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Underwater Disorientation as Induced by Two Helicopter Ditching Devices

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Background:

Spatial orientation is based on the integration of concordant and redundant information from the visual , vestibular, and somatosensory systems. When a person is submerged underwater, somatosensory cues are reduced, and vestibular cues are ambiguous with respect to upright or inverted position. Visual cues may be lost as a result of reduced ambient light Underwater disorientation has been cited as one of the major factors that could inhibit emergency egress after a helicopter d itching into water. One counter measure to familiarize aircrew with underwater disorientation is emergency egress training. This study examined the relative degree of underwater disorientation induced by the Modular Egress Training Simulator (METS™) and the Shallow Water Egress Trainer (SWET).

Methods:

There were 36 healthy subjects (28 males and 8 females) who participated in the study. Underwater disorientation was quantified by measuring the deviation of subjective vertical-pointing from the gravitational vertical, time to egress, and subjective reports of disorientation and ease of egress. A repeated measure design was employed with seat position (SWET c hair, METS1M window, and METS™ aisle) as the sole factor.

Results:

Subjective response data indicated that the degree of disorientation is rated significantly higher, and the ease egress is rated worse from two METS™ seat positions than from the SWET. This is supported by the findings that subjective vertical-pointing accuracy is worse in the METS™ seat positions than in the SWET ($p < 0.01$). The time to egress is longer from the METS™ seat positions than from SWET ($p < 0.01$).

Conclusion:

Our results indicate that the METS™ device is effective for inducing underwater disorientation as provoked by simulated helicopter ditching.

Keywords: disorientation, vestibular, subjective pointing.

INTERRESTRIAL ENVIRONMENT, our perception of position, motion and attitude with respect to the fixed frame of reference provided by the gravitational vertical and the surface of the earth is based on the neural integration of concordant and redundant information from the visual, vestibular and somatosensory systems. To a lesser extent, the auditory system also provides information on orientation. The relative contribution of the various sensory systems involved in the perception of one's orientation is significantly altered when exposed to unusual gravity inertial environments such as during flight, in space, and underwater. Specifically, when a person is submerged underwater in an accident, such as in helicopter ditching, somatosensory cues are markedly reduced because muscles that are normally responsible for posture and balance are neutrally buoyant and not subjected to the normal effect of gravity. The otoliths of the vestibular system only respond to tangential shearing forces and do not recognize whether one is upright or inverted. Finally, the visual frame of reference underwater may be lost as a result of a reduction of ambient light being obscured by bubbles and debris or being confused by the underwater magnification effect. Under such circumstances, the central nervous system has the added responsibility of determining which sensory information is valid and which is not. When presented with reduced and/or conflicting sensory information, it is normal to experience episodes of spatial disorientation. Spatial disorientation occurs when subjects lose the ability to accurately sense their position, motion, or attitude within the fixed frame of reference, as mentioned above, regardless of whether they are in flight, in space, or underwater.

When a helicopter ditches into water, it is inherently unstable whether or not it has a flotation system; a breaking wave may inadvertently capsize it. In 50"/0 of cases, it sinks rap idly (1, 4, 8, 11) and commonly in an inverted position (11,16,17). In the absence of significant injury, failure to escape may be due to: a) confusion and disorientation associated with the sudden immersion and inversion in water; b) inability to release the restraint harness; and c) the poor visibility that could prevent the location and operation of suitable escape exits. In a survey by Rice (9), 26 of 43 survivors reported that they were disorientated and confused. The survivors cited that in-rushing water and the resulting disorientation from being submerged underwater often prevented them from reaching escape hatches. In addition, survivors reported that escape hatches cannot be easily seen in underwater darkness especially when the mishap occurred at night.

Disorientation underwater is a physiologic al response rather than a pathological condition, and therefore very little can be done to prevent its occurrence. Successful escape from a submerged and inverted aircraft may depend largely on reflexive action, which could best be learned in a realistic underwater egress device, It has been shown that training significantly reduced the confusion and disorientation caused by helicopter rolling inverted after ditching (12). Devices for simulating the ditching and inversion of helicopters have been used for 40 yr to train aircrew and passengers, and to provide them with experience in emergency egress. Cunningham (3) reviewed 234 U.S. Navy helicopter accidents from 1963-1975 in which 1093 personnel were involved. With training 91.5% escaped; without training only 66% escaped.

The Survival Systems Ltd. Modular Egress Training Simulator (METS™) is a typical example of a current underwater egress device. The shallow Water Egress Trainer (SWE1) is a typical example of a device for familiarizing the uninitiated into the problems of being immersed and inverted underwater, and for basic training in underwater breathing apparatus. More recently, some training facilities have employed the SWET chairs for underwater escape training as well. Although the two systems have been employed routinely for underwater egress training for more than 10 yr, their relative effectiveness in inducing disorientation has not been investigated.

There are some laboratory evidence indicating that we are susceptible to disorientation when submerged underwater in the inverted position. A previous study by Brown (2) revealed that when subjects were submerged in a tank and placed in some random orientation after several disorienting turns, they had difficulty pointing to the gravitational vertical. Errors were greatest with the head down in the inverted position. A subsequent study by

Nelson (6) also supported the classical concept of reduced sensitivity in the head down as compared with the head-up position during underwater immersion. The observation that the greatest degree of postural disorientation underwater *oc*curred in the inverted position was also reported by Schone et al. (13) and Ross et al. (10).

To our knowledge, as mentioned previously, underwater disorientation as induced by simulated helicopter Ditching has no t been investigated. This study attempts to quantify underwater disorientation as induced by the METS™ and the SWET, and to compare the relative degree of underwater disorientation induced by these two devices. In order to quantify induced disorientation the ability to perceive gravitational vertical during water immersion was investigated in the first study. In the second study, the subjects' ability to escape from the two devices was investigated by measuring the time to make an underwater escape from an inverted position.

METHODS

Subjects

There were 36 healthy subjects (28 males, 8 females) between the ages of 19 - 39 with a mean age of 28±0.9 yr and a mean sitting height of 91±0.6 cm who were recruited. All the subjects were able to swim and none of the subjects have prior underwater egress training. Recruitment was from local universities and the local business community, and was directed at attracting a sample representative of the age of military and civilian personnel working offshore. Approval for this experiment was obtained from the DO EM Human Ethics Committee. Subjects gave informed consent and completed a medical questionnaire. All but one (male) subject passed the medical examination and participated in the study. Subjects were instructed to refrain from alcohol l consumption and from prescribed or over-the counter medication for 36 h before the familiarization run and all the experimental sessions.

Apparatus

The experiments were performed at Survival Systems Ltd., Dartmouth, Nova Scotia, Canada. Evaluation of disorientation by the indication of perceived subjective vertical was conducted in the Modular Egress Training Simulator (METS™) and the Shallow Water Egress Trainer (SWET).

The Modular Egress Training Simulator (METS™) is constructed of stainless steel and plastic panel in the form of a helicopter fuselage. It is controlled by a KONE XL402N overhead hoist mounted on an I-beam. This enables the hoist operator to position the METS™ over the pool at any position and lower it to the prescribed depth underwater. Around the center of the fuselage structure is a circular rotation ring on which a rotation trolley rides. The rotation trolley contains an air brake system. Four stainless steel buoyancy pods filled with closed cell polyethylene foam are attached to the base of the simulator. When the METS™ is lowered into the water and the brake released, the buoyancy pods attempt to float to the surface, causing the METSTh1 to rotate around its longitudinal axis to an inverted position. In this study, the hoist was lowered to the surface of the water at 19 m min^{-1}. The clockwise rotation of the METS™ from upright to an inverted position took approximately 7- 8 s. The METS™ can be fitted with a variety of escape apertures and seats. For the current study, the METS™ was configured to the seating and window arrangement of the starboard side of the Sikorski 561 commercial helicopter (Fig. 1).

The Shallow Water Egress Trainer (SWET) is a single seat emergency underwater familiarization device. It measures 132 X 132 X 119 cm and is constructed from lightweight, marine grade aluminum. It is fitted with buoyancy pods that allow it to be easily maneuvered and rotated to an inverted position. In this study, a window frame similar to that of the METS™ was filled on the starboard side (Fig. 2). Since the SWET is not mechanized, it normally rests on the water surface and two divers maintain its equilibrium with the subject secured at the seat. Inverting the SWET, i.e., rotation in the frontal plane was induced physically by the chief instructor and a safety diver. The clockwise rotation of the SWET from upright to an inverted position took approximately 7-8 s. An identical standard 4-point harness with a right-pull releasing mechanism was used to restrain the subjects to the seats in both devices.

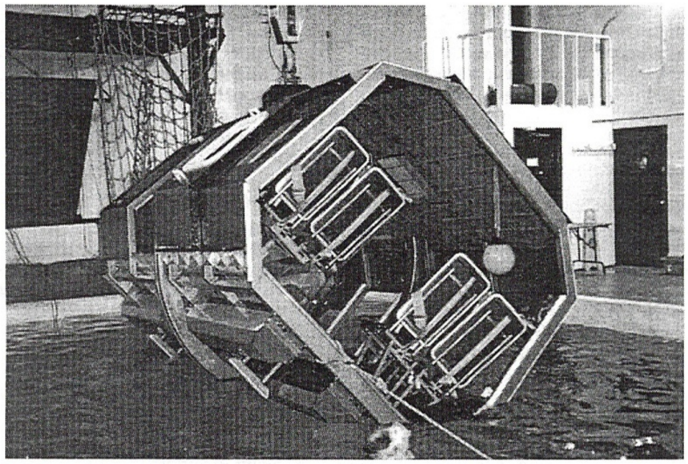


Fig. 1. Photograph of the Modular Egress Training Simulators (METS™) configured to the seating and window arrangement of a Sikorsky S61 helicopter; the fluorescent buoy can be seen serving as the gravitational vertical reference when the METS™ is inverted underwater.

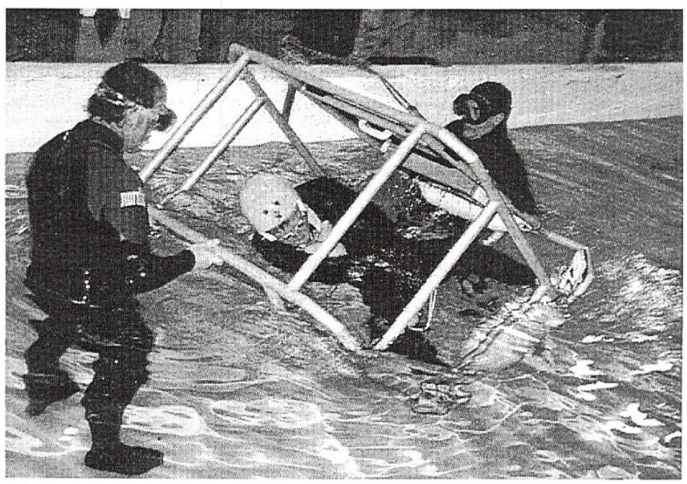


Fig. 2. Photograph of the Shallow Water Egress Trainer (SWET) constructed with light weight marine grade aluminum, fitted with buoyancy pods that allow it to be easily maneouverd.

Procedures

A repeated measures factorial design was employed with seat position as the sole factor (SWET chair, METS™ chair adjacent to window, and METS™ chair adjacent to aisle). Subjects attended 1 familiarization session and 6 experimental sessions, on 7 consecutive days. As mentioned previously, in the first study we measured subjective vertical-pointing when the subjects were inverted underwater. In the second study we measured the time to egress from the two dev ices after the subjects were inverted underwater. Each study consisted of three separate sessions, one for each of the seat positions. The order of seat position assignment within each part was counter balanced across subjects. The water temperature during all the trials was kept at 28° C and the ambient temperature of the pool area was kept at 20°C. A diving medical officer was in attendance at the poolside with full resuscitation equipment throughout the entire experiment. In addition to the chief diving instructor, two safety divers were in the water at all times.

Familiarization

The familiarization session involved the following: a review of the experimental protocol, a review of the safety features and risks of both the METSTM and SWET devices, and hands-on training about the restraint harness release mechanism. In the shallow end of the pool, with vision occluded, subjects also practiced holding their breath underwater. Finally, subjects were immersed and rotated underwater to various end positions in each device. During all the familiarization sessions, the chief instructor and safety divers assisted the subjects to escape by releasing their harness and bringing them back to the surface.

Subjective Vertical-Pointing

A typical ditching scenario using the METS™ took place as follows. With the subject secured in the assigned seat and assuming the pre-crash brace position, the device was raised to 0.5 m above the water level. When the principal investigator was satisfied that everyone was ready to proceed, the order "ditching, ditching, ditching" was given by the chief diving instructor. When the device reached the surface at 0.33 m s^{-1}, it rolled over according to the mechanism as described previously. The device continued to descend until the bottom of the fuselage was level with the water surface, at which time the subject was inverted underwater with respect to the gravitational vertical. This end position was chosen because it was reported to be the most effective position to induce postural disorientation (6, 10, 13). The mean depth of head level below the water was 1.52±0.06 m. Following the cessation of all movements and air bubbles created by the ditching (lasting about 10s), the chief instructor made two tapping sounds on the fuselage to alert the subject to perform the subjective vertical-pointing task. The task involved pointing in a ballistic manner with the hand and forearm to the direction where the subject thought the sky was relative to the torso. This position was maintained for 2 s.

An identical procedure was performed in the SWET chair with the exception that two divers physically rotated the SWET chair until it was inverted. Head level depth below water was < 0.91±0.06 m (identical or less than sitting height).

The specific instructions given to the subject in both devices were as follows:
1. Assume the pre-crash brace position.
2. You will be rotated to a different position underwater.
3. On hearing two taps, think about where the sky is with respect to yourself.
4. Point in a ballistic manner with your hand and forearm to the direction where you think the sky is and hold this position for 2 s.

Observations on the egress times and accuracy of the response and any gross body or head movements were recorded by an underwater video camera. A buoy fastened to the back of the two devices served as the gravitational vertical reference. If a subject failed to provide a correct vertical indication within 10s the divers released the subject and assisted the subject to the surface.

Time* to *Egress

The procedure was identical to the first part of the study (pointing to subjective-vertical), with the exception that, on hearing the two tapping sounds, the subject proceeded to egress from the device. The exact instructions were:

1. Use the left hand to locate the escape window frame.
2. Use the right hand to release the restraining harness.
3. Pull the body through the open window to the starboard side.
4. Swim to surface.

Observations about any gross body or head movements and any assistance from the instructors or safety diver were recorded. Time to egress was measured by three independent observers with stopwatches; it was measured from the end of the two tapping sounds to the time when the subject's feet were clear from the window of the device.

Subjective Questionnaire

Immediately on completing a session, each subject was shown a five-point Likert scale questionnaire to assess the degree of disorientation, in the case of the subjective vertical-pointing sessions; or to assess the ease of egress, in the case of the time to egress sessions. Subjects were not permitted to see any of their previous answers. (See Appendix A for a copy of the Likert questions.)

Data Analysis

The accuracy of perceived subjective vertical (as indicated by pointing) for each subject was recorded on video cassette in each of the three trials (the SWET, and METS™ window and METS™ aisle). Prior to the statistical analysis the vector arrays for each subject's three pointing sessions were reviewed for inaccuracies, and the angle between the gravitational vertical vector (buoy reference) and the arm vector (direction of pointing) was measured. Specifically, after the desired video frame was selected, the gravitational vertical and the pointing arm vectors were drawn onto translucent tracing paper superimposed on the screen. The angle of intersection of the two vectors was then measured with a protractor. Although the process was tedious and labor intensive, the measurement is accurate. A one-way repeated measure ANOVA was performed on the accuracy of the subjective vertical-pointing data. The second analysis, performed on the time to egress data, was a 3 (seat position) X 3 (time to egress) repeated measure ANOVA. A one-way repeated measure ANOVA as well as Friedman's ANOVA were performed on the Likert questionnaire. P-val ues with more than two factors were adjusted using the GreenhouseGeisse r's epsilon correction factor.

RESULTS

Subjective Vertical-Pointing

A total of 105 pointing sessions were recorded and measured. Scatter plots of the pointing angles for each seat position by the subjects are illustrated in Fig. 3. Most of the subjects painted in a direction parallel to the frontal plane in all positions (SWET vs. METS™ window and METS™ aisle). Angular deviation from gravitational vertical ranged from 0-180°. The angular deviation scatter in the METS window was much higher, while the scattering in the SWET condition was primarily confined to the first quadrant (between 0- 90°). Moreover, despite the position of the camera, it was clearly evident from the video images that some subjects pointed in a direction orthogonal to the frontal plane: either forward (in front of the subject) or backward (to the back of the subject). In these cases, it was not possible to accurately measure the angle of deviation from the gravitation al vertical from the video image, because it was out of the frontal plane of the camera. The number of subjects pointing orthogonal to the frontal plane is reported as follows. There are 5 cases in the SWET, of which 3 pointed backward and 2 forward. In the METS™ window there are 11 cases, of which 10 pointed backward and 1 forward. In the METS™ aisle there are 9 cases, of which 7 pointed backward s and 2 forwards.

A one-way repeated measures ANOVA was performed on the subjective vertical-pointing data. There is a significant effect [F (2, 68) = 11.55, P ≤ 0.0001, *e* = 0.75363) on seat positions. The group means for this data are illustrated in Fig. 4A. Post hoc analysis using the Sheffe' test revealed that the accuracy of pointing with respect to the gravitational vertical following helicopter ditching simulation was significantly less accurate in the METS™ window seat (p ≤ 0.0001) and the METS™ aisle seat compared with the SWET chair (p =0.034). The difference between the METS™ window seat and aisle seat was not significant. These results indicate that the METS™ trainer was more effective in inducing underwater disorientation.

Subjective Disorientation

Based on the Likert scale questionnaire, the group means for subjective disorientation for each seat position are illustrated in Fig. 4B. A one-way repeated measure ANOVA was performed on the data and revealed a significant effect [F (2, 68) = 7.397205, P = 0.01, *e* = 0.98288. Post hoc analysis using the Sheffe' test confirmed that the results are consistent with the subjective vertical-pointing task. Subjects rated themselves, significantly more disoriented when painting from either of the METS™ sea t positions compared with the SWET chair (SWET vs. METS™ window: p = 0.002; SWET vs. METS™ aisle: p = 0.035). Disorientation ratings did not differ among the METS™ seat positions. In addition, Friedman's non-parametric ANOVA by ranks was per formed on the data resulted in a greater significance [$_x^2$(2, 35) = 13.65, P = 0.001]. Further n on-parametric analyses using the Wilcoxon matched-pairs signed-ranks confirmed that subjects rated themselves significantly more disoriented when pointing from either of the METS™ seat positions compared with the SWET chair (SWET vs. METS™ window: z = 2.96, P = 0.003;SWET vs. METS™ aisle: z = 2.49, P = 0.013).

Time* to *Egress

A total of 105 egress sessions were completed with 9 failed attempts. The number of failures for each seat position is as follows: 4 SWET chair, 1 METS™ window, and 4 METS™ aisle. A 3 (seat position) X 3 (observer) repeated measures ANOVA was performed on the time to egress data collected from the successful trials. There were sign main effects for seat position [F (2, 52) = 12.72, P ≤ 0.01, E = 0.93497] and observer [F (2, 52) = 16.35016, P ≤ 0.01, E = 0.99442] as well as a significant seat X observer interaction [F (4, 92) = 12.05562, P ≤ 0.01, *e* = 0.73456] as illustrated in Fig. 5A. Inspection of Fig. 5A revealed two significant features. Egress time recorded for the SWET chair differed significantly among the observers (observer 1 vs. 2, P ≤ 0.01; observer 1 vs. 3, P ≤ 0.01; and observer 2 vs. 3 P ≤ 0.01 as indicated by Planned Comparisons) but were virtually identical for both METS™ sea t positions. This finding can be explained by the interpretation of the egress end-point. The egress end-point was defined to be the time at which the subject's feet were cleared from the escape window. However, due to the shallow resting position of the SWET simulator, the head level of subjects was often above water before their feet were cleared from the escape window. Once their heads were above water, subjects often paused momentarily or stopped completely, resulting in an inter-observer variation of egress time from the SWET chair. Despite the variation, Planned Comparisons revealed that even the most liberal observations of time to egress from either of the METS™ seat positions was significantly longer than egress from the SWET chair (p ≤ 0.01). No significant differences in time to egress were evident among the two METS™ seat positions.

Ease of Egress

Based on the Likert scale questionnaire, the group means for ease of egress for each sea t position are illustrated in Fig. 5B. A one-way repeated measure ANOVA was performed on the data and revealed a significant effect [F (2,68) = 4.811531, P ≤ 0.01, E = 0.93782]. Post hoc analysis using the Sheffe' test revealed that subjects rated the SWET chair significantly easier to escape from than either the METS™ widow (p =0.022) or the METS™ aisle (p = 0.049). Ratings of the METS™ seat posit ions did not differ. The pattern of results is consistent with the objective time to egress results (SWET < METS™ aisle < METS™ window). In addition, Friedman's non -parametric ANOVA by ranks was performed on the data and confirmed the significant effect [x" (n = 35, df = 2) = 6.021276, P = 0.049]. Non-parametric analyses using the Wilcoxon matched pairs signed -ranks revealed that subjects rated the SWET chair was significantly easier to escape from than either the METS™ window (z = 2.64, P =0.0081) or the METS™ aisle (z = 2.53, P = 0.011).

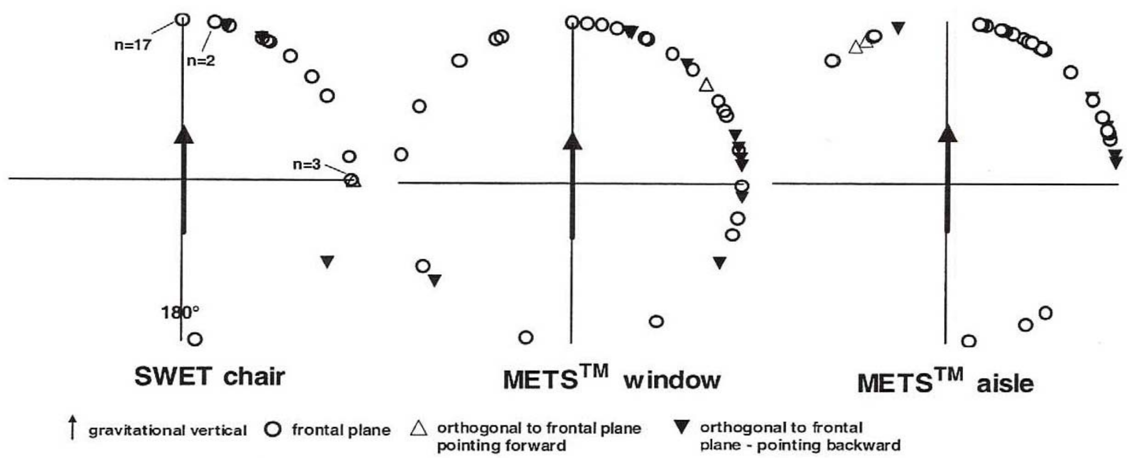
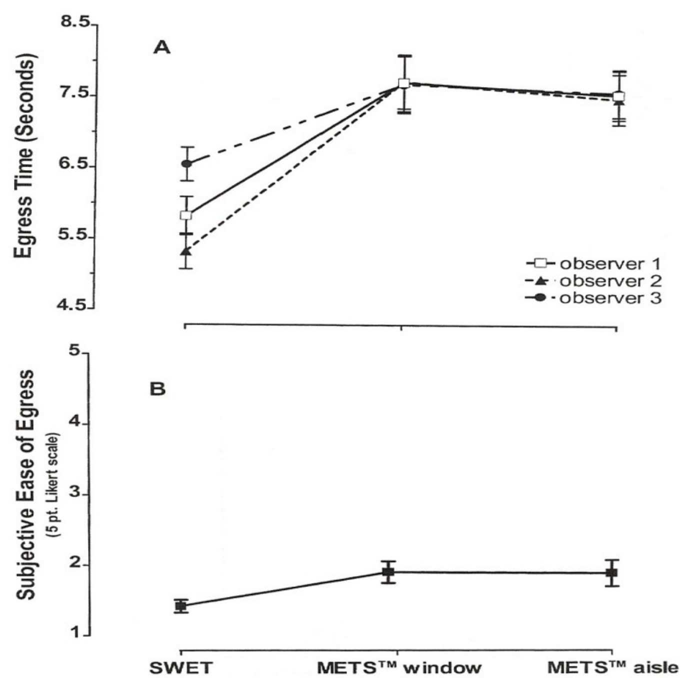


Fig. 3.
Scatter plots of subjective vertical-pointing data for each seat position. Each symbol representsone subject. Numbers in brackets indicate overlapping data points.



Seat Position

Fig. 4.
A. Angular deviation from gravitational vertical as a function of seat position. Error bars are standard error of means (SEM).

B. Subjective disorientation as a function of seat position. Error bars represent SEMs

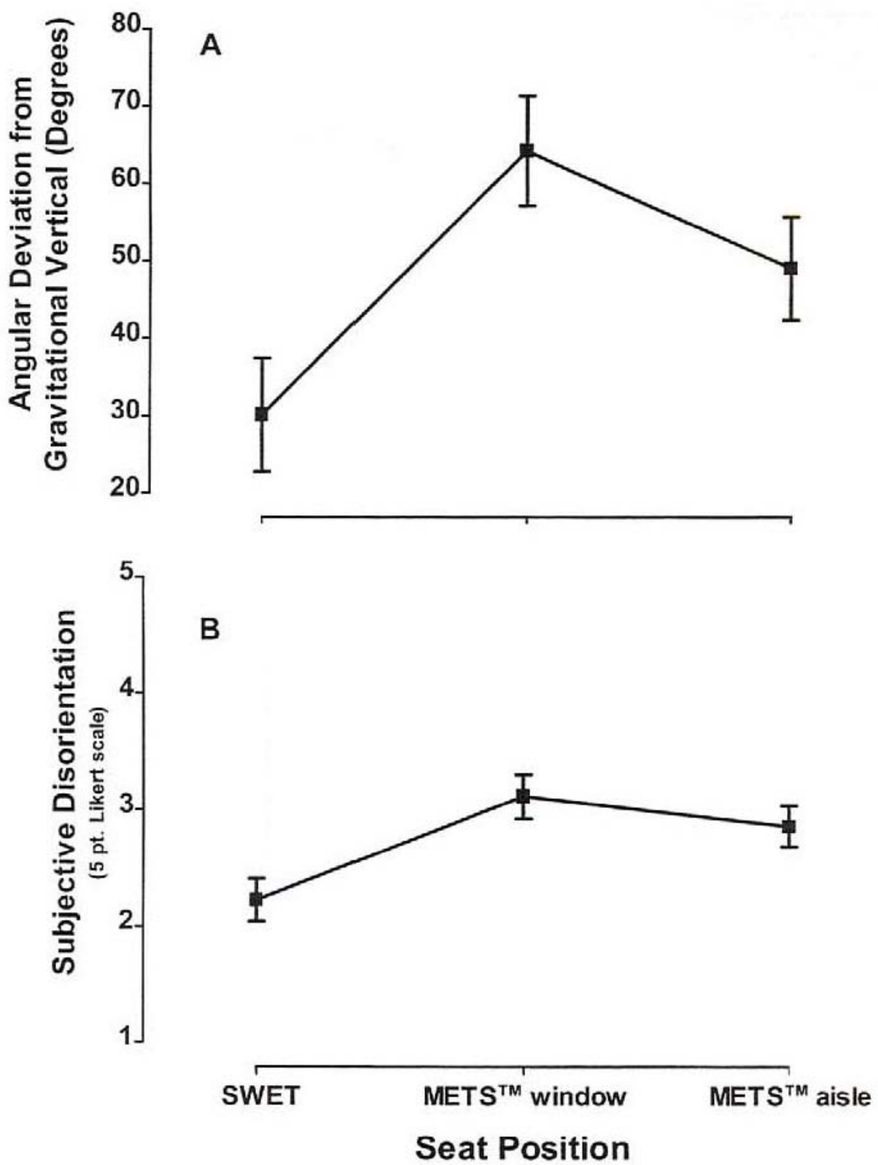


Fig. 5. A. Underwater egress time as a function of seat position and observer. Error bars represent SEMs. B. Subjective ease of egress as a function of seat position. Error bars represent SEMs.

DISCUSSION

Humans are extremely sensitive to variations of head position from the gravitational vertical (5). Specifically, they can easily be disoriented with respect to the direction in which they are facing by rotation about the earth vertical axis. Such disorientation is attributed to the effect of angular acceleration (and deceleration) of the semicircular canals of the vestibular apparatus. However, rotation about the earth horizontal axis in a vertically oriented gravitational field is more complicated and it results in a characteristic-changing pattern of stimulation of the utricles and saccules on each rotation as well as stimulation of the semicircular canals.

In this study, results from the subjective vertical pointing test, time to egress and subjective questionnaires all indicated that the METS™ device induced a significantly greater degree of disorientation than the SWET device. With the resolution of our measurement estimated to be ±3°, in the SWET there were 17 subjects out of 35 who were able to accurately point to gravitational vertical while submerged underwater as opposed to only one subject in the METS™ window seat and none in the METS™ aisle seat. The preponderance of the pointing being confined to the firs t quadrant (in all three positions) could be due to the fact that the devices were rotated in the clockwise direction. The other possibility could be because the subjects were instructed to use their right hand and forearm for ballistic pointing to perceived gravitational vertical. Further investigation using counter-clockwise rotation and the left hand is required to clarify this observation.

The number of cases where the subject pointed in the direction orthogonal to the frontal plane was also higher in the two METS™ positions than the SWET trainer, 11 and 9 cases compared with 5, respectively. This observation further indicated the METS™ is more effective in inducing disorientation. As it was not anticipated that subjects would be pointing out of the frontal plane, it was not possible to quantify the angular deviation from gravitational vertical. The implication of the out of frontal plane pointing awaits further investigation. The fact that some subjects did not rate the SWET chair as disorienting as the METS™ aisle suggests that the failure rate among the SWET chair is likely due to factors other than disorientation. As stated previously, the SWET chair was never designed as a disorientation inducing device, but as an underwater familiarization device and for training in the use of underwater breathing apparatus. Indeed, we observed that the four failures in the SWET chair occurred as a result of the difficulty subjects had in locating the edge of the escape aperture among the tubular framework of the SWET construction. With that in mind, consistent with the results of the objective and subjective portions of the experiment, the METS™ aisle displayed the highest failure rate due to disorientation.

One reason why the METS™ device is effective in inducing disorientation is because a realistic simulation of in-rushing water during rotation to the inverted position occurs. This is enhanced by the structure of the cabin design. Even in those helicopter accidents where no fatalities resulted, in-rushing water in conjunction with disorientation was quoted as a deterrent to escape far more frequently than any other problems (9). The SWET trainer is essentially a tubular cube; when it begins to submerge there is no in-rushing water but a rapid diffusion from all angles .

With respect to induced disorientation underwater, our results are consistent with previous investigations. Whiteside (18) tested orientation as measured by vertical pointing during immersion in water up to the neck. There was some loss of directional sense reported in this situation even though the utricular sense was not diminished . This loss was attributed to the altered muscle balance, absence of visual information and reduced proprioceptive cues. It was also reported that with a moderate amount of passive motion subjects tended to lose their orientation to the vertical when immersed underwater at a depth of 3.04-7.62 m (2). Most adult males achieve neutral buoyancy at a depth of approximately 4.57-7.62 m. From our results, it appears that the human body submerged to a level less than that suggested for neutral buoyancy was effective in inducing disorientation. However, direct comparison under similar conditions is required to further investigate the effectiveness of different immersion levels on underwater disorientation. In our opinion the ad equate level of underwater immersion was an important factor in this study. Due to the fact that the design of the SWET requires the instructors to stand in the shallow end of the pool, it was impossible to totally submerge the subject in 1 m of water in the SWET chair. It is postulated that this was another contributing factor responsible for the reduced effect of induced disorientation.

The Likert scale has a number of limitations including the assumption that Likert scale yields interval data.
A second limitation in using this type of questionnaire is that respondents tend to resist the alternative nature of the question and cluster their responses toward neutral. However, non-parametric analyses using the Friedman's

ANOVA confirmed the significant findings. Nevertheless, when the ease of escape was compared with subjective vertical pointing, the results suggested that disorientation might not necessarily hinder successful egress. The sequence of relatively simple movements may be performed with very little difficulty. In other words, despite the disorientation indicated by our data, successful egress could be achieved with some practice. Requiring subjects to carry out a more demanding sequence of events (mentally and physically) during underwater egress will clarify the validity of this suggestion.

Causes of Underwater Disorientation

When subjects maintain themselves to the postural vertical, it is obvious that they will use all of the available information to minimize their errors, including tactile and various proprioceptive information. When people are submerged underwater, the somatosensory cues are markedly reduced, since no effort is required to maintain posture under water. The righting reflexes do not exist, and muscles, which normally are responsible for posture and balance, are relaxed. Vestibular information concerning the direction of "subjective down" may be incorrect. The erroneous and inadequate vestibular signals are due to the fact that the otoliths only respond to tangential shearing force acting on the otoconia, and do not recognize when the body position is upright or inverted. Buoyancy gives a state of weightlessness, which affects the sense of position and direction. An increased reliance must be placed on visual information. However, visibility in helicopter ditching could be reduced due to the bubbles and murkiness of the water, cabin debris, floating personnel and equipment or the time of day. Also there is a possibility that experiencing vertigo underwater can be induced by caloric stimulation on the way to or on reaching the surface of the water. Vertigo is a condition whereby the subject experiences a sensation of irregular or whirling motion either of oneself or of an external object. Although these symptoms are mild, prolonged disorientation could lead to aspiration of water and subsequent drowning. In addition to the aforementioned causal factors, disorientation experienced underwater induced by helicopter ditching is complicated by the rate of descent, force of impact and the rate of rotation of the fuselage underwater. How these additional factors may affect disorientation and underwater egress awaits further investigation.

Effective Simulation

The concept that realistic appearance is necessary to ensure that training received in a simulator will transfer to operational equipment underlies the design and use of training simulators. This concept is based on a theory developed by Thorndike (15) who suggested that transfer of training would occur to the extent that a simulator and the equipment share common elements. In addition, according to Osgood's (7) transfer surface theory, one could map an assumed relationship between elements or features of a simulator an d the equipment simulated. Where there is a one-to-one correspondence, transfer of training will be high and positive. Less than one-to-one correspondence will yield decreasing transfer to the point that none will occur when the correspondence is zero. Based on these theories, simulation of underwater egress from a d itched helicopter requires a realistic, accurate and comprehensive representation of the particular system. In this case, a simulator that resembles the fuselage of an aircraft will be more effective. Our results on the effectiveness of the METS™ trainer in inducing disorientation underwater confirm this notion. This is more apparent as most helicopters, especially in military aviation, have multiple seats and that not every seat in the helicopter has a single escape door or window nearby. The underwater egress training for those located away from windows and doors is of utmost importance. In order to facilitate effective training in egress, a simulator resembling the METS™ would be the minimum requirement. Although the SWET trainer is relatively inexpensive, structurally simple, easy to operate and hence, can be made more available at other locations, based on our data it is poor at simulating disorientation underwater. The SWET chair as designed should serve as a procedural trainer to familiarize the subject with underwater immersion. It is recommended that proper training of crewmembers and passengers will reduce disorientation and panic (11,14). Implementation of realistic underwater egress training will enhance survival. Further improvements on the fidelity of the training could include the capability of controlled roll and pitch, and velocity of impact in the next generation of helicopter-d itching trainers. In conclusion, our objective was to investigate underwater disorientation using the METS™ and SWET devices.

Our results indicate that the METS™ trainer induced a significant degree of disorientation as measured by subjective-vertical pointing and time to egress. The SWET did not. The results of this study could be used to formulate a cost effective disorientation program as well as assisting in the development of the next generation of underwater egress trainers. The knowledge gained from this study may prove invaluable in the case of future accidental helicopter ditching in military, search and rescue, and civilian settings by increasing our understanding about how pilot and aircrew react when disoriented while underwater.

APPENDIX A: LIKERT SCALE QUESTIONNAIRE Gender: M F Age:										
On a scale of t to 5 how difficult was it to escape from the seat position										
SWET chair		Not difficult		1	2	3	4	5		Difficult
METS™ aisle		Not difficult		1	2	3	4	5		Difficult
METS™ window		Not difficult		1	2	3	4	5		Difficult
On a scale from 1 to 5 how disoriented would you say you were.										
SWET chair		Not disoriented		1	2	3	4	5		Disoriented
METS™ aisle		Not disoriented		1	2	3	4	5		Disoriented
METS™ window		Not disoriented		1	2	3	4	5		Disoriented

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REFERENCES

1. Brooks CJ. Human factors relating to escape and survival from helicopters ditching in water, 1989; Neuilly-SurSeine, France: NATO, Agardograph No. 305(e); ISBN 92·8350522·0.
2. Brown JL. Orientation to the vertical during water immersion. Aerosp Med 1961; 32:209-17.
3. Cunningham WF. Helicopter underwater escape trainer. In: Knapp SC, ed. Fort Rucker, AL: AGARD Conference Proceedings No. 255: Operational helicopter aviation medicine, May 1-5, 1978. London: Tech Eds Reprod 1978:66-166-3.

4. Giry P, Courcoux P, Taillemite JP. Accidents d'helicopter e au dessus de J'eau dans la marine nationale: etude ep idemiologique sur la periode 1980-1991. Neuilly, France: NATO AGARD Proceedings. 1992. ISBI\1 92-835-0687-1.
5. Howa rd JP, Temple ton WB. Orientation to gravity I, II and III. In:Howard IP, Templeton WB. Human spatial orientation. New York: John Wiley & Sons, 1966; 175-255.

6. Nelson Je. Effects of water immersion and body position upon perception of the gravitational vertical. Aerosp Med 1969; 39: 80&- 11.
7. Osgood CE. The similarity paradox in human learning: a resolution. Psychol Rev 1949; 56:132- 43.
8. Reader OC. Helicopter ditchings- British military experience 1972- 88. Farnborough: RAF Institute of Aviation Medicine, 1990. Report No. 677.
9. Rice EV, Greear JF. Underwater escape from helicopters. Phoenix, AZ:. Proceedings of the Eleventh Annual Symposium. Surv Right Equip Assoc 1973; S9-60.
10. Ross HE, Crickman SO, Sills NY, Owen PE. Orientation to the vertical in free drivers Aerosp Med 1969; 40:728-32.
11. Ryack BL, Luria SM, Smith PF. Surviving helicopter crashes at sea: a review of studies of underwater egress from helicopters. Aviat Space Environ Med 1986; 57:603-9.
12. Ryack BL, Walters GB. Chaplin SM. Some relationships between helicopter crash survival rates and survival training. Groton, CT: Nava l Submarine Medic al Research Laboratory, 1976. Report No. 77-1.
13. Schone H, Udo De Haes H. Perception of gravity -vertical as a function of head and trunk position. Z Vergl Physiol 1968;60:440- 4.
14. Sowood PJ. Escape and survival following helicopter ditching: training aspects. Aeromed Digest 1990; 4:31-3.
15. Thorndike EL. Human learning. New York: Century; 1931.
16. Vyrnwy-Jones P. A review of Royal Air Force helicopter accidents 1971-1983. Famborough: RAF Institute of Aviation Medicine, 1985. Report No. 635 (Restricted).
17. Vyrnwy-Jones P, Turner JM. A review of Royal Navy helicopter accidents 1972- 1984. Famborough: RAF Institute of Aviation Medicine, 1989. Report No. 648.
18. Whiteside Te, Gra ybiel A, Niven JL. Visual illusions of movement. Brain 1965; 88:193- 210.