Is there a functional relationship between hydration and memory in children and adolescents? A meta-analysis.

Gilberto Ramos Vieira1, Lívia Maria de Lima Leôncio1, Clécia Gabriela Bezerra1, Mirian Celly Medeiros Miranda David2, Rhowena Jane Barbosa de Matos2,3,*

1Physical Education and Sports Science Nucleus, Academic Center of Vitória, Federal University of Pernambuco (UFPE). Vitória de Santo Antao, Pernambuco, Brazil.
2Postgraduate program in Neuropsychiatry and Behavioral Sciences, Health Sciences Center, Federal University of Pernambuco (UFPE). Recife, Pernambuco, Brazil.
3Health Sciences Center, Federal University of Recôncavo da Bahia (UFRB), Santo Antônio de Jesus, Bahia, Brazil.

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ABSTRACT

Objective: Hydration can favor cognitive functions during childhood and adolescence, helping with daily and school activities. This study aimed to identify possible interactions between hydration and memory in children and adolescents.

Methods: This is a systematic review with meta-analysis. The bibliographic search was conducted in the MEDLINE/PubMed, SciELO, LILACS, Web of Science, Embase, and Cochrane Library databases, through a combination of the descriptors: “hydration” AND “memory”; “hydration” AND “memory” AND “child”; “hydration” AND “memory” AND “children”; “organism hydration status” AND “memory”; “organism hydration status” AND “memory” AND “child”.

Results: The search resulted in 816 articles, of which ten were selected for qualitative synthesis and two for the meta-analysis. The results indicated that hydration could not enhance working, visual and visuomotor memories, or visual attention (Line Tracing Task, MD 0.67, 95% CI -0.87 to 2.22; Indirect Image Difference, MD 0.32, 95% CI -0.75 to 1.40; Letter Cancellation, MD 1.68, 95% CI -0.81 to 4.17).

Conclusion: From the obtained results, hydration per se does not reinforce working, visual and visuomotor memories, or visual attention. However, there are still gaps regarding other types of memory and cognitive, motor, nutritional and environmental integration.

*Corresponding author:
Centro de Ciências da Saúde, Universidade Federal do Recôncavo da Bahia
Addr.: Avenida Carlos Amaral, 1015, Cajueiro. Santo Antônio de Jesus, Bahia, Brazil | CEP: 44.574-490
Phone/Fax: +55 75 36730568
E-mail: rhowena.matos@ufrb.edu.br | rhowenajane@gmail.com (Matos RJB)

The study was conducted at the Federal University of Pernambuco (UFPE)

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INTRODUCTION

Drinking water is essential for preserving the body’s hydration. Since water intake can be lower than the loss of body fluids, this may generate a deficit of 2%, thus causing the dehydration process\(^1,2\). Dehydration results in decreased blood volume and an increase in plasma osmolarity, activating baroreceptors and osmoreceptors. Additionally, it triggers fluid retention, subsequently activating the thirst mechanism, restoring water balance. A lack of fluid replacement can cause changes to the physiological systems, mainly to the nervous system, along with cognitive changes\(^2,3\). Thus, it appears that even slight dehydration with a body water loss of 1% to 2% can cause impairments in cognitive performance\(^2\).

Cognitive performance is related to attention, perception, thinking skills, decision making, reasoning, language, and memory\(^4\). Several researchers have investigated methods to assess the influence of hydration on human memory in the last decade, but these studies are still unclear due to the divergences in investigated methods to assess the influence of hydration on human memory. To outline how hydration status can influence cognitive aspects of children and adolescents.

Memory is one of the cognitive functions and can be defined as the brain’s ability to acquire, store and remember information based on lived experiences\(^5\). It can be classified according to duration in ultra-fast memory, short-term memory, and long-term memory. Furthermore, according to the information stored, it can be divided into declarative or explicit, non-declarative or implicit, and working memory\(^6\). The mnemonic process involves acquiring, retaining, consolidating, and evoking memories\(^7,8\). These processes are formed by new neuronal connections, which depend on the intra- and extracellular hydro-electrolytic balance, which comes from a hydrated body\(^9,10\). Inadequate hydration, especially in childhood, can cause problems in the memory acquisition and consolidation process, leading to learning difficulties and impaired motor development\(^11,12\).

The importance of hydration for health aspects has been constantly evidenced. Its effects help in daily well-being and are essential for organism functioning; however, the mechanisms of the functional integration between hydration and memory in children and adolescents are still unclear. Therefore, in this work, we sought to identify studies in the scientific literature that showed possible relationships between hydration and memory to outline how hydration status can influence cognitive aspects of children and adolescents.

METHODS

This study is a systematic review with meta-analysis developed according to the Cochrane Handbook for Systematic Reviews of Interventions\(^13\), which guided the realization of this review. The writing of this review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses - (PRISMA)\(^14\). The study is registered in the International Prospective Register of Systematic Reviews - PROSPERO (CRD42020170310).

The PECO\(^15\) strategy (Population, Exposure, Comparison, Outcome) was used as an eligibility criterion for the studies included in this review, as well as for elaborating the following guiding question: “Is there a relationship between hydration and memory in children and adolescents?” (P: Children and adolescents, E: Increased or decreased fluid intake, C: Individuals who were not stimulated with fluids, O: Changes in memory). Studies were searched in the following databases: MEDLINE/PubMed (via National Library of Medicine), Scientific Electronic Library Online (SciELO), Latin American and Caribbean Literature in Health Sciences (LILACS), Web of Science, Embase and the Cochrane Library. The articles were selected without restrictions to the publication year or language. The following combinations of descriptors were applied: “hydration AND memory”; “hydration AND memory AND child”; “hydration AND memory AND children”; “organism hydration status AND memory”; “organism hydration status AND memory AND child” (Table 1).

The inclusion criteria considered in this review were the following:
• Randomized or crossover studies (crossover studies were included to verify the effect of hydration considering the contextual and physiological variability of each organism) on the relationship between hydration and memory;
• Studies with children and adolescents, aged 4 to 17 years;
• Studies with at least one control group.

Articles were excluded if they were 1) incomplete or unpublished; 2) studies on animals or plants; 3) about the presence of any pathology or use of drugs. The decision to exclude incomplete articles was due to the need to know the details of the study design and the results found to conduct a more careful and less biased analysis. Similarly, unpublished articles were excluded since they may present less methodological and statistical rigor as they do not undergo peer review, culminating in inconclusive results.

### Table 1 — Combinations of descriptors applied in the search for studies.

| Combinations of descriptors                  | Embase | MEDLINE/PubMed | Web of Science | Cochrane Library | SciELO | LILACS |
|---------------------------------------------|--------|----------------|----------------|------------------|--------|--------|
| Hydration AND Memory                        | 200    | 186            | 244            | 34               | 5      | 0      |
| Hydration AND Memory AND Child              | 21     | 16             | 21             | 11               | 0      | 0      |
| Hydration AND Memory AND Children           | 26     | 16             | 21             | 11               | 0      | 0      |
| Organism Hydration Status AND Memory        | 0      | 2              | 0              | 2                | 0      | 0      |
| Organism Hydration Status AND Memory AND Child | 0      | 0              | 0              | 0                | 0      | 0      |
| Total                                       | 247    | 220            | 286            | 58               | 5      | 0      |

The search and selection of articles according to the eligibility criteria occurred in December 2020 by two evaluators (GV and LL) who acted independently. The articles were grouped in spreadsheets according to the selection step, which was initially performed by reading the titles and abstracts, followed by reading in full. The evaluators discussed and agreed in cases of conflict. When there were no agreements between the two initial reviewers, the third reviewer (CB) decided whether or not to include the article.

A PRISMA flowchart was used to present the selection of articles (Figure 1). The critical analysis of the studies was conducted by two evaluators (MD and CB) using the Risk of Bias tool (RoB 2)\textsuperscript{18} for randomized studies and the Risk of Bias in Non-randomized Studies tool (ROBINS-I)\textsuperscript{18,21} for crossover studies. The results of the critical analysis were plotted using Risk-of-bias Visualization (RoBVis)\textsuperscript{22}. The qualitative synthesis was performed by grouping the results extracted in tables according to the participant characteristics and the studies, objectives, instruments used, and molecular/cellular and behavioral results. The memory outcomes established in this review were working, visual, visuomotor, and declarative memories, as well as short and long-term memories.

Quantitative synthesis was performed using Review Manager 5.4 and presented in a forest plot graph\textsuperscript{23}. The synthesis was composed of similar variables among randomized studies with similar methods. The mean, standard deviation, and sample size of the studies were used to calculate the effect size of the results. The association adopted was the standardized mean difference, and the random-effects model was used because the effects of exposure are unlikely to be truly identical. Heterogeneity was measured using $I^2$ and the chi-square test.

### RESULTS

The search identified 816 articles using the reference terms proposed, of which only 10 were selected to perform a qualitative synthesis of their content (5 randomized and 5 crossover studies). From the studies evaluated using the RoB 2 (Figures \textsuperscript{2})\textsuperscript{6,7,10,28,29}, 4 presented some concerns on the overall critical analysis of bias\textsuperscript{6,7,10,28}, and one had a high risk of bias\textsuperscript{29}. Regarding the crossover studies (Figure 3), all studies showed some concerns on the risk of bias through ROBINS-I\textsuperscript{19,24-27}.

Regarding the participants’ characteristics in the selected studies, the sample was composed only of children and adolescents whose ages varied between 4 and 17. Most of the selected studies conducted their interventions within the school where they selected students at random, allocating them into two or three groups, with one being the control and the others for interventions\textsuperscript{6,7,9,25,27,29}. Five studies made a single group and performed the intervention with all participants, evaluating them before and after the intervention\textsuperscript{6,7,9,25,27,29}.

Among the studies included in this research, only the work by Khan et al. (2019)\textsuperscript{26} performed a water supplementation period of more than one day. The amount of water supplied and/or ingested by the subjects varied between 1.5 to 2.5 L and 250 mL per day. Six studies had divergences in the quantity of water supplied and/or ingested by the subjects, ranging from 25 mL to 1.5 L in a single day of intervention\textsuperscript{6,7,9,25,27,29}.
**Figure 1** — Flowchart of article eligibility.

**Figure 2** — Assessment of the risk of bias (RoB 2) for all included randomized studies.
One of the studies did not define the amount of water that the participants should drink; however, the individuals participated in a training session on the importance of water intake before the intervention day, and then on the intervention day, they were reminded to drink water during the day. Thus, the children drank water ad libitum, and the total amount of intake was recorded at the end of the school day28 (Table 2).

### Table 2 — Quantity and time of water intake and type of cognitive function investigated.

| Authors                              | Study Type   | Age of participants | Water intake (mL) | Ingestion time (min) | Hydration assessment            | Cognitive assessment                        |
|--------------------------------------|--------------|---------------------|-------------------|----------------------|---------------------------------|---------------------------------------------|
| Benton & Burgess, 200924              | Crossover    | 8 y and 7 m         | 300               | 20 to 35             | Not measured                    | Memory; Attention                           |
| Edmonds & Burford, 20097             | Randomized   | 7 y and 7 m - 9 y and 8 m | 250               | 20                   | Subjective scale of thirst      | Memory                                      |
| Fadda et al., 20126                  | Randomized   | 9-11 y              | 1,000             | 360                  | Osmolality                      | Memory                                      |
| Perry et al., 20159                  | Crossover    | 9-12 y              | 750               | 180                  | Osmolality                      | Memory                                      |
| Trinies et al., 201610               | Randomized   | 8-17 y              | Not specified     | 360                  | Urine color; Urine specific gravity | Memory                                      |
| Edmonds et al., 201729               | Randomized   | 7-10 y              | 25 - 300          | 20                   | Subjective scale of thirst      | Memory; Visual attention                     |
| Edmonds et al., 201822               | Crossover    | 9-10 y              | 25                | 20                   | Subjective scale of thirst; Osmolality | Memory                                      |
| Khan et al., 201926                  | Crossover    | 9-11 y              | 2,500             | 1,320 during 4 days  | Urine color; Urine specific gravity | Memory; Attention; Cognitive control and flexibility |
| Chard et al., 201925                  | Crossover    | 9-16 y              | 1,500             | 360                  | Subjective scale of thirst; Urine color; Urine specific gravity | Memory                                      |
| Drozdowska et al., 202028            | Randomized   | 10-12 y             | 1,175 ± 640       | 360                  | Subjective scale of thirst; Urine color | Memory; Attention; Cognitive control and flexibility |
From the studies included in this research, only the amount of water ingested was measured, while the participant's hydration level was not assessed. For example, the participants in one study received a bottle of drinking water, which could be refilled throughout the day as many times as needed. However, the total volume of water ingested by the respondent was not measured at the end of the day.10

Concerning the water intake period, half of the studies included in this review ingested it between 30 min to 2 h7,9,24,27, while others throughout the school day6,25,28. Khan et al. (2019)26 performed two interventions of 4 days each, while low water intake (0.5 L/day) was performed in one group, and there was a high water intake (2.5 L) in the other group. Regarding the study by Trinies et al. (2016)10, the methodological procedure for the number of assessment days was unclear. The studies used a subjective thirst scale for evaluating the participants’ thirst through self-assessment and perception indicated by the respondent.7,25,27,29

The most used methods for the cellular analysis of hydration were to check the osmolarity level6,9,26 and/or the urine-specific gravity10,25,26. In addition, four studies used the urine color scale to assess the hydration level of the individuals10,25,26,28.

The articles assessed attention, memory and cognitive control, and flexibility to discover a possible interaction between children and adolescent hydration and cognitive aspects. Thus, the most used tests for assessing the attention and concentration of individuals were Letter cancelation and Forwards digit span6,7,9,10,25,27,29. Additionally, attention and cognitive control were described in three studies that used the Flanker task26,28. Another study used the paradigm of Shakow to assess the ability to maintain attention24. Finally, the Switch Task was used in the studies by Khan et al. (2019)26 and Drozdowska et al. (2020)28 to assess spatial attention and switching skills between two different tasks (Table 3).

Table 3 — Instruments for assessing the cognitive aspects.

| Cognitive test                  | Type of memory and/or attention evaluated | Cognitive aspects                              | Authors                                                                 |
|---------------------------------|------------------------------------------|------------------------------------------------|------------------------------------------------------------------------|
| Letter cancellation             | - Working memory; - Visual memory; - Visual attention | Memory / Attention                            | Trinies et al., 201610; Chard et al., 201925; Perry et al., 20159; Edmonds & Burford, 20097; Edmonds et al., 201827; Edmonds et al., 201729. |
| Direct image difference        | - Working memory; - Visual memory; - Visual attention | Memory / Attention                            | Trinies et al., 201610; Chard et al., 201925; Edmonds & Burford, 20097.   |
| Indirect image difference      | - Working memory; - Visual memory; - Visual attention | Memory / Attention                            | Trinies et al., 201610; Chard et al., 201925; Edmonds & Burford, 20097.   |
| Forward digit recall           | - Short-term memory; - Declarative memory | Memory                                         | Trinies et al., 201610; Chard et al., 201925; Perry et al., 20159; Fadda et al., 20126; Edmonds et al., 201827; Edmonds et al., 201729. |
| Reverse digit recall           | - Short-term memory; - Declarative memory | Memory                                         | Trinies et al., 201610; Chard et al., 201925; Perry et al., 20159; Fadda et al., 20126. |
| Line tracing task              | - Visuomotor memory                      | Memory                                         | Trinies et al., 201610; Chard et al., 201925; Edmonds & Burford, 20097.   |
| Recall of objects test         | - Short and long-term memories           | Memory                                         | Benton & Burgess, 200924.                                               |
| The paradigm of Shakow         | - Short-term memory; - Declarative memory | Memory                                         | Benton & Burgess, 200924.                                               |
| Flanker task                   | - Visual attention                       | Cognitive control: Attention / Focus           | Khan et al., 201926; Drozdowska et al., 202028.                          |
| Go/No go                       | - Visual attention                       | Cognitive control: Attention / Focus           | Khan et al., 201926.                                                    |
| Switch task                    | - Spatial attention                      | Cognitive Inhibition and flexibility; Memory   | Khan et al., 201926; Drozdowska et al., 202028.                          |
| Corsi black tapping            | - Visuospatial attention; - Working memory | Memory / Attention                            | Drozdowska et al., 202028.                                             |
| 2-back task                    | - Storage; - Information retrieval       | Memory                                         | Drozdowska et al., 202028.                                             |
Some studies used tests for memory, visual attention, and visuomotor skills, such as a difference in direct and indirect images, line tracing task, forward, and reverse digit recall. One study used the Recall of objects test, while another study used the Corsi Black-Tapping Task to examine the performance of visuospatial attention and working memory. In the study by Fadda et al. (2012), the researchers chose to adapt an Italian test battery, Wechsler Intelligence Scale for Children - III, and the Group Embedded Figure Test. The 2-back task was used in one study to examine the ability to store and retrieve new information.

Other researchers have also chosen to use validated tests in previous research and to construct new ones. These studies assessed short and long-term memory, working memory, executive functions, visuomotor performance, verbal analogies, and visuospatial skills.

For the time taken to perform the memory tests, there were differences in the time interval between water intake and application of the memory tests, which varied between 20 and 45 min for some studies. Other studies performed memory tests at the end of the school day, meaning after an average time of 6 h of intervention with water intake. Furthermore, one study applied the tests after the end of the fourth day of water supplementation and another in the school interval, after an average of 3 h.

Higher water intake was associated with better short-term memory, working memory, visual memory, cognitive flexibility, cognitive functions, and visual attention. Alternatively, the studies by Trinies et al. (2016) and Edmonds et al. (2017) found no association between hydration and memory (Table 4).

**Quantitative synthesis of the results**

Only two randomized studies showed sufficient similarities to participate in the meta-analysis. Therefore, it was possible to perform the quantitative synthesis for the outcomes of three instruments: the Line Tracing Task, Indirect Image Difference, and Letter Cancellation. Regarding the Line Tracing Task (two studies, 334 participants), there was no statistically significant effect in favor of hydration or the control group (MD 0.67, 95% CI -0.87 to 2.22; p > 0.05; I² = 0%). Likewise, a significant effect was not verified for the Indirect Image Difference (two studies, 323 participants) in any group (MD 0.32, 95% CI -0.75 to 1.40; p > 0.05; I² = 86%). Finally, there was no effect of hydration (two studies, 330 participants) on Letter Cancellation (MD 1.68, 95% CI 0.81 to 4.17; p > 0.05; I² = 58%).

![Figure 4](image-url) — Effects of hydration on the memory of children and adolescents.
Table 4 — Studies investigating the relationship between hydration and memory.

| Authors (year)          | Gender                     | Age                  | Objective                                                                                                                                                                                                 | Molecular and/or cellular results                                                                 | Behavioral results                                                                                   |
|------------------------|----------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Benton & Burgess, 2009  | 18 girls, 22 boys, n = 40  | 8 y and 7 m          | Examined the influence of giving additional water on memory and attention of school children.                                                                                                             | The main effect of whether the water had been consumed was not significant.                         | Memory was better when water had been consumed. However, the sustained attention was not influenced by hydration. |
| Chard et al., 2019      | 46 girls, 61 boys, n = 107 | 9-16 y               | Assessed hydration levels and investigated the impact of supplemental drinking water on the cognitive performance of students from water-scarcity schools in rural Mali.                               | -                                                                                                   | Hydration did not improve the cognitive performance. However, boys performed worse when dehydrated and girls had better performance when dehydrated. |
| Edmonds & Burford, 2009 | 32 girls, 26 boys, n = 58  | 7 y and 7 m - 9 y and 8 m | Investigated whether drinking water improved children's performance in cognitive tasks.                                                                                                                | -                                                                                                   | Children who drank water performed significantly better. Performance in history memory and visuomotor tracking tasks was not significant. |
| Edmonds et al., 2017    | 35 girls, 25 boys, n = 60  | 7-10 y               | Evaluated the dose response effect of water on cognitive performance and mood of children and adults.                                                                                            | -                                                                                                   | Among children, hydration improved the performance of visual attention. However, water intake did not influence memory. |
| Edmonds et al., 2018    | 14 girls, 10 boys, n = 24  | 9-10 y               | Examined the effect of mouth rinsing and dry mouth on cognitive performance.                                                                                                                               | -                                                                                                   | Significant improvement in visual attention.                                                        |
| Fadda et al., 2012      | 86 girls, 82 boys, n = 168 | 9-11 y               | Investigated the physiological hydration status of children at the beginning of the school day; Examine whether and to what extent hydration levels are influenced by water consumption at school; Verified how cognitive performance and transient subjective states are influenced by hydration levels during a school day. | Drinking supplementary water at school had a positive effect on the hydration status of dehydrated children. | There was a beneficial effect of drinking supplementary water at school on short-term memory.          |
Table 4 — Studies investigating the relationship between hydration and memory (cont.).

| Authors (year) | Gender | Age | Objective | Molecular and/or cellular results | Behavioral results |
|----------------|--------|-----|-----------|-----------------------------------|--------------------|
| Khan et al., 2019<sup>26</sup> | 43 boys, 32 girls, n = 75 | 9-11 y | Investigated the effects of water intake on urinary markers of hydration and cognition of pre-adolescents. | Urine color in the low fluid intake > habitual fluid intake > high fluid intake. | Cognitive flexibility selectively benefits from greater hydration. |
| Perry et al., 2015<sup>9</sup> | 26 girls, 26 boys, n = 52 | 9-12 y | Examined the effects of water intake on children hydration status, memory and attention. | Urine osmolality at awakening and during the control day were predictors of urine osmolality reduction during the water day. | Children who exhibited smaller decreases in urine osmolality following water intake performed significantly better on the water day compared to the control day on a digit-span task and pair-cancellation task. |
| Trinies et al., 2016<sup>10</sup> | 147 girls, 129 boys, n = 276 | 8-17 y | Evaluated the impact of drinking water on cognition among school children in environments with water scarcity. | Students were classified as dehydrated in the morning. | No influence of hydration on cognitive tests. |
| Drozdowska et al., 2020<sup>28</sup> | 154 boys, 96 girls, n = 250 | 10-12 y | Investigated the effects of increased water intake on of cognitive performance, hydration, and physical activity. | - | Increasing water intake improved children’s memory (executive functions). |
DISCUSSION

The results of this review show that free access to water for children and adolescents, especially during the school day, enables better results in hydration levels. Additionally, it was found through meta-analysis that dehydration did not improve working, visual and visuomotor memories, or visual attention.

Thus, it is worth noting that the water balance differs between different age levels. For example, the average daily water consumption (endogenous, food, and water intake) in a sedentary adult varies between 2 to 3 L, while this variation in children and adolescents is around 1.2 to 2.6 L per day. Water loss greater than intake may result in a dehydration process, generating numerous physiological changes in the body, such as increased circulating cortisol, dendritic atrophy in brain tissue, and increased glutamine, which in high concentration can favor inflammatory processes in nerve cells and even cause neurodegenerative pathologies. One of the consequences of changes in nerve cells due to the dehydration process may be impairment in the individual’s cognitive performance.

Given the information described above, studies have pointed to a prevalence of mild dehydration level in children and adolescents at the beginning of the school day, corroborating the findings of Bar-David (2009; 2005). However, another study included in this review reported that about 18% of the participants had not drunk water during the early morning. Such a state of mild dehydration may be due to the long nighttime sleep with an absence of water intake during this time interval. Additionally, the preference of replacing water with other liquids at the beginning of the day can be considered. Such preferences can be associated with economic, cultural, and body composition issues.

Another factor that can contribute to the dehydration of children and adolescents throughout the school day is the lack of knowledge on behalf of teachers about the importance of hydration, often depriving students of drinking water during class, or even due to an absence of public policies aimed at guaranteeing the supply of drinking water in schools. According to the United Nations Children’s Fund (UNICEF) report in 2016, 19% of schools worldwide did not have a water supply service available to students.

A significant improvement in hydration levels was identified in children and adolescents whose access to water was facilitated during the school day. Thus, water can be seen as another vital component to compose the students’ diets. Furthermore, studies show that children and adolescents with better hydration levels had an adequate diet. Thus, chronic water intake can be an additional diet component related to developing the cognitive functions of children and adolescents.

Dehydration can directly impair cognitive performance. This concept is due to some symptoms resulting from changes in the individual’s hydration level, such as reduced hypovolemic perfusion in the brain and some metabolic and electrolyte changes that can cause hypernatremia and elevate the plasma urea concentration, alkalosis associated with hypovolemia. Additionally, there may be some hormonal changes related to glucocorticoids, primarily cortisol, which alter the stress level and can impair attention and concentration, vasopressin, and some other substances such as nitric oxide and cytokines. This finding indicates the direct relationship between maintaining the hydration level and controlling the level of circulating cortisol. As this hormone is related to stress, its regulation can improve psychological stability in an individual when performing cognitive tests.

Studies show that a high hydration level is responsible for significant improvements in visual attention. Also, there is evidence regarding the positive relationship between maintaining the hydration level and cognitive aspect through the Flanker Task, whose objective is to assess the focus and attention of children. Some brain areas activated during visuospatial attention and motor control tasks are the frontal gyrus, cerebellum, pre-central gyrus, upper temporal lobe, and parietal and occipital areas. Thus, there is a need for studies regarding the hydration mechanism’s interference in the activity of these areas.

This review does not point to the benefits of hydration in the working, visual and visuomotor memories or visual attention of children and adolescents. However, it also signals a need for future research since the evidence shows that hydration favors cognitive aspects. However, there are some uncertainties about the assessment instruments used to analyze each aspect of cognition, understanding the complex nervous system process mechanisms. In addition, the effects of water intake on cognitive aspects may not have the same benefit for all children and adolescents due to the social and biological differences in each one.

It is known that a lack of adequate fluid intake and too much fluid loss can lead to severe dehydration, altering the functions of many systems and causing life-threatening conditions. However, mild dehydration of 1 or 2% loss of water from the body can impair cognitive functions and even the capability to perform physical exercise due to muscle fatigue caused by dehydration. Besides, environmental differences that can interfere with the balance of body fluids in children and adolescents need to be considered, especially when it is associated with moderate exercise in a high-temperature environment. The balance is maintained, and hyperthermia is avoided through voluntary water consumption during such activity. In addition, children’s voluntary water intake can maintain their hydration status, even if that water has different additional flavors.

Other limitations were found in the studies included in this review, such as a lack of standardization in the amount of water ingested, although the existence of water intake recommendations from the Institute of Medicine (2008) by age and a study that indicated supposedly ideal values for daily water consumption. Also, a lack of consensus among the studies regarding the methods used, such as memory/cognition tests, intake periods, and quantity of water ingested, hindered comparisons and analyzes among the included studies.

Based on this information, there is a need for
additional research addressing the theme of this study among children and adolescents. Thus, studies can consider variables integrated into these functions, such as promoting nutritional guidelines regarding the recommended water intake values. It is still possible to highlight the need to assess food consumption since it is directly linked to the hydration level and affects the brain. Additionally, the influence of hydration on the physical fitness of children and adolescents can be assessed, whether in the school environment or outside. Finally, it is worth mentioning that free access to drinking water in schools being encouraged by teachers and educational campaigns can positively improve the habit of drinking water and consequently improve students’ hydration levels.

Therefore, research involving all these aspects can help understand the functional mechanisms in the interaction between hydration, memory, and motor aspects. In broader terms, they can provide essential data to develop strategies that seek to favor children and adolescent motor and cognitive development.

CONCLUSION

Hydration does not enhance working, visual, and visuomotor memories, or visual attention. Therefore, future research should consider variables that involve integrating cognitive, motor, and nutritional factors and the context in which these individuals are inserted, developing strategies that favor the development of children and adolescents.

REFERENCES

1. Kremer IM, Kolega M, Kunac SF. The effects of drinking water on attention. Procedia - Soc Behav Sci. 2014;159:577-83. https://doi.org/10.1016/j.sbspro.2014.12.428

2. Riebel SK, Davy BM. The hydration equation: update on water balance and cognitive performance. ACSMs Health Fit J. 2013;17(6):21-8. https://doi.org/10.1249/FIT.0b013e3182a9570f

3. Armstrong LE. Hydration assessment techniques the importance of hydration assessment. Nutr Rev. 2005;63(suppl 1):S40-S54. https://doi.org/10.1111/j.1753-4887.2005.00015.x

4. Schmit C, Hausswirth C, Le Meur Y, Duffield R. Cognitive functioning and heat strain: performance responses and protective strategies. Sport Med. 2017;47(7):1289-302. https://doi.org/10.1007/s40279-016-0657-z

5. Benton D. Dehydration influences mood and cognition: A plausible hypothesis? Nutrients. 2011;3(5):555-73. https://doi.org/10.3390/nu3050555

6. Fadda R, Rapinett G, Grathwohl D, Parisi M, Fanari R, Calò CM, et al. Effects of drinking supplementary water at school on cognitive performance in children. Appetite. 2012;59(3):730-7. https://doi.org/10.1016/j.appet.2012.07.005 PMID:22841529

7. Edmonds CJ, Burford D. Should children drink more water? The effects of drinking water on cognition in children. Appetite. 2009;52(3):776-9. https://doi.org/10.1016/j.appet.2009.02.010

8. Khan NA, Raine LB, Drollette ES, Scudder MR, Cohen NJ, Kramer AF, et al. The relationship between total water intake and cognitive control among prepubertal children. Ann Nutr Metab. 2015;66(Suppl 3):38-41. https://doi.org/10.1159/000381245 PMID:26088046

9. Perry CS 3rd, Rapinett G, Glaser NS, Ghetti S. Hydration status moderates the effects of drinking water on children’s cognitive performance. Appetite. 2015;95:203-5. https://doi.org/10.1016/j.appet.2015.08.006 PMID:26271221

10. Trinities V, Chard AN, Mateo T, Freeman MC. Effects of water provision and hydration on cognitive function among primary-school pupils in Zambia: A Randomized Trial. PLoS One. 2016;11(3):e0150071. https://doi.org/10.1371/journal.pone.0150071 PMID:26950696 PMCID:PMC4780815

11. Mourão CA, Faria NC. Memória. Psicol Reflex Crit. 2015;28(4):780-788. https://doi.org/10.1590/1678-7153.201528416

12. Mayford M, Siegelbaum SA, Kandel ER. Synapses and memory storage. Cold Spring Harb Perspect Biol. 2012;4(6):a005751. https://doi.org/10.1101/cshperspect.a005751 PMID:22496389 PMCID:PMC3367555

13. von Hameln. Memórias. Aq Maarañ. 2013;7(12):203-5. https://doi.org/10.17851/1982-3053.7.12.203-205

14. Cantarino JMF, Pereira DA. Memória: da filosofia à neurociência. Univ Cienc Saúde. 2004;2(2):164-99. https://doi.org/10.5102/ucsi.v2i2.531

15. Milner B, Squire LR, Kandel ER. Cognitive neuroscience and the study of memory. Neuron. 1998;20(3):445-68. https://doi.org/10.1016/S0896-6273(00)80987-3 PMID:9539121

16. Gerbasi GLBS, da Costa PJ. As transformações da memória: Articulações entre Sigmund Freud e Eric Kandel. Ap. Psicol Latinoam. 2015;33(1):77-89. https://doi.org/10.12804/apl33.01.2015.06

17. Bailey CH, Kandel ER, Harris KM. Structural components of synaptic plasticity and memory consolidation. Cold Spring Harb Perspect Biol. 2015;7(7):a021758. https://doi.org/10.1101/cshperspect.a021758 PMID:26134321 PMCID:PMC484970

18. Cumpston M, Li T, Page MJ, Chandler J, Welch VA, Higgins JP, Thomas J. Updated guidance for trusted systematic reviews: a new edition of the Cochrane Handbook for Systematic Reviews of Interventions. Cochrane Database Syst Rev. 2019;10:ED000142. https://doi.org/10.1002/14651858.ed000142 PMID:31643080

19. Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, et al; PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ. 2015;350:i4086. PMID:25555855

20. Morgan RL, Whaley P, Thayer KA, Schünemann HJ. Identifying the PECO: A framework for formulating good questions to explore the association of environmental and other exposures with health outcomes. Environ Int. 2018;121(1):1027-31. https://doi.org/10.1016/j.envint.2018.07.015 PMID:29808441

21. Sterne JA, Hernán MA, Reeves BC, Savovic J, Berkman ND, Viswanathan M, et al; ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ. 2016;355:i4919. https://doi.org/10.1136/bmj.i4919 PMID:27733354 PMCID:PMC5062054

22. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. Res Synth Methods. 2021;12(1):55-61. https://doi.org/10.1002/14651858.ed000142 PMID:31643080

23. Review Manager (RevMan) [Computer program]. Version 5.4. The Cochrane Collaboration (2020).

24. Benton D, Burgess N. The effect of the consumption of water on the memory and attention of children. Appetite. 2009;53(1):143-6. https://doi.org/10.1016/j.appet.2009.05.006 PMID:19445987

25. Chard AN, Trinities V, Edmonds CJ, Sogore A, Freeman MC. The impact of water consumption on hydration and cognition.
among schoolchildren: Methods and results from a crossover trial in rural Mali. PLoS One. 2019;14(1):e0210568. https://doi.org/10.1371/journal.pone.0210568

26. Khan NA, Westfall DR, Jones AR, Sinn MA, Bottin JH, Perrier ET, Hillman CH. A 4-d water intake intervention increases hydration and cognitive flexibility among preadolescent children. J Nutr. 2019;149(12):2255-64. https://doi.org/10.1093/jn/nzx206 PMID:31504690

27. Edmonds CJ, Harte N, Gardner M. How does drinking water affect attention and memory? The effect of mouth rinsing and mouth drying on children’s performance. Physiol Behav. 2018;194:233-8. https://doi.org/10.1016/j.physbeh.2018.06.004 PMID:29885324

28. Drozdowska A, Falkenstein M, Jendrusch G, Platen P, Luecke T, Kersting M, et al. Water consumption during a school day and children’s short-term cognitive performance: The CogniDROP randomized intervention trial. Nutrients. 2020;12(5):1297. https://doi.org/10.3390/nu12051297 PMID:32370147 PMCID:PMC7282257

29. Edmonds CJ, Crosbie L, Fatima F, Hussain M, Jacob N, Gardner M. Dose-response effects of water supplementation on cognitive performance and mood in children and adults. Appetite. 2017;108:464-70. https://doi.org/10.1016/j.appet.2016.11.011 PMID:27825957

30. Jéquier E, Constant F. Water as an essential nutrient: the physiological basis of hydration. Eur J Clin Nutr. 2010;64(2):115-23. https://doi.org/10.1038/ejcn.2009.111 PMID:19724292

31. Taylor PJ, van Rosendal SP, Coombes JS, Gordon RD, Stowasser M. Simultaneous measurement of aldosterone and cortisol by high-performance liquid chromatography-tandem mass spectrometry: application to dehydration-rehydration studies. J Chromatogr B Analyt Technol Biomed Life Sci. 2010;878(15-16):1195-8. https://doi.org/10.1016/j.jchromb.2010.03.033 PMID:20378424

32. Starkman MN, Giordani B, Gebarski SS, Berent S, Schork MA, Schteingart DE. Decrease in cortisol reverses human hippocampal atrophy following treatment of Cushing’s disease. Biol Psychiatry. 1999;46(12):1595-602. https://doi.org/10.1016/s0006-3223(99)00203-6 PMID:10624540

33. Bar-David Y, Urkin J, Landau D, Bar-David Z, Pilpel D. Voluntary dehydration among elementary school children residing in a hot arid environment. J Hum Nutr Diet. 2009;22(5):455-60. https://doi.org/10.1111/j.1365-277X.2009.00960.x PMID:19486262

34. Bar-David Y, Urkin J, Kozminsky E. The effect of voluntary dehydration on cognitive functions of elementary school children. Acta Paediatr. 2005;94(11):1667-73. https://doi.org/10.1080/08035250500254670 PMID:16303708

35. Drewnowska A, Rehm CD, Constant F. Water and beverage consumption among children age 4-13y in the United States: analyses of 2005–2010 NHANES data. Nutr J. 2013 Jun;12:85. https://doi.org/10.1186/1475-2891-12-85 PMID:23728294 PMCID:PMC3698018

36. Molloy CJ, Gandy J, Cunningham C, Slattery G. An exploration of factors that influence the regular consumption of water by Irish primary school children. J Hum Nutr Diet. 2008;21(5):512-5. https://doi.org/10.1111/j.1365-277X.2008.00880.x PMID:18833589

37. World Health Organization. United Nations Children’s Fund. Drinking water, sanitation and hygiene in schools: global baseline report 2018. New York: UNICEF and WHO; 2018 [cited 2021 Jun 17]. Available from: https://un.org/3gyKM4v

38. Häussinger D, Roth E, Lang F, Gerok W. Cellular hydration state: an important determinant of protein catabolism in health and disease. Lancet. 1993;341(8856):1330-2. https://doi.org/10.1016/0140-6736(93)90828-5 PMID:8098459

39. Deng J, Chung L, Talwar N, Tam F, Churchill NW, Schweizer TA, Graham SJ. Functional MRI of letter cancellation task performance in older adults. Front Hum Neurosci. 2019;13:97. https://doi.org/10.3389/fnhum.2019.00097 PMID:31057377 PMCID:PMC6477506

40. Szinnai G, Schachinger H, Arnaud MJ, Linder L, Keller U. Effect of water deprivation on cognitive-motor performance in healthy men and women. Am J Physiol Regul Integr Comp Physiol. 2005;289(1):R275-80. https://doi.org/10.1152/ajpregu.00501.2004 PMID:15845879

41. Wong SH, Sun FH. Effect of beverage flavor on body hydration and cognitive flexibility among preadolescent children. Pediatr Exerc Sci. 2014;26(2):177-86. https://doi.org/10.1123/pes.2013-0080 PMID:24893377

42. Institute of Medicine. Dietary Reference Intakes for water, potassium, sodium, chloride and sulfate [Book]. Washington, DC: The National Academies Press; 2005. https://doi.org/10.17226/10925

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