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Research Note

Mental and Psychomotor Task Performance In an Open Ocean Underwater Environment

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The inception of self-contained underwater breathing apparatus (SCUBA) has allowed a considerable increase in the freedom of the diver to explore the underwater environment. This freedom has been exploited by commercial and military organizations and more recently by the sport and recreation enthusiast. In the open ocean, SCUBA divers are required to perform both simple mental and psychomotor tasks while submerged, yet relatively little research has been reported concerning the limits of the diver's operational capabilities in such an environment. For the most part, experimental work has focused on the problems surrounding the physiology of survival in conditions hostile to human existence. However, in recent years research concerning task performance limitations as applied to the human operator underwater has begun to emerge (e.g., Egstrom & Weltman, 1974).

Much of this experimental work has been conducted in the controlled conditions of the indoor swimming pool. Information concerning movement characteristics of the diver have been adduced from this setting. Kerr (1973) examined the motor capacity of subjects performing a reciprocal tapping task and showed degrees of decrement in movement control underwater. Streimer (1972) reported on a complex assembly task and indicated that physiological and manual dexterity degradations were likely to occur in maintenance task performance while diving. Most recently, Brady (1979) has demonstrated that dry land practice has a substantial influence on subsequent manual task performance underwater and in addition, that divers exhibit a learning curve on task while submerged.

Although the swimming pool may constitute the learning arena for many divers, especially sport and leisure participants, the objective of many of these divers is to utilize acquired skills to explore and operate in the rich environment offered by the open ocean. Also, the majority of tasks undertaken by the commercial and military diver occur in this practical operational setting. Early studies which examined diver performance capability reported on manual dexterity tasks (Baddeley, 1966; Baddeley & Flemming, 1967) and the ability of the diver to function over extended periods in the open ocean underwater environment (Bowen, Andersen & Promisel, 1966.) Subsequent work has been reported by Baddeley and associates (Baddeley, 1967; Baddeley, DeFigueredo, Hawkswell Curtis & Williams, 1968) who have examined the role of anxiety in underwater task completion and by Weltman and Egstrom (e.g., Egstrom, Weltman, Cuccaro, & Willis, 1973; Weltman, Egstrom, Christianson, & Crooks, 1969) who have initiated work on tolerance and measurement techniques in diving research.

The ability to operate efficiently in the open ocean is in part dependent upon diver experience. Weltman, Christianson and Egstrom (1970) examined the effect of both environment and experience on divers performing sentence comprehension, complex assembly and dive time calculation tests. They identified three factors as influential in work performance underwater: diving experience, situational anxiety and tank versus open ocean environment. All subjects were tested at a moderate 6m depth in the open ocean and the results indicated detriment in novice diver performance which was attributed to the psychological stress of ocean diving. Experienced divers exhibited no such change in performance between tank and ocean exposures.

The current work is concerned with the limitations imposed on the experienced diver in good ocean dive conditions. Specifically, the study examined the performance of experienced SCUBA divers on simple mental and psychomotor tests over a range of depths in the open ocean. The depths selected represent (1) the range over which much current practical work is undertaken (Godden & Baddeley, 1979) and (2) depths at which the professional and sport diver may operate for extended periods without the associated complications of prolonged decompression or inability to perform viable free emergency ascents.

Two tasks were chosen to yield information concerning simple mental performance and movement control underwater. The mental performance task was consonant with dive time calculations for safe dive profiles which negate the necessity for decompression during compressed air diving, and the movement task represented the basis of simple reaching and aiming movements while submerged. The tasks chosen provided data concerning components of performance of many practical tasks which are commonly undertaken in both work and recreational activities.

Method

Subjects

Six male subjects, height 180 ± 10 cm; weight 75 ± 15 kg; age 25.2 ± 9.1 yr (mean ± range), were selected on the basis of diving experience. Four subjects had P.A.D.I. (Professional Association of Diving Instructors) certificates, while the remaining two had N.A.U.I. (National Association of Underwater Instructors) certification. In total the group had logged over 300 hours' diving time in the open ocean. No subject had any visual impairment, movement disability, or was under any medication at the time of experimentation.

Procedure

All subjects performed an initial land control test followed by counter-balanced manipulation at 4.6m and 15.2m depths in the open ocean. The land control test was conducted in the open air at the site adjacent to the point of water entry. This test was performed without diving apparatus worn. While equipment might marginally encumber lower arm movement when working in a sitting position on land, no such restriction is experienced underwater. Consequently, the land test, without equipment, was considered a superior control condition. All tests were conducted at approximately the same time each day for each of the three exposures. The procedure for an initial land test before underwater performance follows the protocol advocated by Baddeley, DeFigueredo, Hawkswell Curtis and Williams (1968) concerning order of exposure presentation. From a beach entry, subjects swam with the use of a buoyancy vest to the experimental location approximately 250m from shore. After deflating the vest the negatively buoyant subject sat on the ocean floor facing the experimenter who acted as the "buddy" in the commonly practiced pairs dive team system. At 4.6m subjects sat on the sandy ocean floor where wave surge was minimal and visibility was clear over at least 30m. Similar conditions were extant at the 15.2m site, which was marginally farther from shore. Water temperature was uniformly high across depths at 32°C.

Experimental Tasks

1. Reciprocal Tapping

A reciprocal tapping task (Fitts, 1954) was used to investigate the control of simple aiming movements underwater. Subjects are required to tap alternately between two targets. Task difficulty may be manipulated by varying the distance between targets (amplitude) and target diameter (width). A movement Index of Difficulty (ID) is derived through the expression:

$$ID = \log_2 \ (2 \times \text{Amplitude/Width}) \ (1)$$

In the current experiment movement amplitude was 6 in. (15.2 cm) and target width ½ in. (1.27 cm) yielding an ID of 4.58. This condition is coincident with one utilized by Kerr (1973) in a swimming pool setting. Subjects received four trials of 20 sec each with an inter-trial interval of 10 sec. Timing of each trial was made by the experimenter using an underwater stopwatch, and commencement and cessation were signaled by a single tap on the head of the subject. A sharp stylus was used to mark circular targets printed in black on a thermofax sheet and set in relief with a white working surface. The total number of correct movements (hits) and of erroneous movements (misses) were recorded for each trial.

2. Number Addition

The simple addition task presented the subject with an imperative number followed by a series of digits. The subject added the digits until the imperative number was reached. This task had been employed previously to test mental performance by Blockley and Lyman (1950). A response was made by marking an appropriate circle above the target number with a pointed stylus. The following represents an example of a single addition:

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      o o o o o o o o o o o
*43*  2 4 3 8 5 6 2 3 8 2 1
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A head tap signaled the start and finish of the task which had a two-minute time limit. Subjects were required to complete as many additions as possible. Total attempted and errors made in each condition were subsequently recorded.

Results

For the reciprocal tapping task, analysis of variance revealed a highly significant effect for condition on the time of individual movements, $F\ (2{,}56) = 34.3$, $p < .001$. Scheffe's post hoc procedure indicated an expected effect at the .01 level of significance for the change of medium of performance, as movement time was elevated in both underwater conditions when compared to equivalent dry land performance. Post hoc analysis failed to find a significant difference between movement time at the two ocean depths. Mean movement times exhibited such an increasing trend, i.e., land = 425 msec per movement, 4.6m underwater = 621 msec per movement, and 15.2m underwater = 648 msec per movement. Subjects did not trade speed for accuracy as there was no effect for condition on error rate, $F\ (2{,}56) = 0.97$, $p > 0.05$, and error rate was consistently low across conditions, 5.3% on land and 5.7% and 5.6% at 4.6m and 15.2m underwater respectively. Subjects did not exhibit any marked practice effect as there was no significant difference between successive trials, $F\ (3{,}56) = 0.3$, $p > 0.05$.

For the number addition task there was no significant difference between the total number of additions attempted in each of the three exposures, $F\ (2{,}10) = 0.06$, $p > 0.05$, the actual means being 14.2, 14.3 and 14.5 on land and 4.6 and 15.2m underwater respectively. However, analysis of variance indicated a highly significant effect for errors committed in the differing conditions $F\ (2{,}10) = 7.4$, $p = 0.01$. Scheffe's post hoc test revealed that errors significantly increased at 15.2m ocean depth (14.8%) when compared to the shallow ocean exposure (7.0%) and the dry land control (8.0%). These latter two conditions showed no significant difference for errors. A summary of these results is presented in Table 1.

Discussion

Movement precision, as investigated in the reciprocal tapping paradigm, has been the subject of previous experimentation in the underwater setting. Kerr (1973) utilized several movement amplitude-target width combinations to study changes in movement control while submerged. Current task procedure and ID were identical with one condition investigated in the Kerr experiments. Land control movement times were very similar, 425 msec in the current study compared to 415 msec reported by Kerr. In the underwater condition at 0.6m, Kerr found that the average time for individual movements was 560 msec in the swimming pool setting. In the present study, movement times for each individual movement were 621 msec at 4.6m and 648 msec at 15.2m ocean depth. These results affirm the expected slowing effect for the change of operational medium. The absence of significant difference between movement times at each depth should be treated with some caution. The difference between depths investigated represents only a limited range of that over which the air-breathing diver may operate (Godden & Baddeley, 1979), and it should not be inferred that increasing ocean depth beyond this range does not affect movement performance. Indeed, analysis of data presented by Baddeley and his colleagues (Baddeley, 1966; Baddeley & Flemming, 1967; Baddeley, DeFigueredo, Hawkswell Curtis & Williams, 1968) demonstrates that performance efficiency on a simple manual dexterity task is progressively degraded up to the investigated limit of 200 ft. ocean depth. To understand further the relationship between depth of operation and simple movement control, it is necessary to examine performance over an extended range of ocean depths; this is the focus of a current investigation.

Table 1
Mean and Percentage Error Rate for the Mental And Movement Tasks in Each of Three Conditions

	Mental Addition		Reciprocal Tapping	
	$\bar{X}$ Total	Error %	$\bar{X}$ MT	Error %
Dry land	14.2	8.0	425	5.3
4.6m Ocean Depth	14.3	7.0	621[b]	5.7
15.2m Ocean Depth	14.5	14.8[a]	648[b]	5.6

[a]$p = 0.01$
[b]$p < 0.01$

In the mental addition task, divers were required to add a series of digits to attain an imperative number given at the beginning of the series. Experienced divers made significantly more errors at 15.2m underwater than at either a land control or a more shallow exposure. This effect was independent of a speed accuracy tradeoff. This pattern of results is consistent with that reported by Davis, Osborne, Baddeley and Graham (1972) on mental arithmetic underwater. Their study tested divers on land and at 3m and 30m underwater in English coastal waters and found that although the total number of problems attempted did not vary, errors increased with ocean depth. The 9% increase in errors between 3m and 30m is consistent with the 8% increase between 4.6m and 15.2m found in this study. In common with the proposal of Kiessling and Maag (1962), Davis et al. suggested that mental performance is particularly vulnerable to the effect of nitrogen narcosis.

Poulton, Catton and Carpenter (1964) reported that mental performance, as exhibited in a card sorting test, was impaired in subjects breathing compressed air at 2 ats abs. However, in contrast, a subsequent study by Bennett, Poulton, Carpenter and Catton (1967) found that a significant increase in card-sorting errors was observed at the equivalent of (100 ft.) 4 ats abs. They concluded that the previous observation of decrement at 2 ats abs was at least partly due to factors other than the narcotic influence of the raised partial pressure of nitrogen. Rate of sorting was indicated as affecting performance efficiency. From the latter work it was posited that 3.2 ats abs represents the limit of unimpaired mental performance from the narcotic effect of nitrogen.

The results from the mental addition task in the present work suggest that performance efficiency may be degraded at only 2.6 ats abs, 15.2m ocean depth. However, the interactional effects of breathing compressed air and of water submergence remain unclear at the present time, pending further empirical investigation. As man begins to utilize the resources of the oceans to a greater extent and contemplates the possibility of prolonged habitation under the water (Bowen & Miller, 1967), the delimitation of human performance capabilities in such an environment becomes an increasing necessity. Results from the present work suggest not only that simple psychomotor performance deteriorates with submersion, but also that simple mental performance may be degraded at relatively shallow ocean exposures. Such observations merit further experimental investigation to elucidate the relative contribution of the various sources of performance decrement, particularly in the open ocean underwater environment.

References

Baddeley, A. D. Influence of depth on the manual dexterity of free divers: a comparison between open sea and pressure chamber testing. *Journal of Applied Psychology,* 1966, *50,* 81–85.

Baddeley, A. D. Diver performance and the interaction of stresses. *Underwater Association Report,* 1967, 35–38.

Baddeley, A. D., & Flemming, N. C. The efficiency of divers breathing oxy-helium. *Ergonomics,* 1967, *10,* 311–319.

Baddeley, A. D., DeFigueredo, J. W., Hawkswell Curtis, J. W., & Williams, A. N. Nitrogen narcosis and performance under water. *Ergonomics,* 1968, *11,* 157–164.

Bennett, P. B., Poulton, E. C., Carpenter, A., & Catton, M. J. Efficiency at sorting cards in air and a 20 per cent oxygen-helium mixture at depths down to 100 feet and in enriched air. *Ergonomics,* 1967, *10,* 53–62.

Blockley, W. V., & Lyman, J. H. Studies of human tolerance for extreme heat: III. Mental performance under heat stress as indicated by addition and number checking tests. Aerospace Medical Research Laboratory, *Technical Report 6022.* Wright-Patterson AFB, OH, 1950.

Bowen, H. M., Andersen, B., & Promisel, D. Studies of divers' performance during the SEALAB II project. *Human Factors,* 1966, *8,* 183–199.

Bowen, H. M., & Miller, J. W. Man as an undersea inhabitant and worker. *Ergonomics,* 1967, *10,* 611–615.

Brady, J. I. Surface practice, level of manual dexterity, and performance of an underwater assembly task. *Human Factors,* 1979, *21,* 25–33.

Davis, F. M., Osborne, J. P., Baddeley, A. D., & Graham, I. M. F. Diver performance: nitrogen narcosis and anxiety. *Aerospace Medicine,* 1972, *43,* 1079–1082.

Egstrom, G. H., & Weltman, G. Underwater work performance and work tolerance: final report. School of Engineering and Applied Science, UCLA, ENG-7427, Los Angeles, CA, 1974.

Egstrom, G. H., Weltman, G., Cuccaro, W. J., & Willis, M. A. Underwater work performance and work tolerance. Biotechnology Laboratory, *Technical Report No. 52,* School of Engineering and Applied Science, UCLA, Los Angeles, CA, 1973.

Fitts, P. M. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology,* 1954, *47,* 381–391.

Godden, D., & Baddeley, A. The commercial diver. In W. T. Singleton (Ed.), *The Study of Real Skills. Volume 2: Compliance and Excellence.* Baltimore: University Park Press, 1979.

Kerr, R. Movement time in an underwater environment. *Journal of Motor Behavior,* 1973, *5,* 175–178.

Kiessling, R. J., & Maag, C. H. Performance impairment as a function of nitrogen narcosis. *Journal of Applied Psychology,* 1962, *46,* 91–95.

Poulton, E. C., Catton, M. J., & Carpenter, A. Efficiency at sorting cards in compressed air. *British Journal of Industrial Medicine,* 1964, *21,* 242–245.

Streimer, I. Human performance characteristics in a complex manual task underwater. *Human Factors,* 1972, *14,* 95–99.

Weltman, G., Christianson, R. A., & Egstrom, G. H. Effects of environment and experience on underwater work performance. *Human Factors,* 1970, *12,* 587–598.

Weltman, G., Egstrom, G. H., Christianson, R. A., & Crooks, T. P. Underwater work measurement techniques. Biotechnology Laboratory *Technical Report No. 46,* School of Engineering and Applied Science, UCLA, Los Angeles, CA, 1969.

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