

Effects of Voluntary Fluid Intake Deprivation on Mental and Psychomotor Performance

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Aim To assess if there is deterioration in mental and psychomotor performance during 24-hour voluntary fluid intake deprivation.

Methods A battery of computer generated psychological tests (Complex Reactionmeter Drenovac) was applied to 10 subjects to test light signal position discrimination, short-term memory, simple visual orientation, simple arithmetic, and complex motor coordination. We measured total test solving time, minimum (best) single task solving time, total ballast time, and total number of errors. Mood self-estimate scales of depression, working energy, anxiety, and self-confidence were used to determine the emotional status of subjects. During the first day of the experiment, subjects had free access to drinks. After a 48-hour interval, subjects voluntarily abstained from fluid intake for 24 hours. During that period, the testing was performed 7 times a day, at 3-hour intervals, except during the night. Z-transformation of the results enabled the comparison of 50 dependent measurements on the same subjects.

Results During dehydration, there was significant deterioration in total test solving time, minimum single task solving time, and total ballast time. No significant deterioration was found by mood self-estimate scales, except on the scale of energy at 23:00 hours.

Conclusion Voluntary 24-hour fluid intake deprivation led to deterioration in objective parameters of psychological processing, but not in subjective parameters. The results suggest that the duration of fluid intake deprivation can be a useful indicator of mental and psychomotor deterioration level.

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There are many life situations when unfavorable circumstances influence the hydration regime. The problem of dehydration in humans has been extensively studied and the physiology of this phenomenon is generally well understood (1-6). The neurophysiological mechanisms affecting mental and psychomotor performance in dehydration are extremely complex and include structural and functional changes of neuronal and glial cells (7-10).

Mental and psychomotor processing deterioration and the dynamics of its onset during dehydration are of great practical importance but are still not completely understood. Deteriorated mental and psychomotor processing could endanger performance of tasks that require high precision, are performed under forced regime and rhythm, permit no mistakes, or involve sophisticated, expensive, or dangerous equipment. Deteriorated psychological processing was described in experiments in which dehydration was either heat stress induced (11-14) or induced by a combination of heat, stress, and exercise (15-17). Both stressors were necessarily multifactorial and could not represent a valid experimental frame for studying dehydration. In rare experiments in which dehydration was a consequence of voluntary fluid intake deprivation, only deterioration in subjective parameters was found (18-20).

Testing mental and psychomotor performance in possibly dehydrated subjects in a real-life situation and under complex circumstances would be most impractical. In such situations, it would be practical to measure a simple parameter indicating deterioration level of mental and psychomotor abilities, at the same time predicting the level of expected performance efficiency.

The objective of this study was to measure the deterioration in mental and psychomotor performance and dynamics of its onset during voluntary 24-hour fluid intake deprivation by objective and subjective parameters of psychological processing under laboratory conditions.

Subjects and methods

Subjects

The study included 10 male, non-paid volunteers, of an average age of 25 (range 21 to 30). All subjects were healthy, without injuries, and not taking any psychoactive substances 30 days before and during the experiment. The subjects were medical students or young physicians interested in the experiment and motivated by the possibility to use the same equipment in their future research. All subjects signed an informed consent and the study was previously approved by the Ethical Committee of the Split University Medical School, Croatia.

Methods

The study was conducted at the Naval Medical Institute of the Croatian Navy, Split, Croatia, in autumn 2005, in a separate and especially prepared room, which provided the isolation for two subjects at a time. Psychological testing was performed at 7 time points a day during two days of the experiment. Testing started at 08:00 hours and were conducted at 3-hour intervals, except during the night rest from 23:00 to 08:00 of the next day, with a 48-hour interval between the days. During the first day, the subjects were allowed to freely take drinks. During the second day, subjects refrained from any fluid intake. The possibility of cheating was absolutely excluded during the entire experiment because of controlled environment of the test room. During both days of the experiment, all activities of the subjects were reduced to resting and reading.

The daily intake of food during the experiment was previously defined by an experienced nutritionist to 10 460 KJ (2500 KCal), served at usual times (09:00, 13:00, and 19:00 hours). Daily water intake in food mass was 500.0 ± 43.4 g. The menu did not include any food subjects would dislike or reject for any reasons. The room was adequately lighted and furnished to enable

comfort. The room temperature was adjusted to 22°C, which was within the temperature comfort frame for light sitting work of lightly dressed persons (21).

Psychological testing of objective parameters

Complex Reactionmeter Drenovac (CRD-series), a battery of computer generated psychological tests, was used to measure objective parameters of psychological performance (22). Prior to the experiment, subjects practiced operating on CRD-series instruments for 3 consecutive days, two hours a day, and reached stable baseline results, without a tendency of improvement.

In several earlier studies (23-34), CRD-series was able to detect even the slightest mental and psychomotor changes. CRD-series is based on chronometric principles (22,34,35). It consists of the software and four instruments. Out of its 34 standard tests, 5 representative tests, given in order from the simplest to the most complex one and covering a broad spectrum of mental and psychomotor processing, were selected for the study. The subjects were instructed to solve the tests as accurately and as quickly as possible. At each single testing, each subject was assigned a new variety of each of the tests, so any possible memorizing of the problem sequences was excluded. CRD-series tests used in this experiment were: light signal position discrimination, short-term memory, simple visual orientation, simple arithmetic, and complex motor coordination.

Four parameters were recorded: total test solving time, minimum (best) single task solving time, total ballast (representing "lost" time expressed as a sum of differences between minimum single task solving time and each of all other single task solving times), and total number of errors committed during any of the tests. Total test solving time and minimum single task solving time are descriptors of speed, reliability (accuracy), and mental endurance; total ballast is a descriptor of stability; and total number of errors of concentration and alertness. Thus, these

descriptors could be understood as descriptors of speed (total test solving time, minimum single task solving time) and variability of reactions (total ballast, total number of errors).

CRD-series measures the time needed to perform and solve single tasks in the tests, as well as the complete test. The time of solving psychological tests of different complexity provides information about organizational and functional characteristics of individual psychological processes, and therefore on organization and quality of psychological mechanisms hidden behind cognitive and psychomotor functions. A strong correlation was found between the results on CRD-series tests and cognitive and psychomotor functions (22,34). In each of the 5 tests, consisting of 30 to 60 single tasks, subjects were required to provide the correct answer by pressing the corresponding light-emitting diodes with their dominant hand as quickly as possible. The correct answer would automatically start the next single task. A more detailed description of CRD-series tests could be found elsewhere (22,23).

Psychological testing of subjective parameters

The current emotional status of subjects was measured by printed questionnaires with 10-point mood self-estimate scales of depression, working energy status, anxiety, and self-confidence by Wessman and Ricks (36), modified by Drenovac and Horga (37). On each of the scales, subjects were asked to choose the statement which best describes their actual mood. The questionnaires were filled in anonymously, dropped into a sealed box, and collected after the experiment. Self-estimate testing was performed at the same intervals, but prior to the testing on CRD-series, in order to avoid a possible negative feedback. Subjects were informed that all results on CRD-series would be good, and that the differences between them would be normal and expected. In one of the earlier studies it was noticed that subjects were highly competitive while solving the CRD-series (23). Besides, it is known that

subjects, when tested under experimental conditions, are more engaged than during the practicing period (37). Thus, the values even better than the control were also expected. Special attention was paid to a possible drop of motivation. The experimenters were constantly observing subjects' reactions, such as possible disappointment, anger, and drop of motivation since these reactions might influence the results.

Statistical analysis

Statistica 7.1 software package (StatSoft, Inc., Tulsa, USA) was used to perform statistical anal-

ysis of the data. Z-transformation of the results for total test solving time, minimum single task solving time, total ballast, and total number of errors on all 5 tests enabled the comparison of 50 dependent measurements on the same subjects collected on both days of the experiment. Differences between variances of the data obtained at different points of testing and between the two days of the experiment were estimated by General Linear Models ANOVA for repeated measures and LSD *post-hoc* test (CRD-series data) and by ANOVA for repeated measures with Bonferroni correction (mood self-estimates). Statistical values were considered significant at $P < 0.05$.

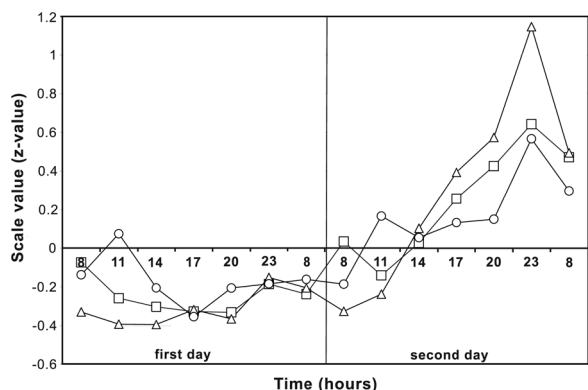


Figure 1. The results of testing (z-values) of mental and psychomotor performance on CRD-series during the first (free hydration) and the second (voluntary 24-hour fluid intake deprivation) day of the experiment ($n = 10$). Squares – total test solving time; triangles – minimum single task solving time; circles – total ballast (“lost” time, a sum of differences between minimum single task solving time and each of all other single task solving times).

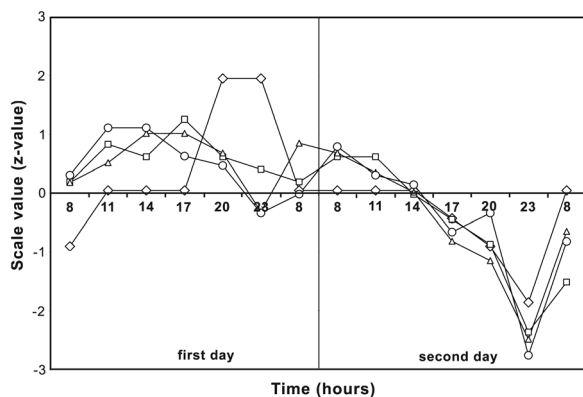


Figure 2. The results of mood self-estimate testing (z-values), on the scales of depression, working energy, anxiety, and self-confidence during the first (free hydration) and the second (voluntary 24-hour fluid intake deprivation) day of the experiment ($n = 10$). Rhombs – depression; squares – energy; triangles – anxiety; circles – self-confidence.

Results

When all 7 time points of measurements were compared between the two days of the experiment, statistically significant deterioration was found on the second day for total test solving time ($F = 16.99$, $df = 13$, $P < 0.001$, repeated measures ANOVA), minimum single task solving time ($F = 25.97$, $df = 13$, $P < 0.01$), and total ballast ($F = 4.77$, $df = 13$, $P < 0.001$, Figure 1). On the first day, no statistically significant difference was found among all points of measurement for total test solving time ($F = 2.17$, $df = 6$, $P = 0.06$), minimum single task solving time ($F = 1.36$, $df = 6$, $P = 0.231$), and total ballast ($F = 1.47$, $df = 6$, $P = 0.187$), but the difference became statistically significant during dehydration ($F = 12.17$, $df = 6$, $P < 0.01$; $F = 19.22$, $df = 6$, $P < 0.001$; and $F = 4.59$, $df = 6$, $P < 0.001$, respectively, Figure 1). A significant increase in mean value (z-scores, first day vs second day) was noticed on the second day of the experiment for total test solving time at 14:00 (-0.3 ± 0.96 vs 0.03 ± 0.98 , $P = 0.001$), 17:00 (-0.33 ± 0.84 vs 0.26 ± 0.89 , $P < 0.001$), 20:00 (-0.33 ± 0.88 vs 0.43 ± 1.12 , $P < 0.001$), and 23:00 hours (-0.19 ± 0.95 vs 0.64 ± 0.96 , $P < 0.001$). For minimum single task solving time, a significant increase was noticed at 11:00 (-0.39 ± 0.89 vs -0.24 ± 0.89 , $P = 0.01$), 14:00 (-0.39 ± 0.81

vs 0.10 ± 0.76 , $P < 0.001$), 17:00 (-0.32 ± 0.83 vs 0.39 ± 0.80 , $P < 0.001$), 20:00 (-0.37 ± 0.9 vs 0.57 ± 0.99 , $P < 0.001$), 23:00 (-0.15 ± 0.94 vs 1.14 ± 1.04 , $P < 0.001$), and at 08:00 hours of the next day (-0.20 ± 1.15 vs 0.49 ± 1.02 , $P < 0.001$). For total ballast, a significant increase was noticed at 17:00 (-0.35 ± 1.14 vs 0.13 ± 1.07 , $P = 0.008$), 20:00 (-0.21 ± 0.96 vs 0.15 ± 1.02 , $P = 0.013$), 23:00 (-0.18 ± 0.92 vs 0.57 ± 0.89 , $P < 0.001$), and 08:00 hours of the next day (-0.16 ± 1.07 vs 0.30 ± 0.99 , $P = 0.010$).

No significant deterioration of mood self-estimate was found on the second day of the experiment (Figure 2), except on the scale of energy at 23:00 hours ($P = 0.016$).

Discussion

Our study showed that mental and psychomotor abilities deteriorated during progressive 24-hour voluntary dehydration. During the second day of the experiment, deterioration in the performance on CRD-series tests was expressed as an increase in total test solving time, minimum single task solving time, and total ballast. All changes became statistically significant 9 hours after the beginning of the second day of the experiment. The descriptors of speed, reliability (accuracy), and mental endurance deteriorated 3 hours (minimum single task solving time) and 6 hours (total test solving time) after the beginning of fluid intake deprivation. The descriptor of stability (total ballast), indicating a change in the problem-solving strategy, deteriorated after 9 hours of dehydration. Statistical analysis of total number of errors did not provide any reliable conclusions. Deterioration did not occur on all CRD-series tests, in all the subjects, or at every point of testing. The trend of deterioration was clearly marked on the second day of the experiment, especially toward its end. However, no clear dose-response type changes were found with the increase in the time during which the subjects were deprived of fluid intake.

The experiments in which a deteriorated mental and psychomotor performance was a consequence of dehydration induced by exercise, heat stress, or increased ambient temperature (11-17,38) must have been necessarily influenced by fatigue, increased body temperature, and increased ambient temperature as additional stressors. An experiment in which dehydration would be a consequence of voluntary refraining from fluid intake would be free of such stressors and represent a valid study frame. Such an experimental model was used in earlier studies (18-20), but only subjective changes of mental and psychomotor processing were found, possibly because the psychological tests used were not sensitive enough. On the contrary, no changes of mood self-estimates were found in this study, except on the scale of energy at 23:00 hours of the dehydration day. However, the trends of deterioration were clearly marked. Further research with a greater number of subjects could clarify the real significance of such trends. A recent report (38) revealed statistically significant deterioration in cognitive performance in the dehydrated subjects, but this study addressed the beneficial effect of hydration rather than the effects of voluntary dehydration.

Based on the present results, it could be concluded that, in situations when more complex psychological testing is not possible, the duration of fluid intake deprivation could serve as a useful indicator of mental and psychomotor deterioration level. The present study suggests that deteriorated mental and psychomotor processing occurs early after the beginning of inadequate fluid intake, pointing to the importance of a regular and perhaps planned regime of fluid intake (39).

The primary limitation of this study was the small number of subjects, at least when mood self-estimates are concerned. The comparison of performance between the two days of the experiment on each of 5 CRD-series tests would not be reliable, so the parameters (z -scores) obtained on all CRD-series tests (total test solving time, min-

imum single test solving time, total ballast, and total number of errors) were compared. Another limitation is that only 5 out of 34 CRD-series tests were used and only 4 out of 27 parameters analyzed.

Hormonal and metabolic responses to this type of acute stress are complex and include a variety of changes such as the release of cortisol and catecholamines, activation of glucagon, and growth hormone (40). The research of this kind of responses was beyond the scope of the present study. Besides, we investigated only the effects of dehydration, not of a rehydration regime, so we have no data about the recovery of psychological performance. A similar group of voluntary dehydrated subjects was investigated by Roky et al (41). In their subjects, Ramadan fasting (refraining from drinking and eating from sunrise to sunset) did not dramatically affect the metabolism of lipids, carbohydrates, and proteins, or the daily mean of hormonal serum levels, but affected the circadian distribution of body temperature, cortisol, melatonin, and glycemia.

Further research, with a greater number of subjects and a broader spectrum of CRD-series tests, which would include other dehydration parameters, such as body mass loss, urine osmolality, cortisol in saliva, and hematocrit, might confirm the validity of the present conclusions and reveal other possible indicators of mental and psychomotor deterioration level during dehydration.

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