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Dehydration and cognition: an understated relation

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Abstract

Purpose – Water is essential for mental health. In spite of research evidence that dehydration has detrimental effects on cognitive functioning, the element of water has often been understated in the nutrition literature. The purpose of this paper is to highlight the necessity to integrate water as an essential nutrient for healthy cognitive functioning in nutrition research.

Design/methodology/approach – This study is based on a general review. The first section reviews the literature on the relationship between dehydration and cognitive performance in both adult and children populations, using electronic databases for systematic reviews and meta-analyses (excluding vulnerable populations, such as infants, the elderly and people with disabilities). The second section examines the status of water, as a nutrient, in nutrition and water-related documentation by international authorities (FAO, UNICEF, World Food Program, WHO, etc.).

Findings – Dehydration, even at mild levels, is associated with impairments in basic and higher order cognitive functions. Websites from international authoritative nutrition sources underestimate the role of water in healthy nutrition, and omit the discussion of the impact of dehydration on cognitive functioning.

Originality/value – The relation between dehydration and cognition is under-documented and not enough elaborated in guidelines and texts of authoritative international health policy and dietary sources.

Keywords – Health care quality, Qualitative research, Public health regulations, Determinants of health, Dehydration, Cognitive performance, Cognitive processes

Paper type – General review

Introduction

Water is essential for life across all species living on land. It is the most abundant and the major constituent of the body cells, tissues and organs, including the brain and the central nervous system (Kempton et al., 2011; Asogwa and Lai, 2017). Water and the brain are directly linked as the effective functioning of the brain depends on adequate hydration (Jéquier and Constant, 2010).

Dehydration leads to reversible brain changes (such as the reduction of brain volume), which negatively impact the brain functions underlying important cognitive (executive) processes (Kempton et al., 2011). In their research on patients with Alzheimer’s disease (AD) and mild cognitive impairment (MCI), Streitbürger et al. (2012) note a decrease in the volumes of gray and white matter following dehydration. Normal white matter development predicts normal cognitive development. Nagy et al. (2004) found significant correlations between the white matter maturation index and children’s and adolescents’ performance on working memory and reading speed tasks. According to Streitbürger et al. (2012), the decrease in white matter volume in patients with AD is due to long-term dehydration rather than to the degeneration of brain tissue, and long-term dehydration may be one of the contributing causes, not a consequence, of AD or MCI (Streitbürger et al., 2012, p. 7).

Considering that a loss of more than 2 percent of body water causes reduction in brain performance (Asogwa and Lai, 2017), the impact of dehydration on cognitive performance is a topic of multi-disciplinary interest, including nutrition, medicine and nursing, developmental and cognitive psychology, neuroscience, and in the context of school performance, education.

In nutrition research, water is less commonly discussed than proteins, carbohydrates, vitamins and minerals, and is sometimes referred to as the “overlooked” nutrient (Kleiner, 1999; Masento et al., 2014), or is altogether omitted from dietary recommendations.
Interestingly, dehydration is recognized as a component of malnutrition (Douglas et al., 2014). The aim of this paper is to highlight the relationship between dehydration and cognition as per the research evidence and the necessity to further emphasize the status of water as a nutrient in documentation of authoritative bodies on health, nutrition, and children’s health and education (FAO, UNICEF, World Food Program (WFP), WHO, etc.).

**Method**
For the first part of the study, the initial round of the literature search using electronic databases such as PsycINFO, Academic Search Premier, JSTOR, and PubMed, as well as Google Scholar was made as a function of the following keywords: hydration, dehydration, cognition, cognitive performance. This search yielded 80 resources (meta-analyses, systematic reviews and original articles). Of these, 25 articles were excluded because of their combined emphasis on physical and mental activity; their focus on particular populations such as patients with AD, or pregnant women, or pilots, or Ramadan fasters, or infants; their overly clinical and pathophysiological content, such as relating the causes of dehydration to a combination of physiological and disease processes; the specificity of the discussion (such as the emphasis on delirium as a result of dehydration in older populations); their nature (either protocol study types, or proposals of randomized controlled trials where no findings are reported); and the perceived methodological limitations (such as small sample size or unclear description of the extent to which subjects’ compliance to the study’s water restriction instructions was assessed).

The remaining 55 resources were included in the present review as long as they provided a relevant discussion of the relation between dehydration and cognition through the examination of the effects of dehydration, exposure to hot climate, and both conditions, on cognitive performance, for both healthy adult and children populations. Articles on dehydration in the elderly population were excluded from the present review because they were irrelevant to our topic or to the purpose of our study, as stated above.

Our search revealed an absence of literature on dehydration in populations of people with disabilities, with the exception of one rather speculative and poorly documented article on the relationship between dehydration and attention-deficit hyperactivity disorder. It was decided to exclude, at least for the purpose of the present paper, any reference to intellectual disability to avoid the overlapping effect of the type of disability itself on the cognitive performance of subjects in a study on dehydration and cognition.

For the second part of the study, a search from gray literature (international, governmental or institutional reports and websites) was conducted, with additional keywords such as nutrition policies, health guidelines, diet requirements, etc. This search focused on reports issued within the decade between 2008 and 2018 in order to match the impact of the growing literature on dehydration and cognition with the recent health and nutrition policies and dietary recommendations. The search yielded 12 relevant resources, of which 3 were excluded due to their emphasis on physical rather than mental activity, their highly technical quality, and their irrelevance (whereby “water” was used in the contexts of sanitation and hygiene, and not in the context of the present paper).

**Relationship between dehydration and cognitive performance**

*Definition, induction and measurement of dehydration*

*Definition of dehydration.* Most of the reviewed studies define dehydration as a 1–2 percent loss of bodyweight caused by fluid losses, exposure to heat, sustained physical activity, or a combination of these (Adan, 2012; Benton and Young, 2015; D’Anci et al., 2009; Kempton et al., 2011; Kleiner, 1999).
**Induction of dehydration.** In a typical dehydration research, dehydration is either actively induced in consenting adult subjects through controlled passive exposure to heat, or sustained and controlled physical exercise, or a combination of these, or passively induced through fluid restriction (Adan, 2012; Cian et al., 2001; Masento et al., 2014; Popkin et al., 2010). For ethical considerations, the available literature on dehydration in children populations has focused on children who happen to be dehydrated because of living in hot climates (Assael et al., 2012; Bar-David et al., 2005; Edmonds et al., 2013; Fadda et al., 2012; Gouda et al., 2015; Trinies et al., 2016).

**Measurement of dehydration.** Studies on dehydration measure hydration levels in subjects by determining percent total body water by weight (WT), and/or analyzing urine samples for urine color (Kavouras et al., 2016, 2017), urine-specific gravity, volume, and osmolality (Bonnet et al., 2012; Fadda et al., 2012), or urinary output and urine osmolality (Bar-Or et al., 1980; Gouda et al., 2015; Kavouras et al., 2017). While other hydration markers (blood parameters, skinfold thickness and bioelectrical impedance analysis) have been used, the most promising marker is urine osmolality (Kavouras, 2002; Shirreffs, 2003). When laboratory analysis is not available, and where clinical exactness is not essentially required (Asogwa and Lai, 2017), the assessment of urine color of first morning samples has been used with reasonable accuracy (Guelinckx et al., 2015; Kavouras, 2002), and is valid for both adult and children populations (Kavouras et al., 2016). However, urine color may be affected by dietary intakes, drugs and supplements which are difficult to control (Asogwa and Lai, 2017).

**Definition and measurement of cognitive performance**

**Definition of cognitive performance.** Cognitive performance operationally defines how one uses cognitive functions (such as memory, reasoning, concentration, etc.) to complete one or more tasks (Riebl and Davy, 2013). These functions operate at the external level (attention, perception, storing and processing of incoming messages), and at the internal level (memory processes, concept formation and schematic organization of information). Most of these functions have further sub-functions, such as memory which is divided into sensory, short-term and long-term memory, or perception which operates through different channels (visual, auditory, verbal, and spatial) (Schmitt et al., 2005).

In the present review, cognitive performance encompasses the following functions: working memory (Adan, 2012; Baker et al., 2007; Bar-David et al., 2005; Benton and Burgess, 2009; D’Anci et al., 2009; Edmonds and Burford, 2009; Fadda et al., 2012; Gopinathan et al., 1988; Suhr et al., 2004), sustained attention (Benton and Burgess, 2009), visual attention (Booth et al., 2012; Edmonds and Burford, 2009), vigilance attention (D’Anci et al., 2009), psychomotor speed (Adan, 2012; Baker et al., 2007), speed in reaction time (Booth et al., 2012; D’Anci et al., 2009), concentration (Baker et al., 2007), arithmetic ability (D’Anci et al., 2009; Gopinathan et al., 1988; Popkin et al., 2010), visual-motor tracking (Popkin et al., 2010), perceptual discrimination (Popkin et al., 2010), verbal analogies (Bar-David et al., 2005), and higher order mental processes such as cognitive control (Khan et al., 2015), and planning and problem-solving (Adan, 2012).

**Measurement of cognitive performance.** Cognitive functions are commonly assessed by paper-and-pencil neuropsychological tests as well as computerized tests. Measures include response speed (in processing, psychomotor function, perceptual discrimination, perceptual reaction time, problem-solving time, fine motor function), and response accuracy (in visual memory performance, short-term memory performance, visuo-motor processing, vigilance tasks, distance and target judgment, spatial working memory) (Masento et al., 2014).

In a meta-analysis of 26 studies, Masento et al. (2014) list the tools commonly used to assess cognitive functioning. The list includes, among others, tests of symbol substitution,
word recognition, mathematical efficiency, picture recall, auditory number span, verbal analogies, as well as the Stroop task, mental rotation tasks, trail-making tasks, and subtests of the Wechsler intelligence scales. Such heterogeneity in the tools has been criticized as a methodological weakness (Lieberman, 2007; Masento et al., 2014), and in the absence of standardised assessment methods, there is an ongoing debate as to which assessment method is the best (Riebl and Davy, 2013).

Impact of dehydration on cognitive performance

In adult populations. It is generally noted that cognitive decrements due to dehydration, in all-age populations, are observed starting a 2 percent body water loss (Grandjean and Grandjean, 2007).

In healthy adults, lower hydration status was related to slowed psychomotor processing speed and poorer attention/memory performance (Suhr et al., 2004), while among healthy young male athletes, vigilance-related attention in a highly dynamic environment (simulated basketball game) was impaired by dehydration, and fluid replacement was essential to maintain optimal concentration and attentional skills (Baker et al., 2007). In healthy adults subjected to dehydration and heat stress, a significant correlation was reported between cognitive dysfunction (deterioration in arithmetic ability, short-term memory, and visual-motor tracking) and a 2 percent degree of dehydration and above (Gopinathan et al., 1988), and even mild dehydration (1–2 percent) was shown to lead to impairment in cognitive function (D’Anci et al., 2006).

Yet, in another study, dehydration up to 3 percent did not seem to have any significant effect on cognitive performance (Sharma et al., 2007), and a progressive water deprivation (at a moderate dehydration level) over 24 h for young healthy men and women did not show any decrease in cognitive-motor performance (Szinnai et al., 2005). Similarly, in Cian et al. (2001), a 2.8 percent dehydration (induced by hyperthermia or by exercise) only temporarily impaired visual perception, short-term memory and psychomotor ability, as the subjects’ performance normalized after fluid ingestion (rehydration). A more recent review by Shirreffs (2009) also notes the unlikelihood of an association between mild to moderate dehydration (without heat stress) with decrements in cognitive function and mental readiness, while higher levels (more than 3 percent body mass loss), combined with heat stress, may influence cognitive function and mental readiness.

In child populations. Research relating dehydration to cognitive performance reveals that school-age children are at a high risk for dehydration as they often forget to drink water and are usually negligent of their thirst. This is known as voluntary dehydration whereby children progressively dehydrate when not forced to drink (Bar-Or et al., 1980; Masento et al., 2014). Kavouras et al. (2012) highlight the need to raise children’s awareness of the importance of hydration, especially during physical exercise. Further, because drinking habits are established in childhood, it is important that young children get used to drinking a range of appropriate beverages, including water, in order to maintain hydration (Benelam and Wyness, 2010).

The relationship between dehydration and cognition for young subjects has been consistently reported (Benton, 2011): In school-age children, dehydration can cause impairments in the fundamental cognitive skills that are needed for adequate school performance (D’Anci et al., 2006), and in higher mental processes such as planning and problem solving (Adan, 2012). Voluntary dehydration in children was shown to affect immediate memory (auditory number span) and verbal analogies (Bar-David et al., 2005), perceptual discrimination, arithmetic ability, visual-motor tracking, and psychomotor skills (Popkin et al., 2010) as well as visual attention, perception speed and short-term memory (for number sequences), regardless of environmental temperature (Adan, 2012).
Impact of supplementary water consumption on the cognitive functioning of children

Offering children additional drinking water has a positive effect on their cognitive performance (Edmonds et al., 2013): supplementary water consumption positively affects performance on working memory tests and visual attention tasks in children aged 7–9 years (Edmonds and Burford, 2009), and in conditions of mild dehydration without exposure to exercise or heat or intentional water deprivation, six- to seven-year-old children’s cognitive performance can be improved by water consumption (Edmonds and Jeffes, 2009). When no attempt was made to influence eight-year-old children’s normal drinking pattern in schools that had a policy to allow drinking (permission to carry water bottles in class), additional water consumption (300 ml) led to a significant improvement in sustained attention and verbal recall of objects on the days when additional water had been consumed, vs no such improvement on the days when no additional water had been consumed (Benton and Burgess, 2009). Booth et al. (2012) demonstrated that when given 250 ml of supplementary water, eight- to nine-year-old girls’ performance on tasks requiring speed in reaction time and visual attention was significantly better than without supplementary water. Fadda et al. (2012) report a significantly beneficial effect of supplementary drinking in 9 to 11-year-old children on auditory number span tasks (assessing short-term memory). A study by Khan et al. (2015) showed that higher amounts of water consumption by pre-pubertal children over three days increased children’s ability for cognitive control on cognitively challenging tasks.

On the other hand, Trinies et al. (2016) investigated the relationship between supplementary water provision for pupils from grades 3 to 6 in Zambia and their cognitive test scores, vs a control group who only had access to normally delivered water at school. Hydration level of children was assessed (through urine-specific gravity measures) in the morning prior to water provision. Short-term memory, concentration, visual attention, and visual-motor skills were assessed in the afternoon. Provision of supplementary water was not found to impact cognitive test scores, except for the visual attention test.

Limitations of studies
In addition to the conflicting findings in the existing literature in both adult and child populations, several methodological limitations and weaknesses are noted, including the short-term nature of the studies, the small sampling size, the lack of objective hydration measures, the inconsistency in the measurement tools for cognitive assessment (Adan, 2012; Benton, 2011; Grandjean and Grandjean, 2007; Lieberman, 2007; Masento et al., 2014; Riebl and Davy, 2013), and a generally incomplete inquiry of mediating factors. Benton and Young (2015) note that variables other than mere dehydration ought to be considered before drawing any conclusion regarding the effect(s) of dehydration on cognitive functioning. Moreover, research findings are still inconclusive as to how much water is needed to optimize performance, both at the physical and cognitive levels (Hillyer et al., 2015).

The status of water in the documentation of authoritative nutrition sources
Our survey of the literature on nutritional requirements by international authorities, such as the FAO, WHO or UNICEF, among others, shows that the element of water is almost non-existent in the list of such requirements, or if it does exist, it appears either in a generic recommendation form without further explanations, or in the context of hygiene practices and sanitation.

In the WHO Regional Office for Europe (2003) survey on “Food-based dietary guidelines in the WHO European region,” water is mentioned only once (p. 22) in the Bulgarian national dietary guidelines, as Bulgaria is the only country which recommends drinking mineral water instead of soft drinks. In the WHO Programme for Nutrition and Food Security (2006) report on “Food and nutrition policy for schools,” water is mentioned in the general context

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of hygiene practices. Although the report criticizes today’s school vending machines for not offering water as a healthier option than soft drinks, it does exclude water from the list of the “12 steps to healthy eating for children and adolescents” (WHO Programme for Nutrition and Food Security, 2006, p. 24). In the 2016–2017 WHO Global Nutrition Policy Report (WHO, 2018), water is mentioned in a generic recommendation form.

In the Food and Agriculture Organization (FAO) report entitled “Coping with water scarcity: challenge of the twenty-first century”, there is no mention of “dehydration” as a possible consequence of water scarcity in the world, although it does discuss water-related illnesses (diarrhea and malaria) (FAO, UN-WATER, 2007, p. 20). In the FAO Background Document for the High-Level Expert Forum on “How to feed the world in 2050” (FAO, 2009), the problem of water scarcity is discussed in the contexts of natural resources making up the ecosystem, water reserves, water technology, and irrigation. Dehydration, as one of the major consequences of water scarcity, is absent from the report.

In the joint report by the FAO, IFAD, UNICEF, WFP and WHO entitled “The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security” (FAO et al., 2017), the element of water is mentioned as a generic recommendation without further details. The word “dehydration” is completely omitted from this report.

In the joint report by the WFP and UNICEF, entitled “The Essential Package: Twelve interventions to improve the health and nutrition of school-age children” (WFP and UNICEF, n.d.), dehydration is not mentioned as a potential threat for the physical and mental development of children.

In the discussion paper by the United Nations System Standing Committee on Nutrition (UNSCN, 2017), entitled “Schools as a system to improve nutrition,” the importance of water as an integral part of a healthy nutrition package for school-age children is overlooked, as the element of water appears as a generic recommendation for the “provision of clean drinking water” (UNSCN, 2017, p. 20).

In a 2002 survey of international food guide illustrations from different countries of the world, it is noted that only Puerto Rico includes water in both its illustration and recommendations, most likely due to the country’s tropical climate (Painter et al., 2002).

Martinez et al. (2015) analyzed the graphical representations used in the dietary guidelines of 35 selected countries in the Americas, Europe and Asia. It is noted that the first US Food Pyramid, published in the early 1990s by the US Department of Agriculture, did not include any mention of water; nor did the 2005 revamped version. It was not until 2011 when researchers from the Harvard School of Public Health developed the Healthy Eating Plate that water was recommended in addition to healthy oils and physical activity. Dietary guidelines from Argentina, Costa Rica, Uruguay and the Dominican Republic also contain recommendations for water intake. With respect to Europe, 6 out of the 12 surveyed countries include the intake of water (or other fluids) in their dietary guidelines. Out of the six Asian countries included in the survey, only China and Japan expressed recommendations for water/fluid intake.

**Discussion**

This review highlighted, on one hand, the negative effects of dehydration on cognitive functioning in general, and on school-age children’s cognitive performance in particular, and on the other hand, the positive impact of supplementary water consumption on cognition. The evidence for an association between hydration and cognition is correlational, and correlation does not mean causality (Benton, 2011); yet, in spite of their limitations, these studies have something substantial to say about the importance of water in children’s nutrition.

Although it is a known fact that children are at greater risk of dehydration than adults (D’Anci et al., 2006; Edmonds, 2010), researchers on school-age child nutrition admit that
water requirements are an often overlooked aspect of diet (Riebl and Davy, 2013; Weichselbaum and Buttriss, 2011), underemphasized and frequently underestimated (Bergeron, 2003). Proper water hydration for school-aged children must be a priority item on the school nutrition agenda, and healthful water drinking should always be a part of the diet record (Kleiner, 1999).

Patel and Hampton (2011) identify the challenges that limit access to drinking water in schools in the USA; these could be applicable everywhere else in the world, and include, among others, unsafe school drinking water (especially in schools with old infrastructure), insufficient number and inconvenient location of water fountains in schools, poor maintenance of drinking water outlets, and the increasing availability of competitive sugar-sweetened beverages that are sold and marketed in schools.

In several countries, adequate hydration has been recognized as an integral part of school food standards: In England, Scotland, Wales and Northern Ireland, easy and free access to clean drinking water has become a requirement in school-lunch servings (Weichselbaum and Buttriss, 2011). In the USA, the 2010 federal “Healthy, Hunger-Free Kids Act” requires early childhood day-care centers to make water available to children throughout the day, not just at meal times (Centers for Disease Control and Prevention, 2014).

Dehydration among children is much more common than one may think. Studies have shown that around two-thirds of children living in the UK, Germany, and the southeast coasts of the USA come to school in the morning in a dehydrated state (Edmonds et al., 2013). In France, Bonnet et al. (2012) reported a morning hydration deficit in almost two-thirds of a sample of 9- and 11-year-old children, despite their breakfast intake, implying that children’s water consumption at breakfast is not enough to maintain an adequate hydration status for the whole morning. In hot climates such as in Egypt, a study assessing the morning hydration status in a sample of school-age children shows that the majority of children arrive to school with a hydration deficit (Gouda et al., 2015). Similarly, in Italy, 84 percent of a sample of 168 school-age children in the city of Sardinia begin their school day in a mild, voluntary dehydration state (Fadda et al., 2012), and 67.2 percent of a sample of 515 school-age children in the city of Verona were found to come to school in the morning with a hydration deficit despite breakfast intake (Assael et al., 2012). Bar-David et al. (2005) found 32 cases of voluntary dehydration in a sample of 58 elementary school students in a desert town in the Middle East during Summer. A study on the impact of hydration on cognition in Zambia showed a 42.8 percent morning prevalence of dehydration among pupils whose ages ranged between 8 and 17 years (Trinies et al., 2016).

In a survey by Holdsworth (2012), when asked about their opinion about the importance of water for physical and mental performance, less than 50 percent of a total of 1,980 healthcare professionals from several European countries recognized that hydration had any positive effect on mental performance. Holdsworth (2012) noted a response trend toward overestimating the contribution from food, and underestimating that from beverages, and calls for further reinforcing education among health professionals with respect to the effects of hydration on mental well-being and performance.

**Conclusion**

The limited documentation on the role hydration plays in the cognitive performance of school-age children explains why health experts do not dedicate much discussion to water (Holdsworth, 2012). More studies are needed to highlight the negative effects of dehydration on fundamental cognitive skills that are required for effective school performance in children. Better methodological tools are required to enhance the quality of such studies. The relationship between dehydration and cognition must be tackled in more depth in the documentation of international organizations seeking to improve the status of nutrition in the world. The following lessons have emerged from this review.
Many children, all over the world, come to school in a dehydrated state (Assael et al., 2012; Bar-David et al., 2005; Bonnet et al., 2012; Edmonds et al., 2013; Fadda et al., 2012; Gouda et al., 2015); it is therefore crucial to provide fresh clean water to children early in the school day. A study in Cambodia found a strong association between the provision of free and safe drinking water to schools and reduced school absenteeism, implying that availability of improved hydration leads to improved school experience for children (Hunter et al., 2015).

Children must be reminded of the necessity to drink water (Bar-Or et al., 1980; Benton, 2011; D’Anci et al., 2006; Edmonds, 2010; Kavouras et al., 2012); schools must emphasize and encourage the consumption of water during a typical school day, instead of soft beverages, as a thirst quencher. Lessons ought to be learned from previously documented good practices, such as the “Water is Cool in School” campaign for providing access to fresh drinking water for children in UK primary and post-primary schools (Branden, 2003; WHO Programme for Nutrition and Food Security, 2006).

The consumption of water should be reinforced among children during the school day through a variety of practices, such as allowing children to drink in class, providing bottled water in school vending machines, and designing and implementing awareness-raising strategies and creative lesson plans that educate children on the benefits of healthy hydration.

More research is needed to further explore the relation between the impact of water and dehydration and cognitive functioning, both at the adult and children levels. Such research necessitates the establishment of consistent measurement tools of cognitive performance across different cultural settings. Outcomes of such research ought to be disseminated in a more effective manner so as to reach public audiences, instead of being restricted to the scientific community.

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