Anxiety impact on scuba performance and underwater cognitive processing ability

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Abstract
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Introduction: Anxiety is a substantial consideration in scuba diving and may influence a diver's performance and cognitive activities. This study aimed to simultaneously observe the effect of anxiety trait on actual diving performance and underwater cognitive processing ability.
Methods: Twenty-seven scuba divers completed the STAI-T component of the State-Trait Anxiety Inventory, and were subdivided into two groups on the basis of trait anxiety scores ≥ 39 and < 39. Scuba diving performance was measured in a pool. The completion time of four standardised scuba skills was recorded by a diving instructor. The correct completion rate and response time for a cognitive function assessment (number-Stroop test) were measured both on land ('dry') and underwater at 5 metres' fresh water.
Results: Anxiety trait was associated with prolonged mask clearing: mean completion time 7.1 (SD 3.2) s vs. 10.8 (5.4) s in low and high anxiety trait divers respectively ($P = 0.04$). Low (vs high) anxiety trait divers had reduced response times for the number-Stroop test: 49.8 (3.0) s vs. 53.3 (5.4) s ($P = 0.04$) dry, and 64.4 (5.0) s vs. 72.5 (5.5) s ($P < 0.01$) underwater. Performance of other skills was not significantly affected by trait anxiety nor correlated with the number-Stroop test results.
Conclusions: Personal anxiety trait prolongs mask clearing and underwater cognitive processing ability but the latter did not affect execution of other underwater scuba diving skills.

Introduction

The physical performance and cognitive function of scuba divers are affected by factors such as hydraulic pressure and water temperature.[1,2] Anxiety is a also substantial consideration in scuba diving and can influence divers' physiological and cognitive activities.[3] Anxiety can be defined as a negative emotional experience caused by stress[4] and can be exacerbated by equipment problems, poor physical conditions, or psychological factors.

In previous studies, it has been observed that levels of personal anxiety influence underwater motor skills[5–15] and that it is a good predictor of panic behavior underwater.[13] Panic occurs more often in participants with a trait anxiety score above 39 on the State-Trait Anxiety Inventory (STAI). This is a useful threshold score and can be employed *a priori* for the prediction of panic behavior in novice scuba students with an overall prediction rate of 83%.[13]

In addition, anxiety typically produces negative effects on the performance of cognitive tasks. Cognitive performance of divers in open water was significantly worse than that of subjects in a chamber; this finding was attributed to the anxiety caused by the uncertainty of being in an open sea situation.[16] Impaired attentional processes are among the primary cognitive functions involved in anxious individuals.[17] Attentional control theory (ACT) assumes that anxiety impairs the efficiency of the central executive component of the working memory system and proposes that anxiety impairs processing efficiency more than performance effectiveness.[18] Executive functions are a set of cognitive processes. The core executive functions include inhibition, working memory, and cognitive flexibility.[19] Higher order executive functions require the simultaneous use of multiple basic executive functions and include planning and fluid intelligence. The basic central executive functions most affected by anxiety include shifting and inhibition.[17] Anxious individuals are noted to have impaired inhibitory abilities and show poorer concentration than do non-anxious individuals. Coombes further reported that efficiency of motor planning was compromised only when the motor task to be performed needed increased attentional resources and greater precision.[20]

Table 1

Relevant characteristics of the study groups with a trait anxiety score < 39 (low anxiety trait) vs. ≥ 39 (high anxiety trait). Data are mean (SD). M = male; F = female; OWD = open water diver; AOWD = advanced open water diver; SR = stress rescue diver

Characteristic	Low anxiety trait *n* = 13	High anxiety trait *n* = 14	*P*-value
Gender	M = 10; F = 3	M = 7; F = 7	0.15
Age	21.5 (2.4)	24.1 (6.0)	0.17
Height (cm)	172.5 (7.2)	166.5 (7.9)	0.05
Weight (kg)	67.4 (10.2)	56.1 (10.7)	0.01
Trait anxiety score	32.8 (6.0)	44.9 (6.0)	< 0.01
Logged dives	12.5 (20.8)	38.0 (56.3)	0.13
Certification level	10 OWD; 3 AOWD	10 OWD; 3 AOWD; 1 SR	–

Inhibition, known as interference control, is often checked by the Stroop test.[21] This test asks subjects to cite the colour of the ink that a word is written in; the words all represent colours and it has been found that when a conflict between the word colour and the ink colour exists e.g., the word 'yellow' printed in red ink instead of yellow ink, the subjects take longer to answer correctly and are more prone to errors than when name matches the colour of the ink. This conflict represents an intense interference effect; in some tasks, the correct response requires inhibition to suppress the competing automatic response.[22] The Stroop test has been used to check cognitive function in different groups such as children,[23] the elderly,[24] and athletes,[25] has been proven helpful in investigating selective attentional processes in anxiety disorders[26] and has been applied in some scuba-diving-related studies in which the participants performed the test after diving in open water or within a chamber simulating the underwater environment.[27,28]

To simultaneously observe both the effect of an anxiety trait on actual diving performance and underwater cognitive processing ability to clarify their relationship, this study sought to confirm the following issues: (1) whether anxious divers would exhibit slower diving skills performance; (2) whether anxious divers would have inefficient cognitive processing ability in underwater conditions; and (3) whether the cognitive processing ability predicts execution ability of underwater skills.

Methods

The present study was approved by the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital, and written informed consent was obtained from all participants before the initiation of the experiment.

PARTICIPANTS

Twenty-seven scuba divers (mean age 22.9 (SD 4.7)) years were enrolled in this study and asked to complete a dive history questionnaire to determine their diving experience. The mean logged dives were 25.7 (44.2) for those divers. In accordance with trait anxiety thresholds predictive of panic[13] and respiratory distress,[29] the group was subdivided into participants with an anxiety trait score above 39 (STAI-T ≥ 39) and those with a score below 39 (STAI-T < 39). The Chinese version of State-Trait Anxiety Inventory was applied, which consists of 20 items rated on a 4-point Likert scale. There are seven anxiety-absent statements and 13 anxiety-present statements in the Trait scale. By summarizing all single scores for each item, the scale has a total score of between 20 and 80.

Relevant group characteristics are presented in Table 1.

TEST LOCATION

An outdoor diving pool was selected for the Stroop test. The pool had a length of 25 m and a depth of 10 metres' fresh water (mfw) at the deepest part; the water temperature was maintained at 27°C. Several platforms at different depths (2 and 5 mfw) were installed for training purposes. For safety reasons, only the shallow area of the pool (5 mfw) was used to conduct the Stroop test. To ensure that the instructor could fully observe underwater activity, scuba diving skills performance was measured in a general swimming pool.

EXPERIMENTAL PROCEDURE

The participants were told that the purpose of the experiment was to examine their perception and scuba performance. They completed the trait-anxiety part of the STAI before the formal test. The formal test included the diving skill tests (underwater) on one day, and on another day they undertook the Stroop tests on land and underwater in a random order).

NUMBER-STROOP TEST

During the underwater Stroop test, the participants wore standard recreational scuba equipment, working on the platform of the diving pool with a depth of 5 mfw. They observed a 10.1-inch liquid crystal display screen, placed 30 cm ahead at eye level, on which the experimental task was displayed. At the beginning of each trial, a cross at the center of the screen appeared for 1 s. The participants were instructed to fix their eyes on this cross until it disappeared. One to three numbers (numerals 1, 2 or 3) then appeared in the center of the screen for 2 s. The participants were asked to count the number of numerals (for example '33' would equal 2 numerals), as quickly as possible, and press the appropriate keys on a wireless keypad that they held. They pressed the different keys using fingers of one hand. The participants kept looking at the screen while using the keyboard. Response speed and accuracy were emphasized. If the response was too slow (> 2 s), the program moved onto the next trial. Each subject performed 84 trials. Several practice trials were administered before the real task. For the land-based ('dry') Stroop test, the participants were asked to complete the Stroop test under conditions similar to the underwater ones with the same display screen placed 30 cm ahead at eye level. The participants were in a sitting position.

DIVING PERFORMANCE TESTS

The diving skills completed were as follows:

Mask clearing: The instructor recorded the time taken by the participants to complete the task of removing, flooding, replacing and then completely clearing the mask underwater.

Buddy breathing: The instructor recorded the time taken for the participants to hold the wrist of a diving partner, take two to three breaths, and then pass the regulator over to their partner, who took two breaths and then handed it back.

Regulator recovery: The instructor recorded the time taken for the participants to remove the breathing regulator from their mouths, retrieve it, and insert it back into their mouths, after which they cleared it before taking their next breath.

Buoyancy control: The instructor recorded the total time taken to release all the air in the buoyancy compensator and then re-establish neutral buoyancy so as to remain in a hovering position for 3 s.

Performance times were measured by an instructor with a Dive Control Specialist Instructor license. The participants were provided with an opportunity to practice three times before each test. They were then required to perform the four skills in a random order. They were asked to perform these skills as quickly as possible after initiation by a hand sign from the instructor who observed from a position directly in front of the subject. The instructor decided when each performance was completed, and 'approved' each test before the participant moved to the next skill by giving an OK signal.

DATA ANALYSIS

The participants' trait anxiety levels were calculated as the sum scores of the items of the trait anxiety scales. Scuba performance was represented by the times taken for the diver to complete each of the diving skills (see above). The Stroop test response time was defined as the time to identify the number of characters by pressing the relevant button on the keypad and was measured after target appearance. Regardless of the accuracy of the answer, the time was recorded and summed. If the response was slower than 3 s, then 3000 ms was recorded. Response times less than 100 ms were omitted. The correct answer rate was defined as the percentage of accurate responses.

SPSS 20.0 statistical software (IBM Corp., Armonk, New York, USA) was used to analyse the study data. Means and standard deviations were calculated for all variables. The chi-square test and independent *t*-test were used to test the group differences (high-anxiety vs low-anxiety divers) in basic characteristic data. A two-way mixed ANOVA was used to determine the effect of anxiety state (≥ 39 and < 39) and environment (water vs. land) on Stroop test performance. The relationships between cognitive processing ability and scuba performance were measured using the Pearson correlation test. Statistical significance was set at $P < 0.05$.

RESULTS

The average completion times for each scuba skill and the average response times and accuracy for the Stroop test for the different STAI-T-level groups are listed in Table 2. The high-anxiety divers exhibited significantly longer completion times in the mask clearing skill ($P = 0.04$) and longer response times in the Stroop test on land (dry) ($P = 0.04$) and underwater ($P < 0.01$) than did the low-anxiety divers. The ANOVA results in Table 3 indicate that being underwater had a significant effect on accuracy and response times in the Stroop test. In addition, the participants' trait anxiety levels significantly affected response times. No significant interaction between underwater effect and trait anxiety level was observed. There were no strong or significant correlations between scuba skills performance and either speed or accuracy in the Stroop test.

Discussion

Increased anxiety has been observed to impair the psychomotor and cognitive performance of divers.[11,12] In the present study, the high-anxiety group took more time in mask clearing tests than did the low-anxiety group; hence, anxiety could affect some underwater performance. The reason for this result could be due to the trigeminocardiac reflex, which is triggered by facial immersion in cold water and causes an automatic gasp. Therefore, the participants could be at risk of inhaling water while clearing their masks. Such situations increase the anxiety state of people with relatively high trait anxiety levels. This result suggests that personal anxiety is a contributing factor for underwater performance of mask clearing.

In previous research, inhibitory control ability measured using the Stroop test was not affected by shallow water immersion at a 5 mfw.[28] However, the reaction times of Stroop tests at a 20 mfw were increased without statistically significant changes in error rates,[28] suggesting

Table 2
Scuba skill performance and number-Stroop test results in the study groups with a trait anxiety score < 39 (low anxiety trait) vs. ≥ 39 (high anxiety trait). Data are mean (SD). D = dry; U = underwater

Skill	Low anxiety trait (*n* = 13)	High anxiety trait (*n* = 14)	*P*-value
Mask clearing (s)	7.1 (3.2)	10.8 (5.4)	0.04
Buddy breathing (s)	34.8 (25.7)	43.3 (38.3)	0.50
Regulator recovery (s)	9.8 (3.0)	11.1 (3.5)	0.32
Buoyancy control (s)	22.3 (11.4)	26.9 (12.4)	0.33
Number-Stroop test			
Correct rate (D) (%)	95.6 (2.0)	95.4 (2.7)	0.84
Correct rate (U) (%)	88.9 (3.9)	86.1 (9.3)	0.33
Response time (D) (s)	49.8 (3.0)	53.3 (5.4)	0.04
Response time (U) (s)	64.4 (5.0)	72.5 (5.5)	< 0.01

Table 3
Two-way ANOVA evaluation of the effect of anxiety trait and environment (dry or underwater) on number-Stroop test results

Parameter	Underwater effect		Anxiety effect		Interaction	
	F	*P*	*F*	*P*	*F*	*P*
Percent accuracy	33.10	< 0.01	0.92	0.35	0.87	0.36
Response time	146.41	< 0.01	22.33	< 0.01	2.63	0.12

that the participants' cognitive systems slowed but accuracy remained constant. Inhibitory control ability is strongly involved in behaviour, which is crucial to safety and accident prevention in extreme environments and enables individuals to choose how to respond to special situations and how to behave.[19] In the present study, cognitive processing abilities, such as accuracy and response time, measured using the Stroop test, declined at a depth of 5 mfw. This negative result may have resulted from a lack of experience of the divers in the present study. In comparison, the participants in a previous study were all experienced and the result was that executive functions were not affected at a depth of 5 mfw.[28] Attentional control theory suggests that high-anxiety individuals sometimes show weak performance on tasks that demand attention because processing cognitive information is impaired by high anxiety levels.[17] This theory uses the working memory model, which is proposed to include a central executive and two slave systems.[30] Anxiety occupies resources of the central executive system leading to fewer processing resources being available for work demands. The high-anxiety group took significantly more time to complete the Stroop test in the present study, whereas their accuracy was not affected. This result was consistent with attentional control theory in that while anxiety might not influence the final decision, it nevertheless slows down the cognitive processes.

The results of the present study suggest that scuba skill performance was not significantly associated with cognitive processing ability as measured by the Stroop test, a basic psychological measure of inhibitory control.[19] However, it measures only a part of the executive function. In addition, the participants had all completed basic diving training, which included the diving skills tested in this study. A repetitive practice effect could have masked any effect of cognitive processing ability.

There are several limitations to our study. First, the number of subjects was small and there was a trend toward greater diving experience in the higher anxiety trait divers (Table 1). This could (arguably) bias against showing an effect of anxiety on diving skill performance. Second, performance time is not an ideal measurement parameter. Other methods of evaluating performance should be considered, such as the performance rating on a 7-point Likert scale.[14] Finally, this study was performed under relatively safe conditions, and so the results cannot be completely applied to true open-water conditions. To determine the relationship between activities performed underwater in real-world conditions and anxiety, more complex tasks should be designed. Testing in controlled conditions in open water might be required.

Conclusion

According to attentional control theory, working effectiveness should not be affected by anxiety whereas efficiency may be reduced. The present study verified that the high-anxiety group took more time in completing the underwater Stroop test tasks; however, the accuracy of that group was not affected. However, there was no correlation between diving skill performance and the Stroop test task. Further complex cognitive function tests may be required in future studies to completely represent the required real-world diving capabilities. The present study also indicated that high-anxiety divers took more time clearing their mask, so in regard to practical application, coaches may need to give these students more opportunities to practice this technique.

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