



ORIGINAL ARTICLE

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

Há relação funcional entre hidratação e memória em crianças e adolescentes? Uma meta-análise.

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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.

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PALAVRAS-CHAVE

Adolescente
Água
Cognição
Criança
Hidratação
Memória

RESUMO

Objetivo: A hidratação pode favorecer as funções cognitivas durante a infância e adolescência, auxiliando as atividades cotidianas e escolares. Portanto, objetivou-se identificar as possíveis interações entre a hidratação e memória em crianças e adolescentes.

Métodos: Trata-se de uma revisão sistemática com meta-análise. A busca foi realizada nas bases de dados MEDLINE/PubMed, SciELO, LILACS, Web of Science, Embase e Cochrane Library, por meio da combinação dos descritores: “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”.

Resultados: A estratégia de busca resultou inicialmente em 816 artigos, dos quais 10 foram selecionados para a síntese qualitativa e dois para a meta-análise. Os resultados indicaram que apenas hidratação não foi capaz de potencializar as memórias de trabalho, visual, visuomotora e atenção visual (*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).

Conclusão: A partir dos resultados obtidos, apenas a hidratação *per se* não fortalece as memórias de trabalho, visual e visuomotora e a atenção visual. Entretanto, ainda há lacunas sobre outros tipos de memória e a integração cognitiva, motora, nutricional e ambiental.

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 performance².

Cognitive performance is related to attention, perception, thinking skills, decision making, reasoning, language, and memory⁴. 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 the protocols used, especially in child and adolescent populations⁵⁻¹⁰.

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 experiences¹¹. 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 memory¹². The mnemonic process involves acquiring, retaining, consolidating, and evocating memories¹²⁻¹⁴. These processes are formed by new neuronal connections, which depend on the intra and extracellular hydro-electrolytic balance, which comes from a hydrated body^{12,15}. Inadequate hydration, especially in childhood, can cause problems in the memory acquisition and consolidation process, leading to learning difficulties and impaired motor development^{13,16,17}.

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 Interventions¹⁸, 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)¹⁹. The study is registered in the International Prospective Register of Systematic Reviews - PROSPERO (CRD42020170310).

The PECO²⁰ 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)¹⁸ for randomized studies and the Risk of Bias in Non-randomized Studies tool (ROBINS-I)^{18,21} for crossover studies. The results of the critical analysis were plotted using Risk-of-bias Visualization (RoBVis)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 graph²³. 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 2)^{6,7,10,28,29}, 4 presented some concerns on the overall critical analysis of bias^{6,7,10,28}, and one had a high risk of bias²⁹. Regarding the crossover studies (Figure 3), all studies showed some concerns on the risk of bias through ROBINS-I^{9,24-27}.

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^{6,7,10,28,29}. Five studies made a single group and performed the intervention with all participants, evaluating them before and after the intervention^{9,24-27}.

Among the studies included in this research, only the work by Khan et al. (2019)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^{6,7,9,25,27,29}.

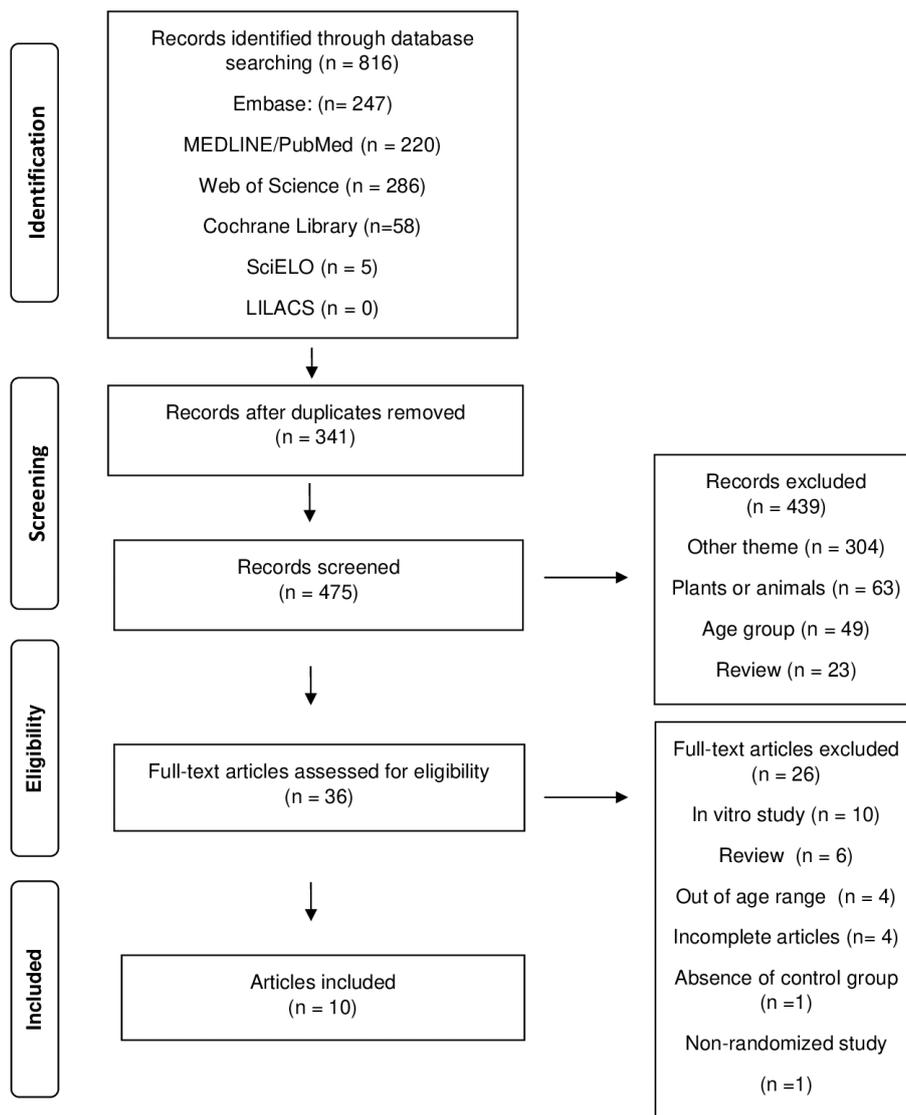


Figure 1 – Flowchart of article eligibility.

Study	Risk of bias domains					Overall
	D1	D2	D3	D4	D5	
Edmonds & Burford, 2009	−	+	+	−	+	−
Fadda et al., 2012	−	+	+	−	+	−
Trinies et al., 2016	+	+	+	−	+	−
Edmonds et al., 2017	×	+	+	−	+	×
Drozowska et al., 2020	+	+	+	−	+	−

Domains:
 D1: Bias arising from the randomization process.
 D2: Bias due to deviations from intended intervention.
 D3: Bias due to missing outcome data.
 D4: Bias in measurement of the outcome.
 D5: Bias in selection of the reported result.

Judgement
 × High
 − Some concerns
 + Low

Figure 2 – Assessment of the risk of bias (RoB 2) for all included randomized studies.

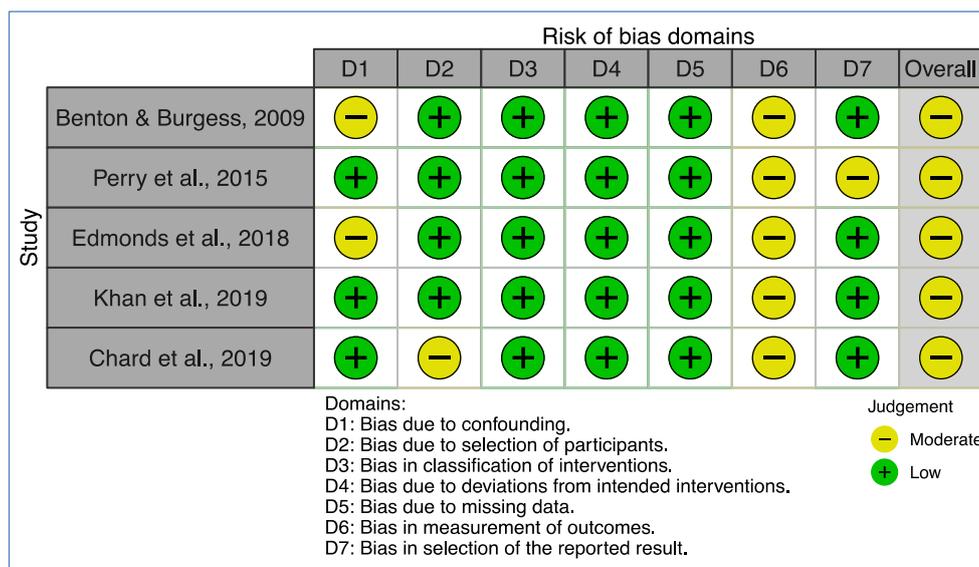


Figure 3 – Assessment of the risk of bias (ROBINS-I) for all included crossover studies.

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, 2009 ²⁴	Crossover	8 y and 7 m	300	20 to 35	Not measured	Memory; Attention
Edmonds & Burford, 2009 ⁷	Randomized	7 y and 7 m - 9 y and 8 m	250	20	Subjective scale of thirst	Memory
Fadda et al., 2012 ⁶	Randomized	9-11 y	1,000	360	Osmolality	Memory
Perry et al., 2015 ⁹	Crossover	9-12 y	750	180	Osmolality	Memory
Trinies et al., 2016 ¹⁰	Randomized	8-17 y	Not specified	360	Urine color; Urine specific gravity	Memory
Edmonds et al., 2017 ²⁹	Randomized	7-10 y	25 - 300	20	Subjective scale of thirst	Memory; Visual attention
Edmonds et al., 2018 ²⁷	Crossover	9-10 y	25	20	Subjective scale of thirst; Osmolality	Memory
Khan et al., 2019 ²⁶	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., 2019 ²⁵	Crossover	9-16 y	1,500	360	Subjective scale of thirst; Urine color; Urine specific gravity	Memory
Drozdowski et al., 2020 ²⁸	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 day¹⁰.

Concerning the water intake period, half of the studies included in this review ingested it between 30 min to 2 h^{7,9,24,27}, while others throughout the school day^{6,25,28}. 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 level^{6,9,26} and/or the urine-specific gravity^{10,25,26}. In addition, four studies used the urine color scale to assess the hydration level of the individuals^{10,25,26,28}.

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 cancellation and Forwards digit span^{6,7,9,10,25,27,29}. Additionally, attention and cognitive control were described in three studies that used the Flanker task^{26,28}. Another study used the paradigm of Shallow 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., 2016 ¹⁰ ; Chard et al., 2019 ²⁵ ; Perry et al., 2015 ⁹ ; Edmonds & Burford, 2009 ⁷ ; Edmonds et al., 2018 ²⁷ ; Edmonds et al., 2017 ²⁹ .
Direct image difference	- Working memory; - Visual memory; - Visual attention	Memory / Attention	Trinies et al., 2016 ¹⁰ ; Chard et al., 2019 ²⁵ ; Edmonds & Burford, 2009 ⁷ .
Indirect image difference	- Working memory; - Visual memory; - Visual attention	Memory / Attention	Trinies et al., 2016 ¹⁰ ; Chard et al., 2019 ²⁵ ; Edmonds & Burford, 2009 ⁷ .
Forward digit recall	- Short-term memory; - Declarative memory	Memory	Trinies et al., 2016 ¹⁰ ; Chard et al., 2019 ²⁵ ; Perry et al., 2015 ⁹ ; Fadda et al., 2012 ⁶ ; Edmonds et al., 2018 ²⁷ ; Edmonds et al., 2017 ²⁹ .
Reverse digit recall	- Short-term memory; - Declarative memory	Memory	Trinies et al., 2016 ¹⁰ ; Chard et al., 2019 ²⁵ ; Perry et al., 2015 ⁹ ; Fadda et al., 2012 ⁶ .
Line tracing task	- Visuomotor memory	Memory	Trinies et al., 2016 ¹⁰ ; Chard et al., 2019 ²⁵ ; Edmonds & Burford, 2009 ⁷ .
Recall of objects test	- Short and long-term memories	Memory	Benton & Burgess, 2009 ²⁴ .
The paradigm of Shallow	- Short-term memory; - Declarative memory	Memory	Benton & Burgess, 2009 ²⁴ .
Flanker task	- Visual attention	Cognitive control: Attention / Focus	Khan et al., 2019 ²⁶ ; Drozdowska et al., 2020 ²⁸ .
Go/No go	- Visual attention	Cognitive control: Attention / Focus	Khan et al., 2019 ²⁶ .
Switch task	- Spatial attention	Cognitive Inhibition and flexibility; Memory	Khan et al., 2019 ²⁶ ; Drozdowska et al., 2020 ²⁸ .
Corsi black tapping	- Visuospatial attention; - Working memory	Memory / Attention	Drozdowska et al., 2020 ²⁸ .
2-back task	- Storage; - Information retrieval	Memory	Drozdowska et al., 2020 ²⁸ .

Some studies used tests for memory, visual attention, and visuomotor skills, such as a difference in direct and indirect images, line tracing task^{7,10,25}, forward, and reverse digit recall^{6,9,10,25,27,29}. One study used the Recall of objects test²⁴, while another study used the Corsi Black-Tapping Task to examine the performance of visuospatial attention and working memory²⁸. In the study by Fadda et al. (2012)⁶, 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 study²⁸ 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^{7,27}. 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^{7,24,27,29}. 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^{6,10,25,28}. Furthermore, one study applied the tests after the end of the fourth day of water supplementation²⁶ and another in the school

interval, after an average of 3 h⁹.

Higher water intake was associated with better short-term memory⁶, working memory⁹, visual memory^{7,9,24}, cognitive flexibility²⁶, cognitive functions²⁸, and visual attention^{7,9,24,27}. Alternatively, the studies by Trinies et al. (2016)¹⁰ and Edmonds et al. (2017)²⁹ 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 (Figure 4)^{7,10}. Therefore, it was possible to perform the quantitative synthesis for the outcomes of three instruments: the Line Tracing Task^{7,10}, Indirect Image Difference^{7,10}, and Letter Cancellation^{7,10}.

Regarding the Line Tracing Task (two studies^{7,10}, 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; $p > 0.05$; $I^2 = 0\%$). Likewise, a significant effect was not verified for the Indirect Image Difference (two studies^{7,10}, 323 participants) in any group (MD 0.32, 95% CI -0.75 to 1.40; $p > 0.05$; $I^2 = 86\%$). Finally, there was no effect of hydration (two studies^{7,10}, 330 participants) on Letter Cancellation (MD 1.68, 95% CI -0.81 to 4.17; $p > 0.05$; $I^2 = 58\%$).

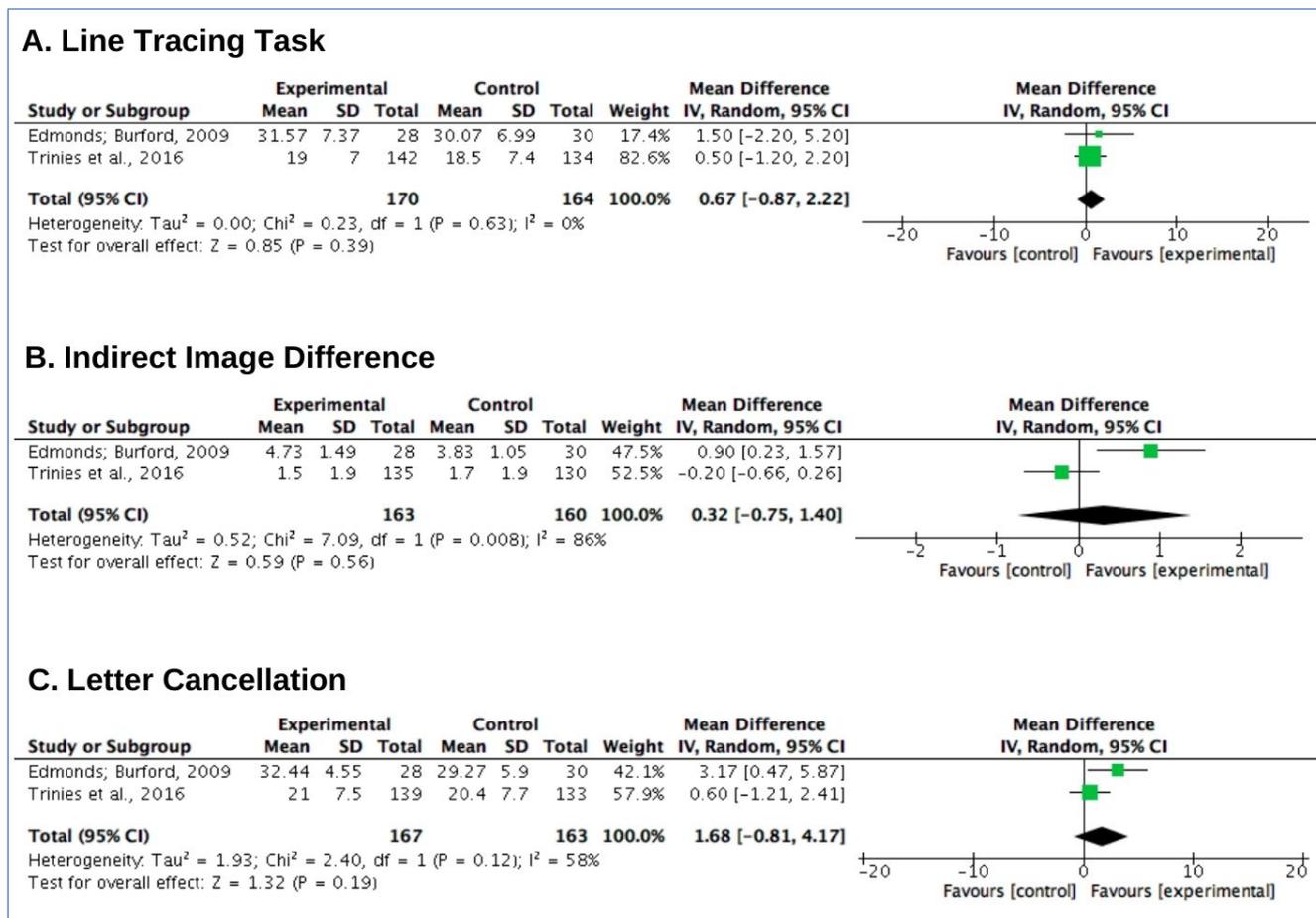


Figure 4 – Effects of hydration on the memory of children and adolescents.

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 ²⁴	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 ²⁵	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 ⁷	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 ²⁹	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 ²⁷	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 ⁶	86 girls, 82 boys, n = 168	9-11 y	Investigated the physiological hydration status of children at the beginning of the school day; Examined 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. The control group's water consumption was not sufficient to improve or maintain adequate levels of osmolality during the school day.	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 ²⁶	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. Osmolality during fluid intake > habitual fluid intake > high fluid intake	Cognitive flexibility selectively benefits from greater hydration.
Perry et al., 2015 ⁹	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 ¹⁰	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 ²⁸	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 hydration 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 day³⁰. 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^{1,26,31,32}. One of the consequences of changes in nerve cells due to the dehydration process may be impairment in the individual's cognitive performance².

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^{6,7,9,10}, corroborating the findings of Bar-David (2009; 2005)^{33,34}. However, another study included in this review found only a small percentage of its sample in a dehydration state in the early morning²⁵. Another study reported that about 18% of the participants had not drunk water during the early morning²⁸. 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 day⁶ can be considered. Such preferences can be associated with economic, cultural, and body composition issues³⁵.

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 schools³⁶. According to the United Nations Children's Fund (UNICEF)³⁷ 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^{6,7,10}. 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^{8,24}. 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 tests³⁸.

Studies show that a high hydration level is responsible for significant improvements in visual attention^{9,10,27}. 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 children⁸. 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 areas³⁹. 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 adolescents⁹ due to the social and biological differences in each one⁶.

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 exercise⁴⁰ 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 flavors⁴¹.

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)⁴² by age and a study that indicated supposedly ideal values for daily water consumption³⁰. 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 Analyses 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.

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Data collection: GRV, LMLL

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Critical revision of the article: RJBM, MCMMD

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