at the 37-foot position of the centrifuge arm. The subject donned a bathrobe, seated himself in the carriage, was strapped in, and the carriage cover was tied in place. A small electric heater was placed in the carriage to prevent excessive evaporative cooling of the wet subject. Within three minutes after emerging from the water, the subjects were exposed to positive acceleration and the LOMA endpoint determined. Twenty-four hours following the period of immersion, they were retested on the centrifuge. In all centrifuge tests, LOMA was used as an objective endpoint. Motion pictures were also taken for documentation and confirmation of LOMA.

Two psychomotor tests were administered to the subjects prior to, during, and following their period of water immersion. The first test, a target aiming task, required the blindfolded subject to place small magnets on a target located in front of him. Vertical deviations in the placement of the magnets above or below the center of the target were considered to be errors in the Y axis. Deviations to the right or left of the center of the target were considered to be errors in the X axis. The second test, a subjective estimation of downward force, consisted of training the subjects to pull downward on a lever with an estimated force of 15 pounds. This was compared with their ability to estimate the same force when completely immersed in water.

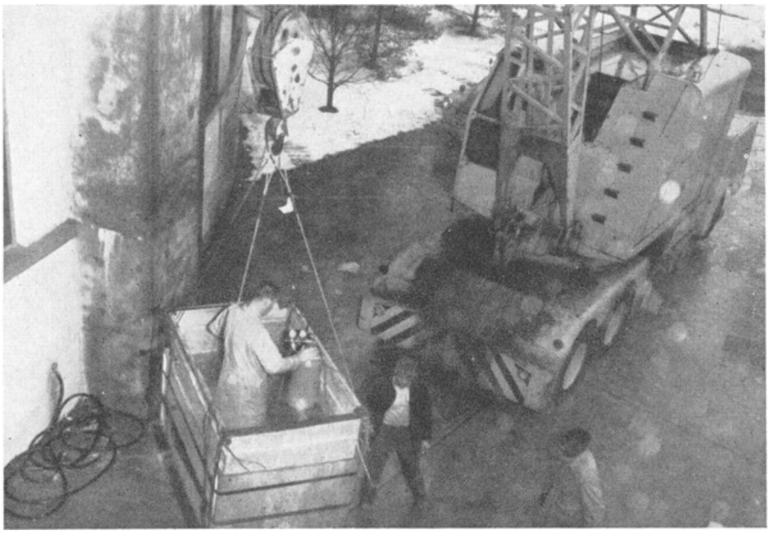

Fig. 3. *(below)* Transfer tank being lifted to centrifuge platform level. Diver is immersed. Safety man is shown standing beside air cylinder.

RESULTS

All of the subjects tolerated approximately 18 hours of water immersion very well, with the exception of one subject who requested to be removed about one hour ahead of schedule because of a painful external otitis. Some of the subjects were able to sleep for short intervals of time. A marked maceration of the hands, fingers, and feet occurred in all of the subjects as a result of the water immersion. This condition caused rather severe pain in some subjects.

In previous studies of subjects immersed in water to the neck level and in total body water immersion, where negative pressure breathing was a factor, a profuse water diuresis and a marked lowering of the specific gravity of the urine was noted.[1,4] In general, the data from this experiment indicate the following: (1) a profuse water diuresis did not occur in any of the subjects in spite of the prolonged period of water immersion and (2) the specific gravity of the urine did not drop to the low levels reported in the previous experiments (Table I).

In the target aiming task (Table II), the subjects placed the magnets below the zero reference point of the target in both the pre-immersion and post-immersion trials, with a greater deviation in the post-immersion trial. While the subjects were completely immersed in water, they placed the magnets above the zero reference point. In the subjective estimation of downward force (Table III), the subjects exerted a significantly greater force in estimating 15 pounds pull while submerged in water than in either the pre-immersion or post-immersion trials. The results of the psychomotor tests have been treated in more detail in a separate report.[5]

The results of the various centrifuge exposures are shown in Table IV. The means of the pre-run control series show a decreasing LOMA end point. Between Control Run II and the Post-Immersion Run, there is a decrease in the level as determined by LOMA of 0.62 G. The post 24 hour run shows an increase of 0.38 G. Inspection of the LOMA data suggested that only very small changes occurred following the water immersion exposure. However, these changes, though small, did appear to suggest a consistent reduction. Consequently, several statistical analyses were conducted to determine the extent to which these small deviations may have been due to chance, and the extent to which the differences among the means may be significant. The statistical procedures used were the t test, the $\mathcal{F}$ test, and chi square.

Since an expected change in the G level at which LOMA was observed might be expected to occur during the first post-immersion run, the matched t test was used to compare the mean G level for the first post-immersion run with the mean base line for control runs 1 and 2. The results of this analysis indicated a significant change in G level between the pre-immersion base line and the first post-immersion run ($t=4.881$; $p<.01$). A chi square analysis conducted on these data showed similar results ($\chi^2=8.167$; $p<.01$). A more detailed analysis of variance of these data was then conducted in order to

TABLE I. PHYSIOLOGICAL CHANGES OBSERVED IN SUBJECTS DURING PERIODS OF TOTAL BODY WATER IMMERSION

Subject	Time in Pool (hours)	Urinary Output	Fluid Intake	Maximum and Minimum Urinary Specific Gravity
H.W.H.	18:50	1115	400	1.026 1.010
L.T.D.	16:55	130	100	1.022 1.022
H.B.C.	18:02	960	100	1.030 1.014
G.E.B.	18:01	600	100	1.020 1.016
F.B.B.	18:50	690	0	1.020 1.010
C.R.W.	18:30	280	400	1.022 1.025
L.M.P.	17:10	730	150	1.020 1.010
J.C.T.	17:40	435	0	1.016 1.027
H.R.W.	18:20	670	240	1.016 1.030
W.E.B.	17:52	80	0	1.020 1.020
T.E.B.	17:46	875	720	1.022 1.005
W.S.M.	17:22	1165	240	1.022 1.010

TABLE II. PSYCHOLOGICAL TEST: TARGET AIMING TASK

Trial Number	Condition of Test	Mean Deviation on Y Axis in Centimeters*
1	Pre-immersion	−0.94
2	Immersed 1 hour	+1.24
3	Immersed 6 hours	+1.76
4	Immersed 12 hours	+0.81
5	Immersed 16 hours	+0.79
6	Post-immersion	−2.30

*Standard deviation=±0.83 cm. per subject

TABLE III. PSYCHOLOGICAL TEST: SUBJECTIVE ESTIMATION OF DOWNWARD FORCE

Trial Number	Condition of Test	Mean Force Extended in Pounds*
1	Pre-immersion	15.14
2	Immersion 1 hour	22.36
3	Immersion 6 hours	19.99
4	Immersion 12 hours	20.60
5	Immersion 16 hours	20.08
6	Post-immersion	17.53

*Standard deviation=±0.69 for any given individual.

evaluate, (1) the effects of repeated trials, and (2) individual differences between subjects. The results of this analysis are shown in Table V. Highly significant differences occurred as a function of trials ($\mathcal{F}=9.713$; $p<.01$). The analysis also showed highly significant differences in the G level at which LOMA occurred among the different subjects ($\mathcal{F}=5.838$; $p<.01$). Based on the results of this analysis of variance, a series of t tests were then conducted, and it was found that the mean for the first post-immersion run was significantly less than the mean for control trial 1 ($t=3.14$; $p<.01$) and also less than the mean for control trial 2 ($t=2.858$; $p<.02$). However, the second post-immersion trial (conducted 24 hours after immersion) was not significantly different from any of the other trials, suggesting a return to the original base line. These statistical analyses support the conclusion that a small, reliable, and significant although temporary reduction in the G level of LOMA occurred following water immersion.

TABLE IV. G TOLERANCES OF SUBJECT AT VARIOUS TIMES PRE-IMMERSION AND POST-IMMERSION

Subject	Control Run I	Control Run II	Control Run III	Post-Immersion Run	Post 24 Hours	Post 48 Hours	Post 72 Hours
HWH	6.5	5.5	—	6.0	6.25	—	—
LTD	6.0	5.0	—	3.5	4.5	—	4.0
HBC	7.0	5.5	—	4.5	4.5	—	—
GEB	7.0	5.0	—	4.5	6.0	5.0	5.5
TEB	5.5	5.25	—	4.75	4.5	—	—
FBB	4.5	5.0	—	4.25	4.0	4.25	—
WEB	5.5	5.0	—	4.5	4.5	—	—
WSM	5.5	5.25	—	4.25	4.0	—	—
CRW	4.0	4.25	4.25	3.5	4.25	—	—
LMP	4.0	4.25	4.0	3.5	4.0	—	—
HRW	5.5	5.5	5.75	4.75	5.75	—	—
JCT	4.75	5.0	5.0	4.75	5.5	4.62	4.75
Average	5.62	5.05	4.75	4.43	4.81	4.62	4.75

*Variations in average G tolerances not statistically significant.

TABLE V. ANALYSIS OF VARIANCE OF G-TOLERANCE DATA

Source	df	Sum of Squares	Variance Estimate	F
Trials	3	7.8622	2.6207	9.713**
Subjects	11	17.3268	1.5752	5.838**
Trials × subjects	33	8.9034	0.2698	—
Total	47			

**p < .01

DISCUSSION

In contrast to previous experiments in which negative pressure breathing and the accompanying water diuresis obscured observable changes in human response to positive G, the negative pressure breathing was eliminated because the divers could adjust their regulators with regard to water depth in relation to the mid-chest position. Normally, the most comfortable condition for breathing underwater is to produce a slightly positive pressure against which the inspired air must be exhaled. The absence of the profuse diuresis previously reported tends to confirm this, as does the relatively small change observed in the urine specific gravities. The design of this experiment appears to have successfully simulated the weightless state insofar as water immersion can accomplish this purpose.

The tendency to place the magnets above the X axis, i.e., a positive Y error, is a well known disturbance of position sense which is due to the buoyancy which results when the body is immersed in a liquid.

The errors in the subjective estimation of downward force are not understandable in the light of variations due to the buoyant force developed by immersing the subject's body in water. One possible explanation may be that there is a variation in the feedback system which plays a part in such procedures under normal circumstances.

The variations in human response to positive G reflected by the statistical analysis of the data from Control Runs I, II and III suggest an increasing familiarity with centrifuge procedures rather than decreasing tolerance. This is the usual observation noted with new subjects who are apprehensive and tend to be tense, consequently, they either consciously or unconsciously strain against the increasing G force. As a result the initial endpoints for new subjects are higher than those which represent the base line after the subjects became more experienced. The decrease of 0.62 G in mean post-immersion LOMA levels probably represents no more than variations resulting from exposure to any non-specific stress situation of equal duration. The post 24-hour data suggests a return to pre-immersion control levels.

From these data, it was concluded that, within the experimental framework utilized, there was a small ($\bar{X} = .62$ G) but significant ($p < .01$) decrement in the G level at which LOMA was reached as a result of 18 hours of total immersion in water. The extrapolation from these data as to the response of human beings to reentry accelerations following a period of relatively prolonged weightlessness is dependent upon the degree of correlation between zero G simulation by water immersion and the true zero G state.

SUMMARY

Twelve members of Underwater Demolition Team 21 used underwater breathing equipment while completely immersed in water for 18 hours. Their response to positive acceleration was determined by observing the G level at which the limitation of ocular motility under acceleration (LOMA) occurred. This G level is approximately the same as when loss of peripheral vision or greyout occurs when subjects are exposed to positive acceleration. The period of immersion was well tolerated. A small but statistically significant decrease in the G level at which LOMA occurred was found following the period of immersion.

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