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THE EFFECTS OF HYPOCAPNIA ON PSYCHOMOTOR AND INTELLECTUAL PERFO--ETC(U)
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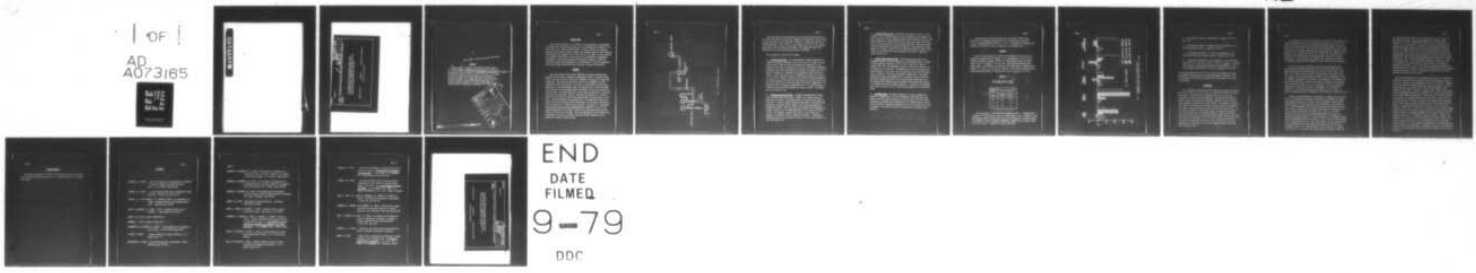

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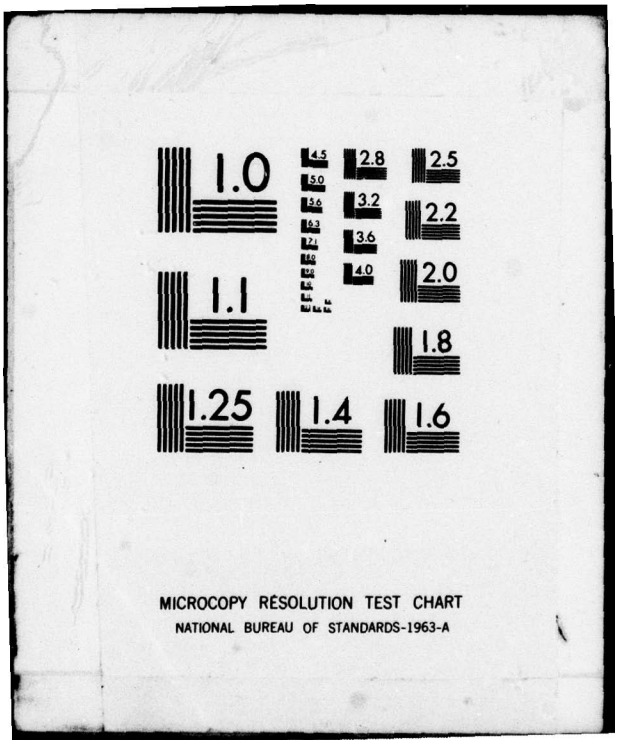
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No. FPRC/1368

Date June 1978

Title. THE EFFECTS OF HYPOCAPNIA ON PSYCHOMOTOR AND INTELLECTUAL PERFORMANCE

Abstract.

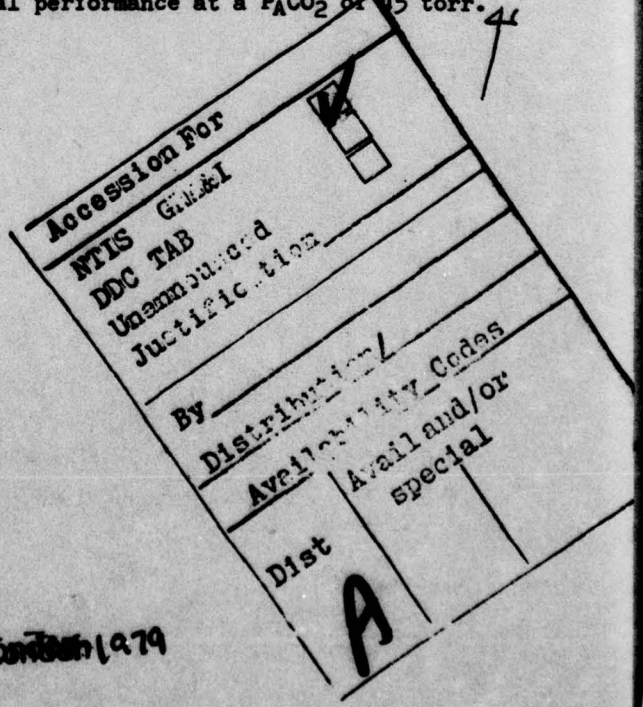
Nine subjects performed 5 psychomotor tasks (2 motor, 2 intellectual and 1 combined motor and short term memory) at 3 levels of P_ACO_2 (38.5, 25.0 and 15.0 torr) with voluntary hyperventilation at 20 $l.min^{-1}$.

Hyperventilation; hypocapnia; psychomotor performance; intellectual performance.

alveolar carbon dioxide tension

ABSTRACT

Nine subjects performed 5 psychomotor tasks (2 motor, 2 intellectual and 1 combined motor and short term memory) at 3 levels of (P_ACO_2) (~~38.5, 25.0 and 15.0 torr~~) with voluntary hyperventilation at 20 ~~l.min^{-1}~~ l/min. There were no performance decrements at P_ACO_2 levels of 38.5 and 25.0 torr. At a P_ACO_2 of 15.0 mm, there were no decrements of intellectual performance but there were highly significant decrements in motor performance. It is suggested that a lack of regional cerebral hypoxia, arising from compensating changes in regional cerebral blood flow, could be responsible for the preservation of intellectual performance at a P_ACO_2 of 15 torr.



INTRODUCTION

Some previous studies of the effects of hyperventilation on psychomotor performance have either been carried out in an unsteady state (Rushmer et al., 1941; Scow et al., 1950; Stoddart 1965), or without control over alveolar carbon dioxide tension (P_ACO_2) (Gellhorn and Spiesman, 1935 and 1935; Gellhorn and Kraines, 1937; Rushmer et al., 1941; Scow et al., 1950), or have neglected the possible contribution of muscle spasm to the decrement in psychomotor performance. This report describes an experiment designed to study the effects of steady state hypocapnia on the performance of several psychomotor tasks which ranged from mainly motor in nature to mainly intellectual.

METHODS

Nine male subjects from the RAF Institute of Aviation Medicine, aged between 21 and 26 years, performed 5 psychomotor tasks at 3 levels of P_ACO_2 (38.5, 25.0 and 15.0 torr). The order of exposure to each level of P_ACO_2 was randomized. Each task was carried out once at rest (CONTROL) and twice (replicates T1 and T2) during a 1 hr period of hyperventilation with P_ACO_2 regulated at the predetermined level. The subject sat in a modified dental chair and wore an appropriately sized cloth helmet to which was attached an oronasal mask. The inspiratory hose of this mask was connected to the hyperventilation circuit shown in Fig.1. Gas flow was adjusted by a reducing valve until the required inspiratory minute volume ($\dot{V}_I$) was shown on a rotameter. Subjects breathed at 20 breaths $.min^{-1}$; the inspiratory signal was a bleep heard in one earphone of the cloth helmet. At each bleep, the subject had to inspire until a reservoir bag was empty. The sensor of a quadrupole (Centronics) respiratory mass spectrometer was attached to a port in the oronasal mask and the CO_2 channel output of the mass spectrometer was displayed on a Devices pen recorder. The mass spectrometer was calibrated with gas mixtures, previously analysed using Lloyd Haldane apparatus, which spanned the expected range of P_ACO_2.

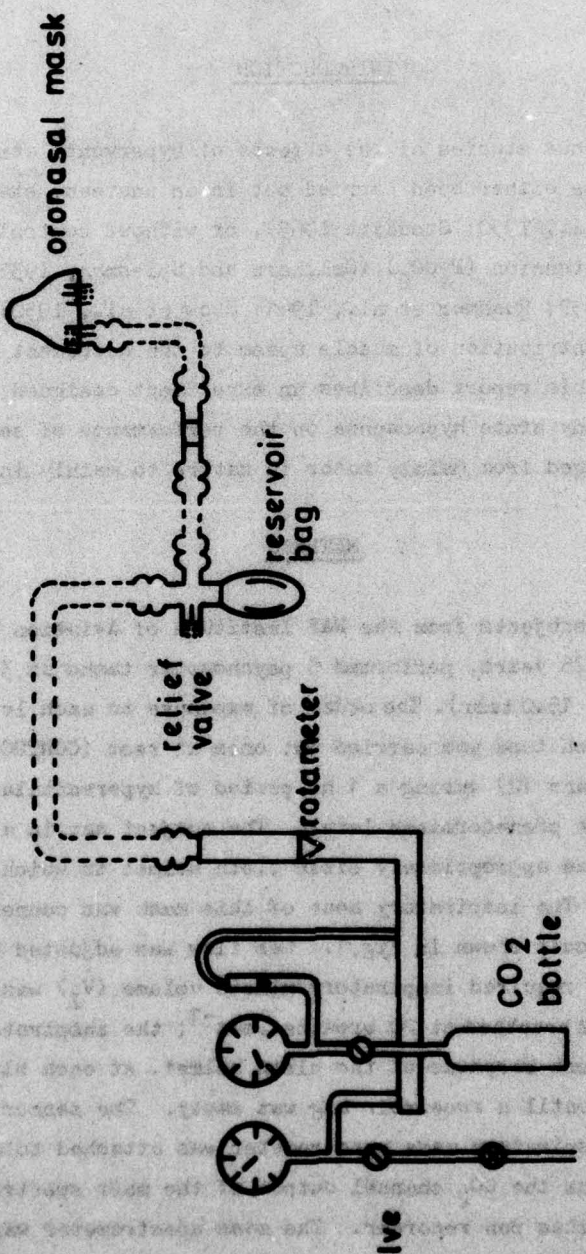


Fig 1. Hyperventilation Circuit

After the control (free-breathing) period, subjects hyperventilated at 40 $\ell.min^{-1}$ until their end tidal P_{CO_2} ($P_{ET}CO_2$) had reached the required level; CO_2 was then added to the inspirate to maintain a steady state during continued hyperpnoea. After 10 min, $\dot{V}_I$ was reduced to 20 $\ell.min^{-1}$ and inspired P_{CO_2} (P_ICO_2) was also lowered accordingly. When $P_{ET}CO_2$ had again been steady for 2 min, the experiment was allowed to proceed.

The 5 psychomotor tasks were as follows:

a. <u>A Digit Recall Task</u>. In a 5 min period, a subject was read 120 numbers in batches of between 6 and 10 at a time, at a speed of 2 numbers a second. Each list was pre-recorded and replayed on a tape recorder, the output of which was fed to one of the subject's earphones. Immediately each batch of numbers was finished, the subject was told to punch the numbers on a keyboard, and the keyboard output was fed to a printer. Each 5 min period had 15 randomly placed lists of 3 each of 6, 7, 8, 9 and 10 digits. Marking of the task was arbitrarily applied as follows: one mark was given for each digit in the correct place; one mark was subtracted for each extra digit at the end or beginning of an otherwise correct sequence; transpositions of 2 or 3 digits scored 1 or 2 marks respectively; and anything else scored no marks. The maximum score was therefore 120.

b. <u>A Manikin Orientation Task</u>. A manikin was projected on a television screen, either on its feet or upside down, facing towards or away from the subject, and holding a disc or a square in its right or left hand. A disc or a square was also projected at the bottom of the screen and the subject had to decide in which hand the manikin was holding this symbol. When the subject had decided upon the answer, he pressed a button on the corresponding side of an answer box in front of him. The response, reaction time and the correct answer were relayed on to magnetic tape for subsequent analysis. A manikin was presented every 6 sec and remained on view for 3 sec; each exposure to the task lasted 3 min.

c. A Rotary Pursuit Task. The subject was required to keep a 1.5 mm diameter tip of a metal pointer on a 12.5 mm diameter metal contact area near the edge of a 254 mm diameter bakelite disc rotating at 20 rpm. The metal pointer had a plastic handle with a joint that allowed free movement of the pointer shaft in the vertical plane only. The pointer shaft was 100 mm long beyond the handle and ended in a 25 mm section at right angles to the shaft. Each 0.1 sec of electrical contact in every 10 sec period was counted and the total displayed on a printer. Each test period lasted 3 min.

d. A Verbal Transformation Task. This task was generated by pre-programmed magnetic tape and displayed on a television screen. A number of short sentences was shown, one at a time, followed by a pair of letters (AB or BA). The sentences claimed to describe the order of the 2 letters, e.g. A follows B. The subject had to read the sentence and decide whether it was a true or false description of the pair of letters which followed it. There were 64 possible combinations. The subject indicated his answer by pressing one of 2 buttons in front of him, the left button signifying 'false' and the right button signifying 'true'. The answer given, response time and problem identification were relayed on to magnetic tape for subsequent analysis. A statement was displayed once every 9 sec for 6 sec at a time and each session of the task lasted 3 min.

e. A Pegboard Task. The Purdue pegboard is a task of manipulative dexterity. Subjects had to build 20 assemblies, each made with a peg, washer, collar and washer placed on top of each other, with both hands as rapidly as possible; each assembly had to be complete before the next could be started. Successive assemblies were built in single file towards the subject. The time to build the 20 assemblies was measured using a stopwatch.

Subjects had one training session on all the tasks combined with experience of normocapnic hyperventilation. Subjects also underwent 4 further training sessions on tasks b, c and d. These training sessions were adequate for subjects to attain a plateau on the learning curve.

RESULTS

Seven of the 9 subjects were unable to distinguish between an hour of normocapnic hyperventilation ($P_{ET}CO_2$ = 38.5 torr) and an hour of hypocapnic hyperventilation at a $P_{ET}CO_2$ of 25.0 torr. Eight subjects correctly identified the run at a $P_{ET}CO_2$ of 15.0 torr; they experienced paraesthesiae and carpal spasm. Two subjects also reported facial and abdominal spasms and one subject felt faint at the end of his exposure. Four subjects commented that the paraesthesiae seemed to diminish with time at a $P_{ET}CO_2$ of 15.0 torr.

Table 1

Mean $P_{ET}CO_2$ Values (n=90)

Nominal $P_{ET}CO_2$	Measured $P_{ET}CO_2$ torr	
torr	Mean	SD
38.5	38.6	0.9
25.0	25.1	1.0
15.0	15.6	1.0

The mean $P_{ET}CO_2$ in each condition is shown in Table 1. The statistical treatment of the data was by split plot ANOVA, split for the 3 periods in each experimental session because these could not be randomized. The mean changes in performance in the 2 hypocapnic conditions compared to the control states are shown in Fig.2. Compared to control, there was:

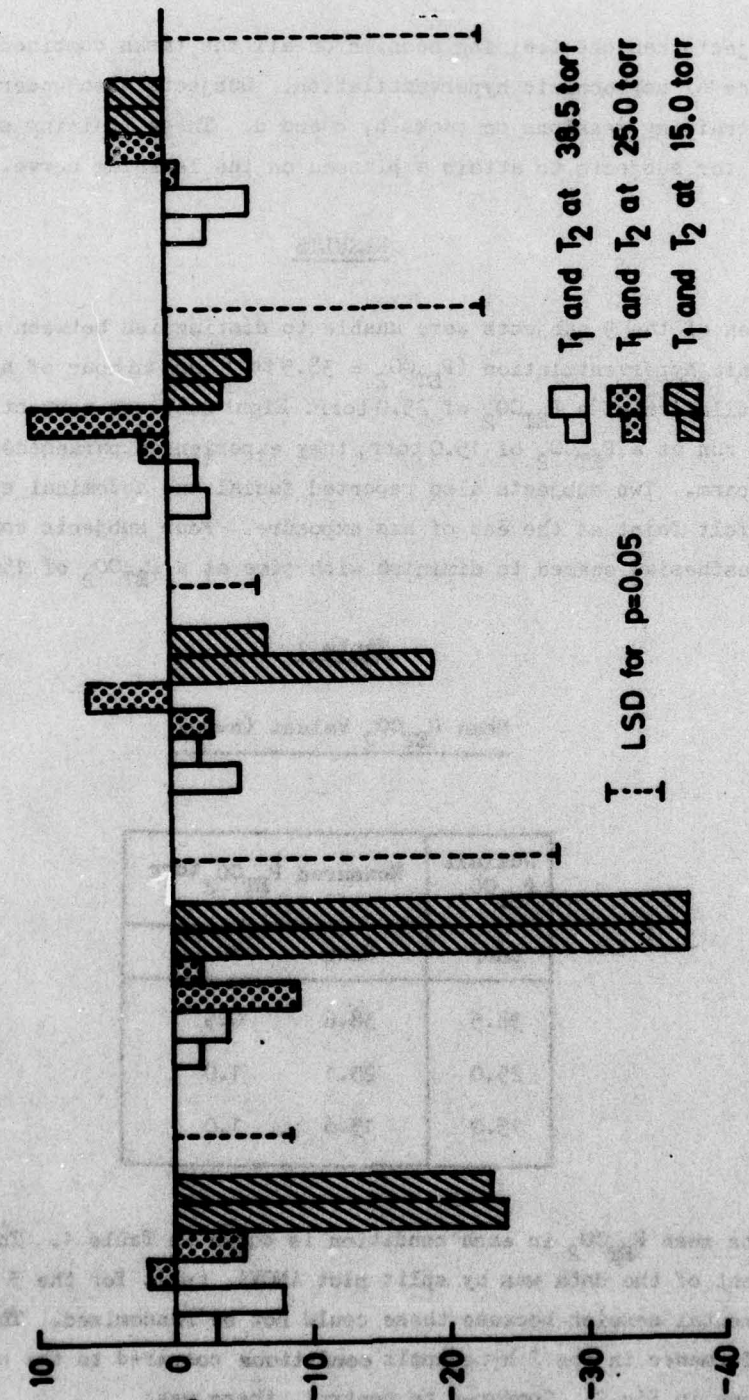


Fig 2. Percentage change in performance from CONTROL to three steady state levels of P_ACO_2

a. No significant change in performance at a $P_{ET}CO_2$ of 38.5 or 25.0 torr.

b. No significant change in response time to the manikin or verbal transformation tasks at a $P_{ET}CO_2$ of 15.0 torr.

c. A significant decrement ($P < 0.001$) in performance of the digit recall and rotary pursuit tasks at a $P_{ET}CO_2$ of 15.0 torr.

d. A significant decrement in the performance of the Purdue pegboard at T1 ($P < 0.001$) and at T2 ($P < 0.05$) at a $P_{ET}CO_2$ of 15.0 torr; there was also a significant improvement in performance ($P < 0.05$) of the pegboard task between T1 and T2 at a $P_{ET}CO_2$ of 15.0 torr.

Two subjects contributed most of the errors in the manikin and verbal transformation tasks; however, further non-parametric analysis of the errors failed to demonstrate any significant relationship to the level of hypocapnia.

DISCUSSION

The 5 psychomotor tasks were chosen because they ranged from mainly motor with little intellectual input, to mainly intellectual with little motor input. They also had the advantage that they could easily be integrated for use in the same experiment. The digit recall task was used as a short term memory task (Baddeley, 1966) but also had a large motor component in pressing the answer buttons. The number of digits in each batch was randomly varied so that no pattern could be discerned by the subject, thus preventing an answer technique from being evolved. It is therefore difficult to say whether short term memory is affected by severe hypocapnia, since the decrement measured could have been motor. The rotary pursuit task was described by Geblewiczowa (1969) as 'the best opportunity for experiments that are free of intellectual processes'. In the same way, Fleischmann and Ellison (1962) concluded that building assemblies with both hands on the Purdue pegboard measured finger and manual dexterity only.

On the other hand, the only motor activity involved in the manikin and verbal transformation tasks was in pressing one answer button each time a decision was made; the activity involved was therefore mainly intellectual. Denison (1974) and Byford (1974) confirm that the manikin test is sensitive to hypoxia, and to hypoxia combined with hyperventilation. Baddeley (1968); Baddeley et al. (1968); and Folkard (1975) report that the verbal transformation task is sensitive to nitrogen narcosis, noise and to diurnal variations. It would therefore be expected that the manikin and verbal transformation tasks would be sensitive to the stress of severe hypocapnia.

The results from this experiment confirm that normocapnic hyperventilation and hypocapnic hyperventilation to a P_ACO_2 of 25 torr fail to degrade psychomotor performance (Balke and Lillehei, 1956; Gibson, 1977; Rahn et al., 1946; Stoddart, 1965) and that hypocapnic hyperventilation to a P_ACO_2 of 15 torr causes a marked decrement in motor performance (Grant and Goldman, 1920; Rahn et al., 1946). The improvement in performance on the Purdue pegboard, with continued hypocapnia, corresponds with the unsolicited, subjective comment, by 4 of the subjects, that the paraesthesiae diminished in severity with continued hypocapnia. The improvement is unlikely to be a training effect because exposure to the 3 levels of P_ACO_2 was randomized and the improvement only occurred at a P_ACO_2 of 15 torr.

However, the demonstration that hypocapnia at a P_ACO_2 of 15 torr has no effect on intellectual performance, as measured by the manikin and verbal transformation tasks, is at variance with the findings of other workers (Balke and Lillehei, 1956; Rahn et al., 1946; Rushmer et al., 1941; Stoddart, 1965). Gellhorn & Spiesman (1935 & 1935) & Gellhorn & Kraines (1937) described alterations in hearing, vision and word association with hypocapnia, but did not control ventilation, or measure P_{CO_2}. Rahn et al., (1946) measured the effects of controlled hyperventilation with oxygen, at a simulated altitude of 30,000 ft, on the performance of 4 psychomotor tasks; they found marked effects in 3 of the tasks at a P_ACO_2 of 20 torr. Nevertheless, these 3 tasks were motor rather than intellectual and would therefore have been adversely affected by the carpal spasm expected at this level of hypocapnia (Gotoh et al., 1965) and which occurred (Rahn et al., 1946). In the same way, the tracking task used by Balke and Lillehei (1956) was

one requiring precise hand and foot co-ordination, and the effects on performance would have been largely determined by muscular spasm. Rushmer et al. (1941) studied the effects of 2 min of maximum ventilation on the performance of a pegboard task and Stoddart (1965) also studied performance during the fall in P_ACO_2 during hyperventilation. Scow et al. (1950) restricted the level to which P_ACO_2 could fall by allowing their subjects to rest for 2 min each time they developed carpopedal spasm, and by measuring performance only after the end of hyperventilation. Thus, these previous experiments were carried out either in the unsteady state, or without adequate respiratory control, or apparently neglected the contribution of muscle spasm to the decrement in psycomotor performance. On the other hand, the present experiment has been carried out in a steady state, and with the knowledge that normocapnic hyperventilation at the level of ventilation chosen did not cause any psychomotor decrement (Gibson, 1977).

A speculative explanation for the apparent preservation of intellectual function (as measured by the manikin and verbal transformation tasks) would be as follows. During hypocapnia, there is a reduction in cerebral blood flow (CBF) and several authors have produced evidence for overall cerebral hypoxia (e.g. Gotoh et al., 1965; Harp and Wollman, 1973). Gottstein et al. (1970) measured a cerebral venous oxygen tension (P_VO_2) of 20 torr during hyperventilation in humans to an arterial P_{CO_2} (P_ACO_2) of 16 torr. Thews (1963) suggested that a cerebral P_VO_2 of 17 to 19 torr would be equivalent to a lowest cerebral tissue P_{O_2} of 3 torr, which would be a critical level for the brain. Further work by Lübbers (1968) indicated that cerebral tissue P_{O_2} might normally be lower than that calculated by Thews; it is therefore possible that the P_VO_2 of 20 torr measured by Gottstein (1970) does not represent the critical level of cerebral hypoxia hitherto proposed. In addition, Lassen (1977) reports that regional CBF changes locally 'in a meaningful manner with functional changes in the region recorded from'. He recorded 'complex patterns of regional CBF increase' with such activities as memorization of numbers, visual perception and verbal perception. If this mechanism were to be maintained during hypocapnia, it could explain the preservation of intellectual performance during severe hypocapnia. Degradation of the motor performance, however, can be attributed entirely to the local muscular effects of the hypocapnia.

ACKNOWLEDGEMENTS

The author is grateful to Miss H. M. Ferres and her staff for carrying out the statistical analyses and to Mr R. G. Green for advice on the psychomotor tasks.

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