



Research report

Effects of drinking supplementary water at school on cognitive performance in children

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ABSTRACT

We investigated the beneficial effects of drinking supplementary water during the school day on the cognitive performance and transitory subjective states, such as fatigue or vigor, in 168 children aged between 9 and 11 years who were living in a hot climate (South Italy, Sardinia). The classes were randomly divided into an intervention group, which received water supplementation, and a control group. Dehydration was determined by urine sampling and was defined as urine osmolality greater than 800 mOsm/kg H₂O (Katz, Massry, Agomn, & Toor, 1965). The change in the scores from the morning to the afternoon of hydration levels, cognitive performance and transitory subjective states were correlated. In line with a previous observational study that evaluated the hydration status of school children living in a country with a hot climate (Bar-David, Urkin, & Kozminsky, 2005), our results showed that a remarkable proportion of children were in a state of mild, voluntary dehydration at the beginning of the school day (84%). We found a significant negative correlation between dehydration and the auditory number span, which indicates a beneficial effect of drinking supplementary water at school on short-term memory. Moreover, there was a positive correlation between dehydration and performance in the verbal analogy task. The results are discussed in the light of the complexity of the neurobiological mechanisms involved in the relationship between hydration status and cognition.

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Introduction

Despite the growing interest in promoting optimal drinking policies at school (see for example: Kaushik, Mullee, Bryant, & Hill, 2007), few studies have demonstrated the beneficial effects of drinking water during the school day. People living in Western societies are known to be particularly at risk of chronic, voluntary dehydration, a condition in which individuals exposed to insensible water loss due to environmental circumstances do not drink adequately in the presence of an abundance of fluid availability (Greenleaf & Sargent, 1965). Recently, it has been demonstrated that severe dehydration might exert a detrimental effect on cognitive performance in adults (see for example: Shirreffs, Merson, Fraser, & Archer, 2004) and that mild voluntary dehydration, which occurs naturally as a result of daily activity, might reduce cognitive functioning (Ganio et al., 2011). Children are known to be at a

greater risk than adults for voluntary dehydration due to their higher proportion of body surface to body mass (D'Anci, Constant, & Rosenberg, 2006). Moreover, they are less likely to restrict their physical activity during the hot hours of the day (Bar-David, Urkin, & Kozminsky, 2005), and they depend upon adults to provide fluids for drinking, but many adults are not aware of the possible signs of dehydration (D'Anci et al., 2006). Mild voluntary dehydration seems to exert a detrimental effect on cognitive performance in children (Bar-David et al., 2005). Thus, it is reasonable to suppose that hydration might produce positive effects. However, empirical evidence in favor of the beneficial effects of drinking water in children, especially at school, is lacking. Our study aimed to produce new data regarding the effects of water consumption on cognitive performance in children. We performed an intervention study to investigate how cognitive performance might change in the course of the school day in relation to the physiological level of hydration.

The effect of dehydration and the benefits of drinking water on adults' cognitive performance

A number of studies have demonstrated significant detrimental effects of severe dehydration on cognitive functioning in adults.

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Sharma, Srivastava, Pickering, and Panwar (1986) observed a significant decrease in concentration in young healthy males who underwent 2–3% body weight loss due to intense exercise and heat exposure. Another study conducted with healthy young males who experienced dehydration corresponding to a 2% or greater body weight deficit under similar conditions revealed comparable effects on the ability of the participants to efficiently solve arithmetic problems, as well as effects on short-term memory, attention and visual motor tracking. The impairments were more pronounced at higher levels of dehydration (Gopinathan, Pichan, & Sharma, 1988). Dehydration corresponding to a 2.7% body weight loss as a result of heat exposure or exercise also significantly decreased alertness, concentration, tracking performance, short-term memory and increases in tiredness and headaches were reported in healthy, young adults (Cian, Barraud, Melin, & Raphel, 2001; Cian et al., 2000). Shirreffs et al. (2004) found that subjects who experienced a body loss of 2.7% due to a fluid restriction over 37 h experienced significantly greater impairments in concentration and alertness compared with the controls, as well as more pronounced headaches and tiredness.

All these studies demonstrated that when severe dehydration is induced by physical activity, heat exposure, fluid restriction or a combination of these conditions, it results in a significantly detrimental effect on cognitive performance in healthy adults (Ritz & Berrut, 2005). However, the lowest level of dehydration that might cause negative consequences in cognitive performance in adults is still unknown (Lieberman, 2007). In all of the studies mentioned above, there is a combined effect of dehydration and other factors related to the method used to induce dehydration. Recently, it has been demonstrated that even mild levels of dehydration, which might be encountered routinely by adults in the course of daily activities, might exert some adverse effect on cognitive performance and subjective mood states in adults (Ganio et al., 2011). A group of young men (mean age = 20 years) were evaluated in randomized, single-blind, repeated-measure trials. The study evaluated individuals with exercise-induced dehydration who received a diuretic, individuals with exercise-induced dehydration who received a placebo, and individuals who conducted exercise while maintaining hydration and received a placebo. Each trial included three 40-min intervals of speed walking at a 27.7 grade. A comprehensive computerized six-task cognitive test battery, a questionnaire to determine the profile of the mood states and a questionnaire about the participants' symptoms (headache, concentration and task difficulty) were administered during each trial. The level of dehydration was mild (>1% body mass loss) and it was associated with declines in specific aspects of cognitive performance, including visual vigilance and the latency of the visual working memory response. Mood states were adversely affected by dehydration at rest, with increasing in tension/anxiety and fatigue/inertia. There were no effects on headaches, the ability to concentrate or perceived task difficulty.

While the effects of dehydration have been extensively studied, results describing the positive effects of drinking water on cognitive performance in adults are limited and often contradictory (Lieberman, 2007). Some studies have demonstrated that when fluids are reintegrated, individuals do not show better performance on cognitive tasks, but only a beneficial effect on alertness (Cian et al., 2000; Neave et al., 2001). By contrast, Rogers, Kainth, and Smit (2001) showed that when thirst is high, the consumption of water might have a positive influence on sustained attention, whereas when subjects are not thirsty, drinking water was detrimental.

The effect of dehydration and the benefits of drinking water on children's cognitive performance

Children are known to be at a higher risk than adults for voluntary dehydration, due to the higher proportion of body surface to

body mass (D'Anci et al., 2006). They also tend to drink less than half of their recommended daily fluid intake (Gregory et al., 2000) and children exhibit higher levels of physical activity compared to adults (Kaushik et al., 2007). Furthermore, children are less likely to restrict their physical activity during the hot hours of the day (Bar-David et al., 2005) and they depend upon adults to provide fluids to drink. Adults may not be adequately sensitive to the possible signs of dehydration in children (D'Anci et al., 2006) and therefore they are likely to ignore the children need to drink. Despite the higher risk for fluid loss, the possible effects of dehydration on cognitive performance have been even less investigated in children than in adults. There is only one observational study that demonstrated that dehydration might negatively affect cognitive performance in children (Bar-David et al., 2005). In this study, children living in a country with a hot climate (Southern Israel) were divided into two groups on the basis of their hydration status at the beginning of the school day, designated as hydrated and dehydrated. All the cognitive abilities of all of the children were tested at the beginning and end of the school day. Five cognitive tests were administered: identifying a given figure in patterns that contain additional lines (deconstructing visual information), immediate memory of a sequence of dictated digits; constructing conceptual categories by selecting related items from a list of seven objects; matching a word from a list of five words to a target based on the analogy to a given word pair; adding sets of one- or two-digit numbers in 2 min. The results showed that at the end of the school day, although the majority of the cognitive abilities tested were not affected by hydration status, short-term memory was significantly lower in the dehydrated children. However, this was an observational study in which no supplementary water was given to the children during the school day, so the beneficial effects of drinking water at school were not specifically investigated.

Recently, some intervention studies have empirically demonstrated a beneficial effect of drinking water on cognitive performance in children. Benton and Burgess (2009) assessed 40 school children (mean age = 8.7 years) for memory and sustained attention twice, once after the children drank 300 ml of water and again on another day when no water was provided. Memory was measured by the recall of 15 previously presented objects in accordance with the Recall of Objects test of the British Ability Scale (Elliot, Smith, & McCulloch, 1996). Sustained attention was measured using the paradigm of Shakow (1962) by asking to the children to respond to a light that followed an auditory warning after a delay of either 3 or 12 s. The results showed that recall was significantly better when water had been consumed, while the ability to sustain attention was not significantly influenced by water consumption.

Edmonds and Burford (2009) investigated whether drinking water at school improved children's performance for story memory, a letter cancellation task, visual attention, memory and visual motor skills. Fifty-eight children aged 7–9 years old were randomly divided into two groups: one group received additional water and one group did not. The results showed that the children who drank additional water performed better on visual attention and memory tasks, in the letter cancellation task and in the difference memory task. The hydration status was measured using a thirst scale to provide a level of subjective thirst. The children were asked to describe how thirsty they felt by marking a 16-cm horizontal line with the words "very thirsty" and a pictorial representation of a thirsty face on the far left and "not at all thirsty" and a photo of pouring water on the far right. The children's subjective thirst was calculated by expressing the distance along the line (from right to left) as a proportion of the total length.

In another study, Edmonds and Jeffes (2009) evaluated twenty-three school children (mean age of 7 years 3 months) at baseline.

Then, eleven of the children received a 500 mL bottle (of which 409 mL was consumed on average) and twelve of the children did not receive any water. The test session began 45 min after the water was given. The results showed that visual attention and visual search functions were better in the children who had been given water, although the visual memory and visuo-motor performance was not altered. The group who drank water rated themselves happier compared to the controls. Drinking water seems to also to improve the ability of the children remain focused on a task at school.

Finally, Benton & Davis (published in Benton, 2011) observed twenty-two children, aged 9 years, on six occasions: on three occasions, the children had been given 200 mL of water, and on three occasions, they were not given any water. After 15 min, the children's behavior was observed for a thirty-minute interval while they performed academic tasks (e.g., writing or solving mathematical problems). The behavior was assessed as being on task or off task (e.g., looking around, talking, out of seat), and the percentage of time that the children were considered on task in six five-minute blocks was reported. On average, the children spent 78.8% of their time on task after drinking water but significantly less time (53%) when water had not been consumed.

Taken together, the results of these studies seem to demonstrate that drinking water has a beneficial effect on some cognitive abilities in children (Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009) and it is associated with staying on task (Benton & Davis, published in Benton, 2011) during the school day.

Knowledge of the beneficial effects of drinking water at school is of particular interest for school policies, which are known to heavily influence children's water consumption at school. A systematic study of school policies on drinking water in England (Kaushik et al., 2007) compared three contexts: schools in which water in the classroom was prohibited, schools that allowed limited access to water (for example, the water was allowed in the classroom, but not on the desk) and schools that had open access to water (for example, water was allowed in the classroom and bottles were kept at the desk). The results showed that the percentage of children who consumed less than the recommended daily amount of fluid was significantly higher in the schools that prohibited water consumption (81%) and in the schools that had limited access to water during the school day (80%). This percentage was considerably reduced in the schools where children had free access to water (46.5%).

In Italy, the school policies might be described generally as allowing limited access to water. Usually, there are not fountains available in the schools, drinking tends to be restricted to lunch and break times and water is not allowed on the desk. To the best of our knowledge, no systematic studies regarding the effect of school drinking policies on the drinking patterns of Italian children are currently available. However, in the absence of systematic studies, it is reasonable to assume that school policies might exert similar effects in Italy as those reported in England in 2007. Thus, because the Italian school policies tend to allow limited access to water, the majority of children are expected to consume less than the recommended daily amount of fluid intake for their age and, therefore, to be particularly at risk for mild voluntary dehydration.

On the basis of these considerations, our study aimed to investigate: (a) the physiological hydration status of school children in Italy at the beginning of the school day; (b) whether and to what extent hydration levels are influenced by water consumption at school; (c) how cognitive performance and transitory subjective states change in relation to the physiological levels of hydration during the course of a school day. To achieve these aims we performed an intervention study in which supplementary water was offered at school. A sizeable sample of school children and physio-

logical measures of hydration status were employed. Consumption of water was monitored to control for compliance and for naturally occurring drinking patterns.

Methods

Participants

A group of 168 school children (86 females; 82 males) from a country with a hot climate (Southern Europe) aged between 9.1 and 10.9 years (mean age = 10.2 years; SD = 4.38) participated in this study. The classes were randomly allocated into an intervention group, which received water supplementation, and a control group, which did not receive any additional water supplementation. There were 5 classes in the control group (75 children in total) and 7 classes in the intervention group (93 children in total). There were similar numbers of males and females in the intervention group (46 females, 47 males) and in the control group (40 females, 35 males).

Materials

The materials used for the study were a blackboard and a stick of white chalk used by the examiner to explain the tasks to the children and to present several examples; one stopwatch to monitor the timing of the tasks; seven booklets to be completed by the children, including five for the cognitive tasks (one for each task), one for the nutrition habit questionnaire and one for the mood questionnaire. A series of colored vignettes were used to explain to the children how to self-collect the urine samples. Sterile urine sample bottles were used for the urine sampling.

Setting

The children were tested in their classrooms. The temperature outside the classrooms ranged between 25 °C and 28 °C. None of the classrooms were air-conditioned, and the windows were open. Although we did not measure the classroom air temperature, we estimate that the indoor temperature was equal to or 1–2 degrees less than the outdoor temperature.

Procedure

The study was approved by the local ethical committee and the parents gave their written informed consent for the children to participate in the study. This was an intervention study, in which the classes were randomly allocated into an intervention group, which received water supplementation, and into a control group, which did not receive any additional water. The classes in the intervention group received 1000 mL of water over the course of the test day (9:30–15:00). This amount is in line with the Dietary Reference Intake for water for children aged 9–13, published in February 2004 by the Institute of Medicine of the National Academies in the US. In the intervention group, children were allowed to keep the water on the desk and the teachers were instructed to explicitly encourage the children to drink during the school day. The 1000 mL of water was distributed in two bottles of 0.5 L. One bottle was distributed after baseline testing (at 9.30 h) to be voluntarily consumed before 12.00 h. A second bottle was distributed at 12.00 h to be voluntarily consumed before 15.00 h. The bottles were collected at 12.00 and 15.00 h and the amount of water consumed was documented by the experimenters to analyze children's compliance with the intervention.

The children in both groups were tested twice for their hydration status based on urine osmolality: early in the morning and at

the end of the school day. Urine osmolality¹ is a measure of hydration status determined by the number of particles in the solution: large values indicate concentrated urine, and small values indicate diluted urine. In our study, according to the definition of Katz et al. (1965), Uosm above 800 mOsm/kg H₂O was considered to represent a state of dehydration, while Uosm below 800 mOsm/kg H₂O was considered a state of hydration. This measure is highly sensitive to the volume and timing of water consumption. When a large bolus of water is consumed rapidly (e.g., 1.2 L in 5 min), this water enters in the blood and the kidneys produce a large volume of dilute urine before the intracellular and extracellular fluids equilibrate. In this situation, urine mirrors the volume of fluid consumed rather than the change in hydration status (Armstrong, 2007). For this reason, in our study 1 L of pure water was administered to the intervention group during the entire school day. The children were instructed to self-collect their urine by two psychologists from the Pediatric Urology Unit of the Brotzu Hospital (AOB) in Cagliari (Italy). Each child was provided with a sterilized urine sample bottle, and a psychologist from the Pediatric Urology Unit collected the bottle outside the bathroom. The samples were sent directly to a laboratory, which analyzed the urine samples and determined the concentrations of specific salts that were used to calculate the urine osmolality. The reliability and the sensitivity of the analysis conformed to the standards that are typically accepted for the analysis of biological samples.

The children's cognitive abilities were assessed twice: early in the morning (pre-test) and in the afternoon (post-test), both immediately after urine sampling, according to the following schedule of the school day:

8:30–09:00	Urine sampling
9:00–9:30	Pre-test: Cognitive and transitory subjective states
9:30–13:00	Regular school activities indoors
13:00–14:00	Lunch time
14:00–15:00	Regular school activities indoors
15:00–15:30	Urine sampling
15:30–15:50	Post-test: Cognitive and transitory subjective states

The cognitive testing was of relatively short duration (20 min) and consisted of the following series of selected tests of memory, concentration, attention and executive functions, which were adapted from Italian test batteries (De Beni et al., 2005; WISC-III (Wechsler, 1992) and from the GEFT (Group Embedded Figure Test, 1971):

- *Deux de Barrage* (a measure of selective attention): This is pencil and paper test of selective attention (Zazzo, 1980) which involves high level of attentiveness. The participants were required to cancel, as fast and as accurately as possible, a target symbol printed on a matrix of 10 lines with 12 pictures each. The time completion limit was 2 min. The participants' scores were the total number of items correctly marked in 2 min.
- *Number additions*: This test measures the perceptual speed and automaticity of applying arithmetic operations. The children were given 6 addition worksheets with 10 addition problems

per page. There were an equal number of one-digit and two-digit addition problems. The maximum time allowed was 2 min. The number of correctly solved addition problems was recorded.

- *Auditory number span*: This test measures the subjects' short-term memory of a sequence of forward- and backward-dictated digits. This test requires the examiner to verbally present digits at a rate of one per second. Four to eight digits per sequence were presented. The children were asked to immediately write down the digits in either the forward (verbatim) or backward (in reverse order) direction. The number of digits increased by one, starting with a sequence of 4 digits and ending with a sequence of 8 digits. The test lasted approximately 5 min. We considered the number of correctly recalled sequences.
- *Verbal analogies*: The purpose of this test was to assess the children's ability to determine the relationship of one word to another and therefore of one idea to another. Thus, verbal analogies did not include difficult vocabulary words and the words used were familiar to the children. The verbal analogy questions were designed so that one word was missing and the children were given choices from which they were asked to complete the analogy.

For example:

“Quiet” is to “sound” as darkness is to:

(a) cellar; (b) sunlight; (c) noise; (d) stillness

The test lasted 3 min, and the number of correct verbal analogies was scored.

- *Visual spatial abilities*: This test evaluates the ability of the participant to mentally manipulate two dimensional figures. The children were given a booklet containing hidden figures and were asked to recognize and identify a target figure within a complex pattern. The number of figures found is an indicator of the individual's separation ability, and individuals who find more of the figures are said to be more field-independent. The score is recorded as the number of hidden figures that are correctly identified. The test lasted 5 min.

The Italian version of the Profile of Mood States (POMS; Italian version: Farnè, Sebellico, Gnugnoli, & Corallo, 1991; McNair, Lorr, & Droppleman, 1971) was administered after each cognitive test battery to assess transitory subjective states. The children completed three self-evaluation scales, which consisted of several adjectives comprising the following mood factors: vigor-activity, fatigue-inertia and confusion-bewilderment. These subjective states are thought to be transitory and specific to a given situation. The children were given a score for each trait according to their responses to certain statements, which include key words such as unhappy, tense, careless and cheerful. For each statement, the subjects state how they feel at the moment by choosing one of the following responses: not at all, a little, moderately, quite a lot, extremely. Finally, because hydration status has been linked with nutrition habits, especially with the consumption of fruit and vegetables which are known to be particularly high in water content, the nutrition habits of the children were surveyed by the means of a self-report questionnaire that was administered at the beginning of the school day. Moreover, children's consumption of food was monitored during the school day.

Study design and statistical analysis

The study procedure involved one intervention group and one control group. However, the groups that were organized for the study procedure (intervention and control groups) were not considered in the statistical analysis. To investigate the effects of

¹ Although there is not a gold standard to measure hydration status (Armstrong, 2007), Uosm was used in our study to determine hydration status for several reasons. First, although the costs are high, the test is manageable and easy to use in the field. Second, it is a valid and accurate index of dehydration, even though more studies are needed to strengthen the empirical evidence of its sensitivity. Third, other physiological measures that are known to be extremely valid in laboratory settings, such as total body mass and plasma osmolality, are too susceptible to change due to the effects of environmental factors that are difficult to control in the field (Armstrong, 2007).

drinking supplementary water on hydration status, the children in the intervention and in the control group were retrospectively classified in hydrated or dehydrated, according to the urine osmolality level (Uosm). We analyzed whether the percentage of hydrated and dehydrated children changed from the morning to the afternoon in relation to the intervention. Then, for each subgroup, we described how the levels of Uosm changed from the morning to the end of the school day in relation to the intervention.

To investigate the relationship between physiological hydration levels and cognitive performance we correlated the change scores from pre-test to post-test. The change scores were calculated as the differences between the scores measured in the morning (pre-test) and the scores measured in the afternoon (post-test) of hydration level and each cognitive test used in our study (selective attention, perceptual speed of applying arithmetic operations, short-term memory, verbal analogies, visual-spatial abilities). Depending on the distributional characteristics, the correlation coefficients were calculated according to Pearson or Spearman. The same correlational analysis was employed to investigate the relationship between hydration levels and transitory subjective states.

Results

Children's nutrition habits

The survey showed that the 92% of the children usually consume breakfast in the morning, which typically consists of 200 mL of milk and 4–5 biscuits. The majority of the children usually consume lunch as follows: pasta (88,82%), meat (83,53%), bread (81,18%), fruit (78,24%) and salad (70%) and they usually drink water (91,76%). The majority of the children usually consume dinner as follows: pasta (82,35%), meat (78,24%), bread (74,12%), fruit (72,94%), soup (56,47%), salad (54,12%) and they usually drink water (89,41%). These results are in line with two previous studies (Tognarelli et al., 2004; Turrini, Martines, Orsini, De Carli, & D'Amicis, 2004), which demonstrated that children in Italy tend to consume the typical Mediterranean diet. The consumption of food in the course of our study was monitored: children consumed small salty or sweet snacks during the break and they eat a standard Italian meal for lunch: pasta, chicken, salad and fruit. The food eaten at school was equally distributed between the children in the two groups.

Consumption of water in the intervention group

Compliance to the intervention of the children in the intervention group was measured by recording the amount of water remaining in the collected bottles. Children in the intervention group consumed on average 624.5 mL of water (range = 0–1 L; SD = 290). Two children (2%) did not drink any water, and 19 children (20%) drank the maximum amount of water.

Consumption of water in the control group

Only a few children in the control group ($n = 25$) drank some of the water that they brought in from home. Each of them drank only once during the entire day. They consumed a quantity equal to a glass of water, which varied from 50 to 200 mL from child to child. This quantity was far below the quantity of water consumed by the children in the intervention group (which was 624.5 mL on average).

The effects of drinking supplementary water on children's hydration status

The hydration status was measured in terms of urine osmolality, which is the concentration of a solution expressed in millios-

moles of solute particles per kilogram of water. According to Katz et al. (1965), Uosm above 800 mOsm/kg H₂O is defined as a state of dehydration. The majority of children in our sample were in a condition of voluntary dehydration at the beginning of the school day (Table 1). The hydrated children (16%) had a mean level of Uosm of 535.44 mOsm/kg H₂O (SD = 172.03) while the dehydrated children (84%) had a mean level of Uosm of 1287.3 (SD = 266.85).

As shown in Table 2, in the intervention group the percentage of the children who were dehydrated in the morning (80%) decreased significantly at noon (42%), while the percentage of hydrated children increased from 20% in the morning to 58% in the afternoon ($\chi^2 = 29,36$; $df = 1$; $p = 0.0001$). There were no significant changes in the hydration status from the morning to noon in the control group ($\chi^2 = 3.659$; $df = 1$; $p = 0.0558$).

The effects of drinking supplementary water at school were more evident when we cross-analyzed the hydration status from the morning to the afternoon for each child (Table 3). In the intervention group, a larger percentage of children who were dehydrated in the morning became hydrated in the afternoon (42%) while, in the control group, a greater percentage of children that were dehydrated in the morning maintained a state of voluntary dehydration in the afternoon (70%).

Drinking supplementary water at school exerted a positive effect on the hydration status of dehydrated children in the intervention group (Table 4): dehydration decreases from mean Uosm 1301 mOsm/kg H₂O (SD = 266) in the morning to mean Uosm = 1248 mOsm/kg H₂O (SD = 252) in the afternoon. On the contrary, the levels of dehydration in the control group get worse from the morning to the afternoon: the mean Uosm at the beginning of the school day, which was 1270 mOsm/kg H₂O (SD = 281), increased at the end of the school day (mean Uosm afternoon = 1418 mOsm/kg H₂O; SD = 263). These results indicate that the habitual drinking patterns of children at school (represented by the water consumption of the control group in this study) are not sufficient neither to improve nor to maintain adequate levels of Uosm during the school day.

The effects of drinking water on cognitive performance and transitory subjective states

To investigate the relationship between physiological hydration levels and cognitive performance, we correlated the change scores

Table 1
Children's hydration status at the beginning of the school day.

Hydration status	n (%)	Mean Uosm (mosm/kg H ₂ O)
Hydrated children (morning Uosm <800)	27 (16)	535.44 (SD = 172.03)
Dehydrated children (morning Uosm >800)	140 (84)	1287.3 (SD = 266.85)

Table 2
Frequencies of hydrated and dehydrated children in the intervention and in the control group after urine sampling early in the morning and after urine sampling in the afternoon.

	Intervention group ($n = 93$)		Control group ($n = 75$)	
	Hydrated children n (%)	Dehydrated children n (%)	Hydrated children n (%)	Dehydrated children n (%)
Morning	18 (20)	75 (80)	9 (12)	66 (88)
Afternoon	54 (58)	39 (42)	18 (35)	57 (75)

$\chi^2 = 29,36$; $df = 1$; $p = 0.0001$.
 $\chi^2 = 3.659$; $df = 1$; $p = 0.0558$.

Table 3

Cross-analysis of the frequencies of hydrated and dehydrated children in the intervention and in the control group from the morning to the afternoon.

		Intervention group (n = 93)		Control group (n = 75)	
		Morning		Morning	
		Hydrated children n (%)	Dehydrated children n (%)	Hydrated children n (%)	Dehydrated children n (%)
Afternoon	Hydrated children n (%)	12 (13)	42 (45)	5 (7)	13 (17)
	Dehydrated children n (%)	6 (7)	33 (35)	4 (5)	53 (71)

Table 4

Urine osmolality (Uosm means) from the morning to the afternoon in the intervention and in the control group.

	Intervention group (n = 93)		Control group (n = 75)	
	Hydrated children	Dehydrated children	Hydrated children	Dehydrated children
Morning Urine osmolality (mean Uosm)	536 (SD = 172)	1301 (SD = 266)	532 (SD = 163)	1270 (SD = 281)
Afternoon Urine osmolality (mean Uosm)	352 (SD = 160)	1248 (SD = 252)	421 (SD = 204)	1418 (SD = 263)

from the morning to the afternoon of hydration level and each cognitive test: selective attention, perceptual speed of applying arithmetic operations, short-term memory, verbal analogies, visual-spatial abilities (Table 5).

The results showed a negative relationship between hydration level and short-term memory ($r = -0.56$; $p = 0.043$). This correlation points to a beneficial effect of hydration on short-term memory, because high levels of Uosm indicates high levels of hydration. There were no significant correlations between the hydration level and the other cognitive abilities, with the exception of the verbal analogy test. Surprisingly, the performance on the verbal analogy test increased with dehydration.

Considering the relationship between hydration status and transitory subjective states (Table 6), the results showed a negative relationship between Uosm status and vigor ($r = -0.56$; $p = 0.039$). As for short-term memory, this correlation points to a beneficial effect of hydration on subjective state of vigor, because high levels of Uosm indicates high levels of dehydration.

Table 5

Correlations between the change scores of hydration status and cognitive abilities.

Cognitive abilities	Correlation coefficient	Confidence interval		p
		Lower	Upper	
Auditory number span (backward + forward)	-0.56	-0.85	-0.02	0.043
Deux Barrage	-0.08	-0.53	0.68	0.238
Number addition	-0.20	-0.70	0.25	0.307
Verbal analogies	0.58	0.18	0.93	0.011
GEFT	-0.33	-0.89	0.35	0.268

Table 6

Correlations between the change scores of hydration status and subjective states.

Subjective states	Correlation coefficient	Confidence interval		p
		Lower	Upper	
POMS vigor	-0.56	-1.00	-0.05	0.039
POMS fatigue	-0.12	-0.72	0.52	0.498
POMS confusion	0.54	-0.07	0.96	0.071

Discussion

In line with a previous study that evaluated the hydration status of school children living in a country with a hot climate (Bar-David et al., 2005), our results revealed an impressive percentage of children in a state of mild voluntary dehydration at the beginning of the school day (84%). A state of mild voluntary dehydration seems to be common also for children living in areas with a cold climatic, such as Germany (Sichert-Hellert, Kersting, & Manz, 2001) or the United Kingdom (Petter, Hounihance, & Rolles, 1995), where the fluid intake is known to be insufficient. All these evidences seems to clearly indicate that school children, both in hot and cold climate Western countries, should be considered as subjects at risk of chronic, mild voluntary dehydration and therefore specific interventions are needed to reduce this risk.

Our study also demonstrated the importance of the school policies in influencing the hydration status of children. In our study, the habitual water intake at school represented by the control condition, in which the access to water was limited (no fountains available, no water on the desk), was characterized by a marked tendency of the children to do not drink water during the school day, which in turns resulted in low levels of hydration. In contrast, the majority of the children in the intervention group, in which the access to water was open (water on the desk, the teachers reminded to the children to drink during the day), consumed a considerable amount of water during the school day which resulted in higher levels of hydration. These results are consistent with a previous study on children's fluid intake during the school day in England (Kaushik et al., 2007), showing that children's water consumption at school was largely influenced by the drinking policy of the schools. Therefore, water-friendly school policies need to be implemented in Western countries to reduce children's risk of mild dehydration.

Our study also investigated whether cognitive performance, that previous studies showed to be related with water intake, might change in relation to physiological levels of hydration. A correlational analysis between the change scores from the morning to the afternoon of the physiological levels of hydration and specific cognitive abilities was employed. This analysis revealed a beneficial effect of hydration on short-term memory. These results are consistent with previous studies in which children who received supplementary water at school improved their performance in short-term memory (Benton & Davis (published in Benton, 2011), Edmonds, & Burford, 2009; Edmonds & Jeffes, 2009; Bar-David et al., 2005). They also indirectly confirm what was reported in another study (Bar-David et al., 2005), in which dehydrated children performed worse in an auditory digit span task compared to their well-hydrated peers.

In addition to the benefits of adequate hydration for short-term memory, we also found that dehydrated children unexpectedly performed better on verbal analogy tests. So, dehydration seems to affect some cognitive performance but not others, leading to the conclusion that the relationship between hydration levels and cognitive outcomes must be not so linear.

These results might be explained in terms of physiological processes that might modulate the relationship between cognitive processes and dehydration. Cognitive dysfunction resulting from dehydration may be the consequence of alterations in the hormonal profile. In particular, animal studies have shown an increase in cortisol levels with dehydration and that hypercortisolemia tends to worsen short term memory (Vedhara, Hyde, Gilchrist, Tytherleigh, & Plummer, 2000). In contrast, achieving euhydration seems to be associated with normalizing of the serum cortisol levels (Francesconi, Sawka, Hubbard, & Pandolf, 1989). Moreover, a reduction in cortisol levels in healthy adults, due to a moderate situation of stress, seems to be associated with enhanced short-term memory as measured by the total number of words recalled in a free recall task (Vedhara et al., 2000).

In the case of verbal analogies, previous studies demonstrated that cortisol levels, which are known to increase with dehydration, exert detrimental effects on declarative memory but no effects on long-term memory (Kirschbaum, Wolf, May, Wippich, & HeUhammer, 1996). Long-term memory plays a key role in verbal analogies: to “solve” an analogy, an individual must activate a series of processes that occurs at a semantic level, which mainly involves long-term memory and learned information, like for example understand the meaning of the words or understand that two different pairs of words must have the same relationship. These results support the view that cortisol can modulate cognitive processes and that the effects of corticosteroids on cognitive function are selective. However, in the light of the complexity of the neurobiological mechanisms involved in cognition, current research tend to propose some hypothesis based on the integration of hormonal theories, neurotransmitters and complex cellular mechanisms that need to be further elucidated (Wilson, Morley, 2003).

In our study, we also found that high levels of hydration are linked with high levels of vigor reported by children. This phenomenon might be explained in physiological terms too, if we consider that fluid ingestion is known to be related to the level of glucose supply to the central nervous system. The level of glucose might enhance the perceived amount of effort required to solve cognitive tasks in children, which in turns might be perceived by the children in terms of increasing “vigor” (Cian et al., 2000, 2001).

Differently from two previous studies (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009), which found a beneficial effect of drinking water on visual attention measured by a Letter Cancellation Task, our failure to find a positive correlation between hydration status and visual attention measured by the Deux Barrage test. These results are quite controversial, since the tests appear to be very similar in terms of psychological processes. The Deux Barrage test (Zazzo, 1980) used in our study is a pencil and paper test of selective visual attention (Zazzo, 1980). The participants were required to cancel, as fast and as accurately as possible, a target symbol printed on a matrix of 10 lines with 12 pictures each. The time completion limit was 2 min. The participants' scores were the total number of items correctly marked in 2 min. In the letter Cancellation Task used by Edmonds and colleagues in their studies, children were instructed to cross through all target letters in a grid also containing non-target letters. The target letter “U” ($n = 38$) was embedded in a 20×20 matrix of non-target letters (“O”, $n = 323$; “V”, $n = 28$; “C”, $n = 11$). The score was calculated by calculating the number of target letters (U) identified in 1 min, minus the number of incorrectly identified letters (O, V, C).

Even though the two tests share similar cognitive and perceptual abilities, the Letter Cancellation Task has been found to be more complex compared to the Deux Barrage test, in a previous study that investigated the effects of sleepiness on visual attention in adults (Porcu, Bellatreccia, Ferrara, & Casagrande, 1998). In this study, it is argued that the Letter Cancellation task needs a high

attentive load compared to the Deux Barrage test and therefore it might be more sensitive to water intake. Another difference between our study and the previous ones is the timing of the task, which was double in our study. This might have masked the effects of hydration on visual attention in children, which might be more pronounced during the first minute and less evident later, when maybe dehydrated children might “catch up” the hydrated ones in the course of task completion.

Comparing findings across studies is quite difficult when different tasks are employed, because they rarely measure exactly the same abilities. As stated by Edmonds and Burford (2009), “pure tasks that assess only one cognitive function are extremely rare, (if they exist at all)”. These considerations highlight the importance of developing standardize protocols to further explore the possible effects of hydration status on specific cognitive performance in children, which might facilitate the comparison between the different studies.

To conclude, even though dehydration might affect some cognitive abilities but not others, it is an adverse state that might render the school day more challenging for children. For this reason, the mutual influence of social, cognitive and biological dimensions involved in water consumption and learning must be further explored in future studies, with particular attention to the mechanisms by which dehydration influences the functioning of the brain. The results of such studies might facilitate the development of effective strategies for promoting appropriate drinking patterns at school.

Notes

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