Methods for assessing the effects of dehydration on cognitive function

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Studying the effects of dehydration on cognitive function presents a variety of unique and difficult challenges to investigators. These challenges, which are addressed in this article, can be divided into three general categories: 1) choosing an appropriate method of generating a consistent level of dehydration; 2) determining and effectively employing appropriate and sensitive measures of cognitive state; and 3) adequately controlling the many confounding factors that interfere with assessment of cognitive function. The design and conduct of studies on the effects of dehydration on cognitive function should carefully consider various methodological issues, and investigators should carefully weigh the benefits and disadvantages of particular methods and procedures.

INTRODUCTION

It is well established that dehydration impairs cognition, eventually leading to coma and death. Healthy humans with ready access to water will not become severely dehydrated due to powerful homeostatic mechanisms that ensure they drink water when needed. Modest levels of dehydration can occur in healthy individuals, but the level at which cognitive function initially becomes degraded by dehydration is not established.1,2 In addition, it is unclear which cognitive functions are affected by dehydration. Furthermore, the lowest level of dehydration that results in cognitive degradation has not been definitively established. Determining this level is critical for ensuring that adequate hydration is maintained in healthy individuals and in vulnerable populations, such as those who exercise in the heat, children, elderly persons, and individuals with various illnesses.3–5

It seems that in healthy humans, relatively modest levels of dehydration can affect the brain and degrade cognitive function (for a recent review, see Lieberman²).6–9 Adverse effects of dehydration on cognition appear to first become detectable at a level of approximately 1.5% body weight loss. Changes in mood, such as increased fatigue and symptoms of dehydration, seem to be the first indication that dehydration is affecting brain function.6,10 In two nearly identical studies of mild dehydration (approximately 1.5% body weight loss), one with young women and one with young men, adverse changes in mood and symptoms were observed, but cognitive performance was largely unchanged.8,9

Studying the effects of dehydration on cognitive function presents a variety of unique and difficult challenges to investigators. These challenges can be divided into three categories: 1) choosing an appropriate method of generating a consistent level of dehydration, 2) determining and effectively employing appropriate and sensitive measures of cognitive state, and 3) adequately controlling the many confounding factors that interfere with assessment of cognitive measures. For example, it is well known that expectation effects due to the lack of a placebo can bias study results. Another important issue is accurate assessment of dehydration. This is a difficult and controversial problem and has been addressed previously.11,12

CHOOSING A METHOD TO INDUCE DEHYDRATION

Several studies of cognitive function have used exposure to a combination of high heat and exercise to rapidly
produce substantial dehydration. While effective, this procedure has limitations. Although it is one of the most consistent ways to quickly produce high levels of dehydration, studies using this method are assessing effects of a combination of heat, dehydration, and exercise, not dehydration alone. Although investigators typically include control conditions in such studies – for example, heat and exercise without dehydration – interactive effects of high heat, heavy exercise, and dehydration make interpretation of the results of such studies problematic.

Another method of inducing mild dehydration is by preventing individuals from consuming water or other beverages. This will, of course, eventually lead to dehydration, but it is a slow process. For example, in a study conducted by Szinnai et al., achieving a mean level of dehydration of 2.6% required 28 h. This method has the advantage of not directly imposing other stressors on subjects, but it does indirectly result in stress because long periods of fluid deprivation are inherently unpleasant and stressful. It should be noted that foods typically contain substantial quantities of water, which is an issue when conducting such studies.

Rapid dehydration can also be produced by the use of diuretics, such as the drug furosemide, in combination with fluid restriction. Although effective, administration of these drugs produces a physiologically different type of dehydration than dehydration resulting from fluid deprivation or the combination of heat and exercise. Whether this form of dehydration results in different behavioral changes than other methods of dehydration is not known, but there is no evidence that it does.

Dehydration can also be induced by combining fluid deprivation and moderate exercise. Dehydration produced in this manner is induced in a few hours, more rapidly than produced by fluid deprivation alone, but not as rapidly as dehydration induced by high heat and intense exercise. Compared with exposure to high heat, intense exercise and fluid deprivation, or long periods of fluid deprivation, the combination of moderate exercise and fluid deprivation is much more likely to occur in the course of real-world activities.

A definitive determination of the optimal manner to induce dehydration in cognitive research is not currently possible. Each method has advantages and disadvantages, although the use of very high heat and intense exercise does not seem to be suitable for studies designed to isolate the effects of dehydration from other stressors.

**ASSESSING COGNITIVE FUNCTION**

A comprehensive review of all methods that could be used to assess changes in cognitive or brain function associated with dehydration is well beyond the scope of this review. Therefore, this article focuses on the methods most commonly used to assess the effects of dehydration and other stressors on cognitive function. The two categories of behavior assessment typically used in such studies are tests of cognitive performance and self-report questionnaires. Evoked potentials and simulators of real-world performance, such as driving, have also been used in dehydration research. Simulators are a special category of cognitive performance tasks.

In addition to tests of cognitive performance and mood, psychologists and neuroscientists have a variety of sophisticated technologies available to measure brain function in humans. Electrophysiological techniques such as evoked potentials and electroencephalography measure brain electrical activity. Techniques such as functional magnetic resonance imaging (fMRI) measure changes in brain blood flow during activation of various brain regions by specific cognitive activities. The technology of functional magnetic resonance imaging is extremely useful for understanding relationships between brain function and cognition, but it would likely provide little or no information that could be used for understanding the practical effects of dehydration. Furthermore, there is no evidence that such methods are as sensitive as mood or performance tests to effects of various stressors, including dehydration, on cognition, and they are much more difficult and expensive to administer.

Choosing optimal tests of cognitive performance to examine the effects of dehydration is a difficult undertaking. There are thousands of different tests of cognitive function available and no consensus among cognitive psychologists as to which are optimal for assessing the acute effects of stressors. The choice of such tasks is complicated if low or moderate levels of dehydration are of interest, because it is especially difficult to detect small changes in cognitive performance resulting from exposure to stressors such as dehydration.

Choosing appropriate cognitive performance tests for a study is easier if the cognitive functions altered by a stressor are known from previous research. Unfortunately, definitive information is not available on cognitive functions that are especially sensitive to dehydration or other environmental stressors. Domains of cognitive performance that have been degraded by moderate or high levels of dehydration include vigilance, short-term memory, reasoning, and hand-eye coordination.

Given the lack of consistent findings across studies, future research in this area should employ a variety of tests of cognitive performance that assess a wide range of functions, including vigilance, reaction time, learning, working memory, and various aspects of executive function.
Self-report questionnaires provide another very effective method of assessing the effects of dehydration on cognitive function. Mood and symptom questionnaires have been shown to be sensitive to low levels of dehydration and are, perhaps, more sensitive than tests of cognitive performance.\textsuperscript{6,9,9} Although cognitive performance is often considered the preferred measure of cognitive function, mood and symptom questionnaires are sensitive to a wide variety of stressors and measure of functions of great importance to individuals. Properly designed mood questionnaires, such as the Profile of Mood States, measure a much wider range of functions than performance tests and only take a few minutes to administer. Moods such as alertness, fatigue, anxiety, and depression are critical aspects of human well-being, as are potential symptoms of dehydration such as a headache and difficulty focusing on the task at hand, which can be easily measured by questionnaire. Given the value of mood questionnaires for understanding the human response to stressors and their apparent sensitivity to low levels of dehydration, they should usually be included in behavioral studies of dehydration.

Overall, it is critical that behavioral experiments be replicated within and across different laboratories using the same tasks. In addition, given the lack of consistent findings to date, it is essential that various levels of dehydration, including high levels, be investigated so that dose-response relationships can be established. If effects on specific cognitive functions are present at high levels of dehydration, then studies at lower levels are more likely to successfully detect similar effects. For more comprehensive reviews of cognitive methods, see the publications of Gawron,\textsuperscript{15} Balkin et al.,\textsuperscript{16} Squire,\textsuperscript{17} and Lieberman.\textsuperscript{18}

**ADEQUATELY CONTROLLING CONFOUNDING FACTORS**

In conducting studies of cognitive function, it is essential to control a variety of factors not typically considered in physiological research. Since humans are easily influenced by their own expectations or subtle cues from other individuals, the use of double-blind procedures is essential in psychological research. Unfortunately, full implementation of such procedures in dehydration studies is not possible. Consequently, strategies to creatively simulate double-blind procedures should be used when possible. For example, investigators responsible for conducting behavioral testing should not be provided with information on the hydration state of the volunteers they are testing. In addition, volunteers should not be informed of the experimental condition in which they are participating, and every attempt should be made to disguise experimental conditions. For example, small amounts of fluid can be provided to individuals who are being dehydrated and the amount of fluid provided can be disguised.\textsuperscript{8,9} More complex procedures, such as the use of diuretics, in combination with matched placebo pills, can also be used to confuse volunteers as to the testing condition.\textsuperscript{8,9}

**CONCLUSION**

In spite of the importance of hydration for maintaining cognitive function, only limited research has been conducted to examine the effects of dehydration on cognition and brain function. A variety of factors contribute to the difficulty of studying the effects of dehydration on cognitive function, including the lack of standardized methods for assessing cognitive performance or generating consistent levels of dehydration. In addition, it is difficult to conduct studies of dehydration with adequate control procedures for biases that occur when subjects or investigators are aware of testing conditions (use of double-blind procedures). Future research will need to creatively address these and other problems associated with studying an area as complex as the effects of dehydration on cognition.

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**REFERENCES**