Effect of water deprivation on cognitive-motor performance in healthy men and women

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Szinnai, Gabor, Hartmut Schachinger, Maurice J Arnaud, Lilly Linder, and Ulrich Keller. Effect of water deprivation on cognitive-motor performance in healthy men and women. Am J Physiol Regul Integr Comp Physiol 289: R275–R280, 2005; doi:10.1152/ajpregu.00501.2004.—Whether mental performance is affected by slowly progressive moderate dehydration induced by water deprivation has not been examined previously. Therefore, objective and subjective cognitive-motor function was examined in 16 volunteers (8 females, 8 males, mean age: 26 yr) twice, once after 24 h of water deprivation and once during normal water intake (randomized cross-over design; 7-day interval). Water deprivation resulted in a 2.6% decrease in body weight. Neither cognitive-motor function estimated by a paced auditory serial addition task, an adaptive 5-choice reaction time test, a manual tracking test, and a Stroop word-color conflict test nor neurophysiological function assessed by auditory event-related potentials P300 (oddball paradigm) differed (P > 0.1) between the water deprivation and the control study. However, subjective ratings of mental performance changed significantly toward increased tiredness (+1.0 points) and reduced alertness (−0.9 points on a 5-point scale; both: P < 0.05), and higher levels of perceived effort (+27 mm) and concentration (+28 mm on a 100-mm scale; both: P < 0.05) necessary for task accomplishment during dehydration. Several reaction time-based responses revealed significant interactions between gender and dehydration, with prolonged reaction time in women but shortened in men after water deprivation (Stroop word-color conflict test, reaction time in women: +26 ms, in men: −36 ms, P < 0.01; paced auditory serial addition task, reaction time in women: +58 ms, in men −31 ms, P = 0.05). In conclusion, cognitive-motor function is preserved during water deprivation in young humans up to a moderate dehydration level of 2.6% of body weight. Sexual dimorphism for reaction time-based performance is present. Increased subjective task-related effort suggests that healthy volunteers exhibit cognitive compensating mechanisms for increased tiredness and reduced alertness during slowly progressive moderate dehydration.

DEHYDRATION IS A STATE of total body water deficit due to primary water losses (e.g., sweating or gastrointestinal losses) or to inadequate water intake (16). The severity of acute or subacute dehydration is characterized by the percentage of body weight loss (20). However, there is no generally accepted definition of different degrees of dehydration in adults. Mild dehydration has been defined as 1–2% loss of body weight (8, 14, 29), while severe dehydration represented a body weight loss of more than 5% (12, 17, 18). For the purpose of the present study, moderate dehydration in the adult was defined as a 2–5% loss of body weight.

Heat- and exercise-induced moderate acute dehydration resulted in a significant impairment of specific cognitive-motor functions such as short-term memory, working memory, perceptual discrimination, and visual-motor function (2, 9, 25). The critical level of acute water deficit causing a decrease in cognitive performance occurred at a level of 2% or more (9). Adverse effects of acute moderate dehydration induced by heat or exercise were identical (2).

In contrast, reduced drinking in the presence of physiological needs may be particularly important in predisposing to subacute and chronic dehydration in the general population (13, 14, 20). Water deprivation for 24 h can induce a comparable level of water deficit, as acute heat or exercise testing during 0.5–2 h (19, 20). However, the effect of slowly progressive dehydration induced by water deprivation on cognitive performance in healthy men and women is unknown. In addition, cognitive impairment assessed by electrophysiological tests such as event-related potentials P300 has not been studied previously during moderate dehydration.

Event-related potentials (P300) and cognitive-motor function measures are particularly sensitive to changes in brain metabolism (1, 22). Therefore, these parameters, as well as subjective ratings of task compliance, were assessed in young healthy men and women after 24 h of water deprivation to determine the effect of slowly progressive dehydration on mental performance.

METHODS

Subjects. Healthy, nonsmoking regularly menstruating women (n = 8, age 25 ± 4 yr, range 21–34 yr, body mass index 19.2 ± 1.3 kg/m², range 18–21 kg/m²) without oral contraceptives for at least 3 mo and men (n = 8, age 28 ± 5 yrs, range 20–34, body mass index 22.6 ± 1.7 kg/m², range 20–25 kg/m²), agreed to participate after giving written informed consent. Physical examination and medical history were normal. The subjects were on no medications, and there was no evidence of illicit drug abuse. Approval from the local Ethics Committee was obtained before beginning the studies.

Protocol. Each subject underwent two studies in random order, one being the control and the other the dehydration phase, both being 6–8 days apart. Because osmotic regulation of arginine-vasopressin and renal sodium handling is modified by menstrual cycle (28), women were investigated during the follicular phase (2–4 days after the beginning of menstrual bleeding and 7 days later for the second study), when osmotic sensitivity is identical in men and women. The costs of publication of this article were defrayed in part by the payment of page charges. The article must therefore be hereby marked “advertisement” in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.
studies started at 0800 on day 1 and lasted 28 h, including a test session on day 2 from 0800 to 1200.

On the morning of day 1, predereprivation data were obtained after a small continental breakfast, according to individual habits without tea or coffee, but with another noncaffeinated beverage instead, and after abstaining from alcohol for at least 24 h. The participants were asked to empty their bladders, and the second urine of the day was sampled. After being weighed, the subjects were seated in a semirecumbent position, and after a minimum of 30 min of rest, a baseline antecubital venous blood sample, blood pressure, and visual analog thirst rating were obtained. During the dehydration study, all fluids were withdrawn, and the subjects were asked to undertake normal activities in the hospital building and to consume a self-selected diet based on a list of foods containing <75% of water by weight according to published tables (15) for the next 28 h, including 4 h of the test session on day 2 from 0800 to 1200. During the control study, the subjects were allowed to consume nonalcoholic beverages except coffee ad libitum throughout the study period, including the test session. The subjects had access to mineral water during the tests and were encouraged to drink after 2 h having finished the first series.

On day 2 after breakfast, samples of urine and blood were obtained, and data on weight, blood pressure, and thirst rating were recorded in the same manner as on the first day.

Visual analog thirst ratings. Thirst ratings were obtained simultaneously with blood samples by use of previously described methods (21). They consisted of the question “How thirsty do you feel now?”, and the extreme answers were “Not at all thirsty” and “Very thirsty”, which the subject answered by placing a mark on a 100-mm line. Changes in ratings from the individual subject’s predeprivation state were calculated on day 2 before and at the end of the cognitive function tests.

Assessment of cognitive function. One week before study, the subjects participated in a preliminary (practice) test session to establish familiarity with the test battery and the test environment. Subjects were in a seated position (armchair) throughout the whole experiment in a room with constant temperature (22°C). All cognitive-motor and neurophysiological tests were administered twice in identical test sequence (auditory event-related potentials P300, choice reaction time task, manual tracking test, paced auditory serial addition task, Stroop word color conflict test, parts A and B) during control and dehydration study. However, to further reduce the likelihood of unspecified arousal effects, only the results of the second test series were used for the final statistical analysis.

Five standardized cognitive-motor function tests characterized by differing proportions of cognitive to motor function were selected. These tests have recently been shown to be sensitive to changes in brain metabolism (1, 22). Furthermore, they resemble a broad range of potential everyday cognitive-motor function tasks and may be applied in repetitive forms by computerized means.

Specifically, an adaptive choice reaction time task was performed to measure sustained visual attention and cognitive-motor speed. During a 5-min period, participants had to respond to the presentation of colored lights appearing in random sequence by pressing corresponding buttons as accurately and quickly as possible. Using a computerized version of the paced auditory serial addition task, electroencephalogram concentrations and plasma osmolality remained unchanged.
during the control study but increased significantly during dehydration ($P < 0.001$ and $P < 0.001$, respectively). No significant change in urine osmolality was observed during the control phase, while during dehydration, urine osmolality increased significantly until the end of the experimental day ($P < 0.001$) (Table 1).

The following parameters differed significantly between the control and the dehydration study: Serum sodium: $P < 0.05$; urinary sodium: $P < 0.001$; serum osmolality: $P < 0.05$; urinary osmolality: $P < 0.001$ (repeated-measures ANOVA). There was a significant gender effect for urinary sodium (mmol/l): control + dehydration values ± SD at baseline: men $121 ± 39$ vs. women $103 ± 52$; 24 h: men $147 ± 63$ vs. women $97 ± 45$; and 28 h: men $156 ± 50$ vs. women $128 ± 62$ (repeated measures ANOVA: $P < 0.05$).

**Fluid balance.** Body weight decreased during the control and the dehydration phases from baseline to the end of the studies (Table 1). However, during the control phase, baseline and 24-h values were not significantly different. A significant weight loss occurred only during cognitive function testing between 24 and 28 h ($t$-test: $P < 0.001$). During dehydration, a significant weight loss occurred during the first 24 h ($P < 0.001$), as well as during cognitive function testing from 24 to 28 h ($P < 0.001$).

The degree of weight loss was calculated as % weight loss from baseline. During the first 24 h of the control study, no dehydration was observed, while during cognitive function testing significant dehydration occurred ($t$-test $P < 0.001$). During the dehydration phase, significant dehydration occurred during the first 24 h, as well as during cognitive function testing from 24 to 28 h ($P < 0.001$) for both time periods. These changes differed from the control study ($P < 0.001$) (Table 1). Women lost significantly less weight than men ($P < 0.01$), but taking the lower mean baseline body weight of the women into account, this difference disappeared when calculating the percent weight loss from baseline ($P = 0.2$).

**Thirst perception.** The subjective rating of thirst increased significantly during both the control and dehydration periods (Table 1). During the control phase, a significant increase occurred from 24 to 28 h ($P < 0.001$), while during dehydration; a significant increase resulted during the first 24 h ($P < 0.001$). Thirst rating differed significantly between the control and the dehydration phases (repeated-measures ANOVA $P < 0.01$); it also differed between males and females (repeated-measures ANOVA $P < 0.05$); however, thirst was not significantly different between sexes at the end of dehydration.

**Cognitive function and P300.** Paced auditory serial addition task response variables were not significantly different between study days and between groups (overall group, accuracy: control 93.9% ± 2.0 vs. dehydration 93.3% ± 1.6, $P = 0.73$; reaction time: control study 1,036 ms ± 76 vs. dehydration 1,050 ms ± 75, $P = 0.55$). There was no main effect for gender and no dehydration-gender interaction for accuracy, but a small dehydration-gender interaction for verbal reaction time ($P = 0.05$; Table 2).

Choice reaction time task-dependent variables were reaction time (control period 570 ms ± 19 vs. dehydration 572 ms ± 17, $P = 0.81$) and interstimulus interval (control 642 ms ± 18 vs. dehydration 645 ms ± 17, $P = 0.58$). There were no significant effects of dehydration and gender.

The manual tracking test response measure was not significantly affected by dehydration and by sex (control study 18.8 pixels ± 1.0 vs. dehydration 19.9 pixels ± 1.3, $P = 0.13$).

The script color naming Stroop color-word conflict test related interference score (difference between response time for congruent vs. incongruent word-color combinations in milliseconds) was not affected by dehydration (control $-43 ± 12.3$ vs. dehydration $-50 ± 7.4$, $P = 0.47$), but there was a significant main gender effect ($P = 0.005$, Table 2). Furthermore, the word naming part of the Stroop test revealed significant dehydration-gender interactions, suggesting response time is slowed by dehydration in females, but accelerated in males (Table 2).

The auditory event-related potential P300 variables latency (in milliseconds) and amplitude (in microvolts) of frequent tones and target tones did not differ significantly between the dehydration and the control state and between sexes (Table 2 and Fig. 1). Overall, reaction time to target tones was not affected by dehydration. However, there was a tendency for a gender × deprivation interaction ($P = 0.09$) suggesting slower reaction time during dehydration in females, but accelerated times in males (Table 2).

**Subjective rating of tiredness, effort, and concentration for test accomplishment.** The subjective rating of effort and concentration for test accomplishment during cognitive function testing differed significantly between the control and the dehydration phase ($P < 0.05$) (Fig. 2A). The subjects perceived tiredness more and were less alert during dehydration com-

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**Table 1. Plasma and urine values of sodium and osmolality, fluid balance, and thirst**

<table>
<thead>
<tr>
<th></th>
<th>CO 1 Baseline</th>
<th>CO 2 24 h</th>
<th>CO 3 28 h</th>
<th>DH 1 Baseline</th>
<th>DH 24 h</th>
<th>DH 3 28 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum sodium, mmol/l</td>
<td>138.7 ± 1.8</td>
<td>139.8 ± 1.5</td>
<td>139.9 ± 1.9</td>
<td>139.4 ± 2.1</td>
<td>141.0 ± 2.0</td>
<td>140.8 ± 2.1</td>
</tr>
<tr>
<td>Serum osmolality, mosmol/kgH₂O</td>
<td>288.3 ± 1.6</td>
<td>290.6 ± 5.7</td>
<td>287.8 ± 3.54</td>
<td>289.8 ± 4.7</td>
<td>296.3 ± 5.3</td>
<td>294.8 ± 4.3ad</td>
</tr>
<tr>
<td>Urinary Sodium, mmol/l</td>
<td>112 ± 40</td>
<td>89 ± 53</td>
<td>105 ± 45c</td>
<td>112 ± 52</td>
<td>154 ± 47</td>
<td>179 ± 2bc</td>
</tr>
<tr>
<td>U-Osmolality, mosmol/ kgH₂O</td>
<td>730 ± 219</td>
<td>610 ± 301</td>
<td>576 ± 257c</td>
<td>691 ± 277</td>
<td>1004 ± 96</td>
<td>967 ± 107c</td>
</tr>
<tr>
<td>Thirst rating, mm</td>
<td>12 ± 12</td>
<td>16 ± 13</td>
<td>31 ± 23ad</td>
<td>21 ± 19</td>
<td>72 ± 18</td>
<td>75 ± 22ad</td>
</tr>
<tr>
<td>Weight loss, kg</td>
<td>0 +0.08 ± 0.45</td>
<td>-0.46 ± 0.63bc</td>
<td>0 -1.14 ± 0.54</td>
<td>-1.70 ± 0.58bc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dehydration, % body</td>
<td>0 ± 0.15 ± 0.7</td>
<td>-0.75 ± 1.0bc</td>
<td>0 -1.77 ± 0.7</td>
<td>-2.56 ± 0.7be</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data are presented as means ± SD; n = 16 subjects/group. CO, control protocol; DH, dehydration protocol; *P < 0.01 within group (paired t-test); **P < 0.001 within group (paired t-test); *P < 0.001 within group (Friedman test); *P < 0.01 CO vs. DH (repeated-measures ANOVA); **P < 0.001 CO vs. DH (repeated-measures ANOVA).
pared with the control study (P < 0.05) (Fig. 2B). There were no gender differences for these two tests.

**DISCUSSION**

Deterioration of cognitive abilities after short-term exercise or heat-induced dehydration have been observed in normal subjects at a dehydration level of 2% or more (2, 9, 25). From these data, it would be reasonable to assume that continuous water deprivation leading to a comparable level of isotonic dehydration (2–3%) as studied in the present report would produce similar negative effects on cognitive function. The present protocol achieved a comparable degree of isotonic dehydration by complete restriction of drinking for 28 h with free intake of food with less than 75% water content as previously described (20). We expected no gender differences for parameters of water balance because fluid losses are pro-

**Table 2. Gender-specific results of cognitive function tests and auditory event-related potentials P300**

<table>
<thead>
<tr>
<th></th>
<th>Women CO</th>
<th>Women DH</th>
<th>Men CO</th>
<th>Men DH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Tracking Test Distance, pixels</td>
<td>19.4±2.4</td>
<td>21.2±4.0</td>
<td>18.2±5.6</td>
<td>18.5±6.4</td>
</tr>
<tr>
<td>PASAT Accuracy, %</td>
<td>92.3±9.6</td>
<td>91.0±9.2</td>
<td>95.4±6.0</td>
<td>95.6±3.6</td>
</tr>
<tr>
<td>Verbal response time, ms</td>
<td>1076±360</td>
<td>1134±300</td>
<td>996±248</td>
<td>965±296</td>
</tr>
<tr>
<td>CRTT Inter-stimulus-interval, ms</td>
<td>636±279</td>
<td>648±65</td>
<td>647±66</td>
<td>642±50</td>
</tr>
<tr>
<td>Reaction time, ms</td>
<td>560±71</td>
<td>570±67</td>
<td>580±77</td>
<td>574±68</td>
</tr>
<tr>
<td>Stroop script color naming verbal response time Congruent, ms</td>
<td>715±116</td>
<td>696±99</td>
<td>712±114</td>
<td>680±164</td>
</tr>
<tr>
<td>Conflict, ms</td>
<td>784±90</td>
<td>767±70</td>
<td>729±142</td>
<td>708±158</td>
</tr>
<tr>
<td>Stroop effect, ms</td>
<td>−69±49</td>
<td>−71±43</td>
<td>−17±49</td>
<td>−28±46</td>
</tr>
<tr>
<td>Stroop word naming verbal response time Congruent, ms</td>
<td>563±73</td>
<td>576±101</td>
<td>589±125</td>
<td>556±110</td>
</tr>
<tr>
<td>Conflict, ms</td>
<td>556±81</td>
<td>582±112</td>
<td>586±135</td>
<td>550±106</td>
</tr>
<tr>
<td>Reaction time, ms</td>
<td>300±58</td>
<td>324±87</td>
<td>318±59</td>
<td>307±49</td>
</tr>
<tr>
<td>Amplitude, μV</td>
<td>8.5±7.6</td>
<td>9±6.0</td>
<td>11.8±18.0</td>
<td>9.1±9.2</td>
</tr>
<tr>
<td>Fz</td>
<td>10.9±7.2</td>
<td>11.5±5.2</td>
<td>14.8±16.4</td>
<td>12.3±12.0</td>
</tr>
<tr>
<td>Cz</td>
<td>8.5±4.8</td>
<td>8.8±4.4</td>
<td>11.3±11.6</td>
<td>9.6±6.4</td>
</tr>
<tr>
<td>Latency, ms</td>
<td>349±40</td>
<td>336±56</td>
<td>322±64</td>
<td>326±48</td>
</tr>
<tr>
<td>Fz</td>
<td>330±60</td>
<td>337±56</td>
<td>323±60</td>
<td>321±40</td>
</tr>
<tr>
<td>Cz</td>
<td>290±44</td>
<td>298±60</td>
<td>318±64</td>
<td>300±32</td>
</tr>
</tbody>
</table>

Data are presented as means ± SD. PASAT, paced auditory serial addition Task; CRTT, choice reaction time task; Stroop, Stroop word color conflict test; P300, auditory event-related potentials P300. *Significant results.
later independent of water intake. Interestingly, performance 3.5 h after acute dehydration returned to baseline levels, showing that the initial drop of short-term memory immediately after dehydration was not a permanent deficit. This is in accordance with the results of Cian et al. (2).

Healthy subjects are able to adapt to a slowly progressive water deprivation. While Cian et al. (2) and Gopinathan et al. (9) have tested exercise-induced dehydration and water deprivation, the mechanisms responsible for the adaptation remain unclear.

Cian et al. (2) found impaired performance only for tests assessing predominantly cognitive function, while Gopinathan (9) found tests with predominantly motor function to be impaired by dehydration. The tests used in the present study varied in the degree of motor function contributing to cognitive task performance, being maximal in the manual tracking task, choice reaction time task, Stroop word-colour conflict test, paced auditory serial addition task. No obvious trend was found, which indicates differential impairment of the two main components of cognitive-motor function (cognition vs. motor function) in our test battery.

For several tests, we found a significant dehydration-gender interaction. The reason for this effect remains hypothetical, but an influence of the natural variation of levels of luteinizing hormone, follicle-stimulating hormone, estrogen, and progesterone can be postulated. Estrogen has been linked to improved memory (6), working memory (26), and articulation (11). In contrast, low estrogen has been associated with better visual-spatial abilities (11). Osmotic sensibility varies with the menstrual cycle (28). Therefore, female subjects performed our study during the early follicular phase, when osmotic sensitivity is identical in males and females, but estrogen levels are lowest and begin to increase. Thus decreased verbal fluency due to low estrogen values in our female subjects could be responsible for significant gender-dehydration interaction in reaction time-based response measures of the Stroop word naming test and of the paced auditory serial addition task. However, because of the randomized counter-balanced order (50% of the subjects starting with the dehydration experiment), this is not an issue in the current study.

Neurophysiological P300 testing confirmed the neuropsychological tests. The latency of P300 reflects stimulus evaluation or categorization time (5). Prolongation of P300 latency can be used as a measure of deterioration of cognitive function (4). The amplitude of P300 represents the processing resources demanded by a particular task (5). We found that neither latency nor amplitude of P300 for frequent or target tones differed between protocols.

During dehydration the subjects felt more tired and less alert. These results are in accordance with the literature (2), observing significantly increased fatigue ratings after dehydration, persisting for 3.5 h without fluid ingestion. Subjective estimates of effort and concentration necessary for task completion assessed by a visual analog scale were significantly higher during dehydration than during the control phase in the present study. Since objective measures of cognitive-motor function did not differ between control and dehydration study, the data indicate, that young, healthy subjects compensate possible negative effects of water deprivation on cognitive function by increasing the effort.

In summary, global cognitive-motor performance is preserved during water deprivation in healthy young subjects of either sex up to a moderate dehydration level of 2.6% loss of body weight, when subjects are able to increase their task-related effort. These findings, which were observed during slowly progressive dehydration, are in contrast to acute water loss due to exercise or heat.

![Graph](http://ajpregu.physiology.org)
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DISCLOSURE

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REFERENCES