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Cognitive Assessments in Hydration Research Involving Children: Methods and Considerations

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Abstract

The effects of optimal and insufficient hydration on human health have received increasing investigation in recent years. Specifically, water is an essential nutrient for human health, and the importance of hydration on cognition has continued to attract research interest over the last decade. Despite this focus, children remain a relatively understudied population relative to the effects of hydration on cognition. Of those studies investigating children, findings have been inconsistent, resulting from utilizing a wide variety of cognitive domains and cognitive assessments, as well as varied hydration protocols. Here, our aim is to create a primer for assessing cognition during hydration research in children. Specifically, we review the definition of cognition and the domains of which it is composed, how cognition has been measured in both field- and laboratory-based assessments, results from neuroimaging methods, and the relationship between hydration and academic achievement in children. Lastly, future research considerations are discussed.

Introduction

The study of hydration and nutrition influences on human brain and cognition is a developing field of study. Much of the current literature has focused either on the effects of dehydration on health outcomes [1] or the detriments of dehydration on cognition. Few studies have sought to investigate the benefits of improved hydration on cognition, and even fewer have focused on children [see 2, 3 for reviews]. Within this limited literature, methods for assessing or modulating hydration have varied across child populations, with the majority focusing either on associations of urinary biomarkers, such as osmolality [4], or acute manipulations whereby hydration is manipulated via water intake and compared to addition-

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al intake conditions or control groups [5–12]. However, it is important to note that not all studies provide measures of urinary biomarkers. Where possible these measures will be described. To date, only one study has focused on the manipulation of dehydration by inducing reductions in body mass through thermal exercise, and this study was conducted with adolescent children [13]. Additional methods have included measuring dietary water intake via survey [14] and a mouth rinsing/drying protocol [15]. While methods of manipulation have differed, all studies have endeavored to explore how varied areas of cognition are affected by changes of body water. Accordingly, the focus of this article is not to provide an extensive review of the literature, which is provided elsewhere [16], but rather to serve as a primer for assessing cognition of children in studies aimed at understanding how optimal and insufficient hydration may affect cognitive and brain health.

Cognition

Cognition is a vast, umbrella term, which is generally thought of as how people think, learn, perceive, and remember information [17]. Many domains exist within cognition including sensation, perception, consciousness, attention, memory, language, problem-solving, creativity, decision-making, reasoning [see 17 for review], and executive function or cognitive control [18]. Additionally, executive function is typically thought to be composed of inhibitory control, working memory, and cognitive flexibility [18], but more broadly reflects higher-order cognitive operations underlying the intentional component of environmental interactions. As such, the paradigms used to study the field of cognition are equally as vast as the term itself.

Unsurprisingly, within the extant literature of hydration and cognition in children, there appears to be differential effects of drinking water, urinary markers, or mouth rinsing on different aspects of cognition. That is, simply being better hydrated does not necessarily improve cognition in the broad sense, and any improvements might depend on how hydration is manipulated, measured, and what aspects of cognition are measured. Broadly speaking, areas of cognition that have illustrated the benefits of improved hydration and acute water intake include attention [7, 9–12], short-term memory [4, 5, 7, 9], delayed memory [6], visual search [9, 10, 12, 15], and executive function [14]. However, not all studies have supported a relationship between various hydration measures and cognition, with some reporting null or negative findings for short-term memory [9, 11, 12, 15]. Of the studies referenced above, only 3 have collected urinary markers of hydration. A cross-sectional study conducted by Bar-David et al. [4] found that insufficient hydration, as indicated by urine osmolality >800 mOsmol/kg, was associated with poorer short-term memory. Similarly, Fadda et al. [5] conducted an intervention study where one group of children received supplemental water and the control group did not receive any additional water. Their findings indicated that improved urinary markers of hydration were associated with improved short-term memory. However, it is worth noting that better performance in verbal analogies was associated with insufficient hydration [5]. In another intervention, Perry et al. [9] compared children who received water to those who did not, while controlling for baseline measures of urine concentration. They found that children who received water and showed small changes in urine concentration performed better on measures of attention, short-term memory, and visual search. However, children that received water and showed large changes in urine concentration did not show improvements, and in the case of memory showed a decrease in performance [9].

To unpack the broad relationship observed for hydration and cognition in the recent literature, the following sections will discuss the different methods by which cognition has been measured, including neuropsychological tests, academic achievement, laboratory-based cognitive tests, and neuroimaging tools.

Neuropsychological Tests

Many paradigms with which to study cognition exist in the literature. Table 1 provides a brief overview of the different domains of cognition along with common neuropsychological and cognitive tests that have been used to assess them. However, the table is limited to a brief list of assessment tools, as more extensive reviews are available elsewhere in the literature [e.g., 19]. Neuropsychological tests have traditionally been delivered via paper-and-pencil assessments and many times are part of larger standardized batteries. Many of these tests were initially designed as part of larger neuropsychological assessments administered by a trained neuropsychologist. However, in recent years, multiple tests have been used in laboratory- and field-based research to measure different aspects of cognition. One significant advantage of these tasks for field-based research is that the paper-and-pencil

Table 1. Neuropsychological, cognitive, and academic tests

Example tasks	Subdomain	Test type	Example in hydration literature	Result
Executive functions				
Eriksen flanker task	Inhibitory control	Cognitive test	Khan et al. [14], 2015	Greater water intake, greater performance
Making groups		Neuropsychological test	Bar-David et al. [4], 2005	No effect
Attention				
Spot the difference, direct	Visual attention	Neuropsychological test	Trinies et al. [11], 2016	Water consumption group improved performance
			Edmonds and Burford [7], 2009	Water consumption group improved performance
			Edmonds and Jeffes [8], 2009	Improved performance after water consumption
Deux de Barrage	Selective attention	Neuropsychological test	Fadda et al. [5], 2012	No effect
Shakow	Sustained attention	Neuropsychological test	Benton and Burgess [6], 2009	No effect
Ravin Rabbids	Visual attention/ Visuomotor performance	Video game	Booth et al. [10], 2012	Water consumption group improved performance
Memory				
Spot the difference, indirect	Short-term memory	Neuropsychological test	Trinies et al. [11], 2016	No effect
			Edmonds and Burford [7], 2009	Water consumption group improved performance
			Edmonds and Jeffes [8], 2009	No effect
Auditory number span	Short-term memory	Neuropsychological test	Fadda et al. [5], 2012	Water consumption group improved performance
			Bar-David et al. [4], 2005	Hydrated students had better performance
Recall of objects (British Ability Scale)	Delayed memory	Neuropsychological test	Benton and Burgess [6], 2009	Improved performance after water consumption
Story memory	Delayed memory	Neuropsychological test	Edmonds and Burford [7], 2009	No effect
Delayed match to sample	Short-term memory	Neuropsychological test	Perry et al. [9], 2015	No effect
Digit span, forwards and backwards	Attention/Working memory	Neuropsychological test	Perry et al. [9], 2015	Improved performance after water consumption in low change group
Forward digit span	Short-term memory	Neuropsychological test	Trinies et al. [11], 2016	No effect
			Edmonds et al. [12], 2017	No effect
			Edmonds et al. [15], 2018	No effect
Backward digit span	Short-term memory/ Working memory	Neuropsychological test	Trinies et al. [11], 2016	No effect
Visual perception				
Mentally manipulate 2 dimensional figures	Visual spatial ability	Neuropsychological test	Fadda et al. [5], 2012	No effect
Letter cancellation	Visual search	Neuropsychological test	Edmonds and Burford [7], 2009	Water consumption group improved performance
			Booth et al. [10], 2012	Water consumption group improved performance
			Edmonds et al. [12], 2017	Water consumption group improved performance
			Edmonds et al. [15], 2018	Mouth rinsing group improved performance
Pair cancellation	Visual search	Neuropsychological test	Perry et al. [9], 2015	Improved performance after water consumption in low change group
Motor function				
Line tracing	Visuomotor performance	Neuropsychological test	Edmonds and Burford [7], 2009	No effect
			Edmonds and Jeffes [8], 2009	No effect
			Trinies et al. [11], 2016	No effect
Ball catching task	Visuomotor performance	Physical test	Booth et al. [10], 2012	No effect
Step ups	Gross motor skills	Physical test	Booth et al. [10], 2012	No effect

delivery is relatively easy to administer to larger groups of children; this affords an opportunity to collect larger amounts of data over shorter periods of time. Another advantage is that these tests go through extensive validity and reliability testing and provide referenced norms and percentile values, allowing for easier comparison across studies. However, it is important to consider that (a) many of these neuropsychological batteries were designed to detect neuropathology [20], as opposed to smaller (health- or lifestyle-based) differences within a population and (b) many neuropsychological test manuals indicate that the examiner should have appropriate training in neuropsychology when used for neuropsychological assessment.

Cognitive Tests

Laboratory-based cognitive tests are typically more complicated to use in school settings because they generally require the use of a computer or tablet to present stimuli on a screen; also, behavioral responses based on task instructions to the participant are necessary to provide a quantifiable set of performance outcomes. Such experiments typically occur between one participant and one experimenter, requiring considerable time for data collection and analyses. However, these laboratory-based tests afford substantially more control over the environment and allow for the opportunity to manipulate presentation parameters of the task to best suit the particular population that is being sampled (i.e., as opposed to a "one size fits all" approach that may be a limitation of some neuropsychological tests). In addition, many computer-based cognitive tasks require a large number of trials during test administration in order to gain the requisite number of samples to assess specific aspects of behavior or task performance (e.g., response speed, variability, and accuracy). As such, the benefits of this type of cognitive testing affords a more nuanced analysis of cognitive processes, allowing for a more precise ability to detect differences in cognition as a function of changes in hydration. An additional benefit is that these types of tests pair well with neuroimaging measures for simultaneous collection, which will be discussed below.

The NIH Toolbox® (http://www.healthmeasures.net/explore-measurement-systems/nih-toolbox) is a relatively easy platform through which to administer different cognitive tasks and a large variety of surveys. Conveniently, this toolbox uses an iPad®, which affords easier administration in field settings such as schools. Executive function is one domain of cognition that has been frequently studied using laboratory-based cognitive tests. Unfortunately, there is a lack of research investigating hydration effects on executive function among children. In the only published study, Khan et al. [14] performed a median split of participants based on their reported total water intake, as measured via a 3-day diet record, and found that the higher consumption group exhibited shorter reaction times on a flanker task that manipulated inhibitory control, one aspect of executive function. In a similar vein, no studies to date have used laboratory-based measures of memory. Yet, measures of executive function and memory are affected by other health behaviors such as fitness [21], weight status [22], diet [23], and are integrally associated with development [24, 25]. Table 1 provides a list of executive function measures, but also see [26] for a list of other measurements that have been used.

Neuroimaging

Neuroimaging tools provide an additional avenue of research for delivering insight into the effects of hydration on brain health. Although not directly a measure of cognition, neuroimaging tools allow us to better understand brain outcomes (i.e., neural architecture, function, and network connectivity) that subserve cognitive operations. Much like the study of cognition, study of the human brain includes a variety of imaging approaches, including magnetic resonance imaging (MRI), functional MRI, electroencephalography and event-related brain potentials, magnetoencephalography, and functional near infrared spectroscopy. Previous MRI work has demonstrated that brain regions that support executive function [21, 24, 25] and memory [21] undergo protracted development throughout childhood and appear sensitive to other health behaviors such as fitness [21].

However, only one study has endeavored to use neuroimaging techniques to better understand brain mechanisms underlying hydration-induced changes in cognition. Kempton et al. [13] utilized an acute thermal-exercise dehydration protocol designed to decrease body mass by 1–2% in 90 min. Dehydration was associated with lateral ventricular volume increase and greater functional activation during the tower of London task (a measure of planning), with no differences in behavioral performance. From the adult literature, Streitbürger et al. [27] also found that not only did dehydration cause ventricular volume increase but also hyperhydration caused ventricular volume decrease compared to normal hydration. Dehydration is accompanied by reduced blood volume and increased serum osmolality, which results in reduced brain volume and cell shrinkage, leading to increased ventricular volume [13, 27]. Thus, dehydration is associated with gross measures of brain structures (ventricular volume) and may relate to changes in executive functioning, such as planning [13].

Academic Achievement and other Externally Valid Tasks

Academic achievement assessments share many of the same benefits as neuropsychological tests, in that they are valid and reliable, and can be easily administered via paper-and-pencil format to larger groups of children. Despite these benefits, there has been a surprising lack of investigation into hydration and academic measures, to date. Yet, examination of the extant literature indicates that measures of academic performance are affected by other health outcomes and behaviors such as physical activity, fitness [28], diet [29], and excess adiposity [30]. The varieties of academic tests include subject-based grades or school grade-point average, standardized achievement tests, released state standardized test marks, and others. For standardized tests of academic performance, the Wide Range Achievement Test – 4th edition [31], Kaufman Test of Educational Achievement – 3rd edition [32], and the Woodcock-Johnson – 4th edition [33] are examples of age-normed, paper-and-pencil batteries that measure reading, spelling, and math skills; these have been used to assess academic achievement using similar research paradigms.

One additional investigation of hydration effects on real-world cognitive outcomes in adults examined university students who brought water bottles with them to exams. Having a water bottle was associated with achieving higher scores on exams, even after adjusting for baseline academic ability, as measured by previously assigned grades [34].

Many of the tasks mentioned above are designed to focus on specific cognitive abilities, thus their measurement as well as the way they are administered may limit ecological (external) validity. That is, no prior research has endeavored (a) to use ecologically valid tests designed for use in environments (e.g., school) that children typically frequent or (b) how hydration or dehydration may influence ability to perform cognitive tasks within these environments. Examples of ecologically valid tasks could include paying attention in the classroom, academic test taking, completing homework, learning class material, navigating attentionally demanding environments, and even street crossing. In the case of street crossing, prior research had children with higher and lower fitness levels cross a virtual street while either undistracted, listening to music, or conversing on a hands-free cellphone. Higher fit children were better able to safely cross the street across the three conditions compared to lower fit children, who performed more poorly under the two distraction conditions [35]. Although promising, additional research is needed to better understand the depth of associations between hydration and dehydration with cognition across a variety of real-world settings.

Conclusion

The extant literature regarding how hydration affects cognition in children continues to emerge. However, there is still much to explore to better understand the importance of this nutrient for cognition and brain health. The current literature is largely comprised of a variety of neuropsychological paper-and-pencil tasks with few examples of supplemental neuroimaging techniques and laboratory-based cognitive assessments. As such, future studies should expand the type of measurements to other neuropsychological and cognitive tests. This research area is ripe for the use of neuroimaging methods to better inform the nature of the effects of optimal and insufficient hydration on brain health (e.g., brain structure and function). Surprisingly, to date, a lack of research investigating the effects of hydration on academic performance also exists. Additionally, in studies where hydration is modulated, there is a lack of consistency in the manipulation protocols, whether by water provision or dehydration. These varied methods may confound the current results and make interpretation and comparison across studies difficult. Not all studies have included assessments of hydration and instead assume that hydration modulates with water intake. Including hydration assessment allows for better understanding of the effectiveness of the water intake protocol, as well as individual differences in hydration modulation and their effects on cognition. Future research would benefit from different measures of hydration, including dehydration, optimal hydration, and hydration process. In particular, hydration process has been found to be important for many different health outcomes in adults, but its importance for cognition in children remains largely unexplored [36]. In summary, the current state of the literature is sparse and would benefit from a more programmatic approach to assessing the effects of optimal and insufficient hydration on cognition and brain functions using a variety of laboratory and field techniques, ranging from brain imaging to academic behaviors.

Disclosure Statement

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