Cognitive Effects of Drinking Water and Improving Hydration Status among Primary Schoolchildren in Eastern Province, Zambia

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SPLASH
Schools Promoting Learning Achievement through Sanitation and Hygiene

EMORY UNIVERSITY | Center for Global Safe Water

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1. Executive Summary

There is considerable evidence that dehydration has a direct link to reduction in cognitive abilities. In the context of water, sanitation and hygiene (WASH) in schools, improved access to drinking water may improve children's ability to learn by improving attention, concentration, and short-term memory. This would provide a direct link between school WASH and educational attainment.

The aim of this study was to investigate the relationship between water consumption hydration and cognition among children residing in settings where water is not readily available. The study was conducted by Emory University with funding and support from USAID Zambia and FHI360/SPLASH in Eastern Province, Zambia. Our objectives for this study were to measure the degree of pupils' dehydration in this setting, the effect of drinking water on cognitive test performance, and the effect of hydration on cognitive test performance.

We collected data from 292 pupils aged 8-18 years in five schools in Chipata region, Zambia. Participants at each school were randomized to either receive a bottle of water during the morning that they could refill throughout the day (water condition) or to receive a bottle of water at the end of the day after the completion of data collection (control condition). During each visit, we assessed hydration in the morning and afternoon using urine specific gravity (U_{SG}) measured with a portable refractometer. We also administered six paper-based tests in a classroom setting that assessed short-term memory, concentration, visual attention, and visual motor skills, from which we generated eight different test scores. We used independent samples t-tests to assess the effect of testing condition (water vs. control) on pupil test scores, the effect of hydration (U_{SG} below 1.010) on pupil test scores, and the effect of testing condition (water vs. control) on a pupil's hydration status. We also conducted linear regressions to test the correlation between hydration and test scores.

Moderate dehydration prevalence among pupils in the morning was high, and the intensity of dehydration increased throughout the day among pupils in the control group. When provided with supplemental water, pupils were more likely to become hydrated during the day. We did not observe any clear trends in the relationship between hydration and cognitive test scores. This report discusses key reasons for these findings.

2. Background

Past research in adult populations has shown that adults, when dehydrated under experimental conditions through a combination of heat and exercise, perform more poorly on cognitive tests. Studies of schoolchildren in Europe have found that water consumption prior to cognitive testing is associated with improved test scores, and a study among school children in Mali revealed non-significant trends towards improved cognitive test scores on days where children received supplemental water at school compared to days when they did not. While few studies have rigorously assessed dehydration among pupils residing in hot, dry climates, two taking place in Israel and Italy have found a prevalence of dehydration ranging from 68%-84%. Taken together, these findings suggest that school children who do not have water access may see improvement in cognitive skills and ability to pay attention and learn in school if they are provided with water to drink during the school day.

There are many limitations to the current body of research linking hydration and cognition. The majority of existing studies focus on healthy and fit individuals who have been temporarily dehydrated under experimental condition, so we can only draw conclusions on impacts resulting from a decline in hydration. Among the few studies that have examined the relationship between drinking water and cognitive test performance in children, only two have taken place outside of Europe and few have been carried out with scientific rigor.

There is an increasing evidence of the impact of improved school WASH conditions on reduced school absence, parasitic infection, and diarrheal disease. However, the precise mechanisms of improved educational attainment have not been explored. We developed a study to access the relationship between water consumption, hydration, and cognition in a setting where school children do not commonly have water access on the school property. We expect that an increased understanding of the relationship between hydration and cognition could provide significant and novel evidence for improving water quantity in schools.

A formative study had been carried out in Mali in early 2013 by the Emory research team in collaboration with Save the Children and the University of East London. The study validated a number of cognitive tests that had been used with children in developed countries as well as the feasibility of low-cost hydration measures. Results from the Mali study showed a trend that supported the hypothesis that increased water access improved cognitive test scores, but the results were not significant. Analysis of the Mali study led to several recommendations for improved methodology that were taken into account in the design of this study.

This study was carried out in Chipata region, Zambia, in partnership with USAID Zambia and FHI360/SPLASH. Emory University staff developed the study protocol and managed study activities. SPLASH hosted the study in the Eastern Province provincial office, provided major logistical support including field vehicles and drivers, and provided staff time to support the study.

3. Methods

3.1. Research Objectives

The primary research objectives for the pilot and study were as follows:

1. Refine a battery of cognitive tests measuring visual attention, visual memory, short-term memory, and visuomotor skills for children in low-income settings and measure the practice effect of repeated cognitive testing
2. Compare different field hydration assessment techniques for accuracy and ease of use
3. Assess the levels of dehydration among children in the Eastern Province of Zambia
4. Quantify the effect of improved water access on hydration status
5. Quantify the effect of improved water access on cognition

3.2. Overview

3.2.1 Pilot

From June-July 2013, we conducted pilot activities. This pilot was intended to a) refine the cognitive tests developed in Mali to ensure their appropriateness in Zambia, b) measure the effect of repeated cognitive testing to inform the design of the trail, c) compare different field hydration assessment techniques, and d) refine the cognitive test script and other study tools.

In June 2013, we conducted a three-day training session with four study enumerators. The training topics included an introduction to SPLASH and its mission, research ethics, field techniques for measuring hydration, and cognitive test measures. The enumerators then spent two days translating study materials from English to Nyanja, a local language.

Pilot testing began on June 24. We visited four schools in order to refine our data collection methods and to assess our measures of hydration and cognition. The four pilot schools were located within the SPLASH catchment area in Chipata District, Eastern Province. They had all been identified for participation in the SPASH program but had not yet received a water, sanitation and hygiene intervention. A total of 64 students in grades 3-6 were randomly selected from class rosters across the four schools for participation in the pilot study. Cognitive measures were piloted in order to refine instructional scripts during one visit at three of the schools. Feedback from participants and enumerators was incorporated into the script to ensure instructions were clear and comprehensible for participating pupils. The fourth school was visited on two consecutive days and both the cognitive measures and the urine hydration measures were piloted to streamline the urine collection and analysis protocol.

Pilot testing was suspended on July 11, 2013 in response to requests for protocol changes from the ERES Ethical Review Board, and no further activities were carried out during the intended pilot period. Despite the early cessation of pilot testing, we were able to achieve some valuable results during this time. Primarily, the enumerators were trained in the data collection methods and had opportunity to refine the data collection tools and protocols. The cognitive test script was edited for optimum comprehension among the pupils, and we were able to validate the image tests and identify those tests that produced the best distribution of results.

3.2.2 Field Trial

Data collection for the trial took place in five schools in Chipata District, Eastern Province. Schools were eligible to participate if they had been identified for participation in the SPLASH program but had not yet received any water, sanitation, and hygiene intervention, there was no water point within 0.5km of the school grounds, and they were within two hours of Chipata.

Permission for conducting this study was secured by the Chipata District Educaltion Board. Five schools meeting the criteria were identified and contacted in advance by FHI360/SPLASH to determine their interest in participating. At each school, an informational meeting was set and all parents were invited to attend. Study staff first explained the study procedures the school officials and obtained their permission to conduct the study in the school. Once permission was received, study staff then explained the study procedures to the parents, responded to questions, and asked the parents to provide consent for their children to participate in the study.

Study staff returned on a second day to conduct study activities. Study procedures were explained to all pupils, and the names of pupils whose parents had provided consent were written on a master list, which assigned whether they were in the water or control group. Pupils were called up individually to ask whether they assented to participate in study activities. Pupils who provided assent were asked a brief questionnaire about whether they had anything to eat or drink that morning, their mode of transportation and distance to school, activities they had participated in that morning, and their household WASH characteristics. They were then asked to provide a morning urine sample. Pupils in the water group were then provided with a bottle of drinking water and told that they could drink as much as they liked and that they could refill the bottles with supplementary water provided by study staff throughout the day. This process took place between 9:30am-12pm in all schools. Pupils were asked to provide a second urine sample between 2:30-3:30pm and the cognitive tests were then administered.

3.3. Research Participants

All pupils in grades 3-6 whose parents provided consent were invited to participate in the study. A total of 292 pupils (53.0% female) in grades 3-6 were recruited from 5 schools. Pupils' ages ranged from 8-18 years, with a mean age of 12.6 years. There were no significant differences between the water and control groups in any of the demographic of WASH indicators (Table 1).

Table 1: Pupil demographics and WASH indicators

	Total *n=292*	**Water** *n=149*	**Control** *n=143*	**p-value**
Number female (%)	154 (52.7%)	85 (57.0%)	69 (48.3%)	0.132
Age range (mean)	8-18 (12.6)	8-17 (12.6)	9-18 (12.6)	0.935
Drank that morning (%)	97 (33.2%)	45 (30.2%)	52 (36.4%)	0.247
Ate that morning (%)	115 (39.4%)	65 (43.6%)	50 (35.0%)	0.119
Distance to school, min (mean)	4-180 (37.5)	4-180 (37.4)	5-180 (37.6)	0.995
Improved drinking water source at home (%)	112 (38.4%)	51 (34.2%)	61 (42.7%)	0.127
Latrine at home (%)	255 (87.3%)	134 (89.9%)	121 (84.6%)	0.285
Sick in last 2 days (%)	52 (17.8%)	28 (18.8%)	24 (16.8%)	0.655

One pupil was not able to provide a morning urine sample, ten pupils did not return for afternoon testing, three pupils participated in cognitive testing but did not provide an afternoon urine sample, and data from four cognitive tests could not be used due to errors in the pupil identification protocol. In total, complete data was available for 274 pupils.

3.4. Study Design

This study is a randomized trial that compares the difference in scores on cognitive tests between two groups. The water condition group was given a water bottle in the morning that they could refill throughout the day. The control condition group was able to access any water that was normally available at the school, including water that they brought themselves, but was not provided any supplemental water until study activities had been completed at the end of the day. We visited each school on one day. We collected hydration measurements in the morning and afternoon and collected cognition measurements in the afternoon.

The original conception of the study involved pre/post testing, with each pupil taking the cognitive test twice, once in the morning and once in the afternoon. Under this study design, the difference in scores between each pupil would have been used as the primary outcome measure. However, due to the shortened time available for pilot testing we were not able to determine how many practice testing sessions were needed prior to the study day in order to minimize the potential practice effect.

3.5. Measures

We used multiple methods to measure hydration and cognition in this trial. At each school we collected hydration data twice, once in the morning and once in the afternoon. We collected cognition data once in the afternoon. We also conducted short interviews with pupils once in the morning of each visit.

Hydration

We collected two measures of hydration: urine specific gravity (U_{SG}) and urine color. U_{SG} was measured with portable handheld refractometers. Refractometers were calibrated using distilled water, and were recalibrated every 15 readings or fewer. Pupils with a urine specific gravity of 1.010 or higher were considered to be moderately-to-severely dehydrated and were classified as dehydrated. Urine color was measured against a validated scale of eight colors. Each sample was scored independently by two enumerators. If the two scores were within ±1, the scores were averaged. If there was a wider difference, a third enumerator was consulted.

Urine samples were collected in the morning and afternoon of each day of data collection. The morning sample was collected between 9am-12pm at the beginning of the school day. The afternoon sample was collected between 2-3:30pm after pupils had returned from lunch break. All urine analyses were conducted on the school grounds.

Cognition

We measured cognition using six tasks that assessed visual attention, visual memory, short-term memory, and visuomotor skills.

1. Letter cancellation. Pupils were given a grid containing target letters randomly dispersed among non-target letters. Pupils were given a fixed amount of time to draw a line through as many target letters as possible. Scores were calculated by subtracting the number of non-target letters identified from the number of target letters identified.

2. Direct image difference. Two nearly identical pictures were presented side-by-side. Pupils were given a fixed amount of time to circle differences between the two images. Scores were calculated by subtracting the number of incorrect differences identified from the number of correct differences identified.

3. Indirect image difference. Two nearly identical pictures were presented in sequence. Pupils were given a fixed amount of time to study the first image. They were then briefly presented with a blank page, followed by a second image. Pupils were then given a fixed amount of time to circle the differences between the two images on the second image, without returning to the first. Scores were calculated by subtracting the number of incorrect differences identified from the number of correct differences identified.

4. Forward digit recall. Twelve sequences of numbers two to seven digits in length were read aloud to pupils at a rate of one number per second. Pupils were asked to write down the sequence in order after the sequence was read aloud. The total number of correctly recalled sequences and the maximum digit span of the correctly recalled sequences were recorded.

5. Reverse digit recall. Ten sequences of numbers two to six digits in length were read aloud to pupils at a rate of one number per second. Pupils were asked to write down the sequence in reverse order after the sequence was read aloud. The total number of correctly recalled sequences and the maximum digit span of the correctly recalled sequences were recorded.

6. Line tracing task. Pupils were presented with two curved parallel lines. They were given a fixed amount of time to draw a line between them as quickly as possible while attempting not to touch the printed lines. Scores were calculated by subtracting the number times the pupil's line touched the side from the total length of the line in centimeters.

All cognitive tests were paper-based and conducted by trained study staff in a group setting within the school classrooms. Testing sessions were standardized using written scripts. Staff introduced each task with a scripted explanation, followed by allowing the class to practice on an ungraded example. For selected tasks, staff used the classroom chalkboard or pre-printed posters as visual aids. Cognitive testing sessions lasted 60-75 minutes and were conducted from 3-4:30pm. Parallel versions of each task were developed to discourage cheating. Test versions were counterbalanced between water and control groups.

Interviews

Pupils were asked whether they had anything to eat or drink that morning, the distance to school and mode of transportation, their drinking habits at school, and household WASH characteristics. The school director was asked about deworming activities within the past 12 months at the school and drinking water availability at the school. Staff also made observations of drinking water availability on the day of the visit.

3.6. Research Ethics

This study was approved by the Emory University institutional review board and the ERES Ethical Review Board. Written permission to conduct the study was obtained from the Eastern Province District Education Board Secretary. Prior to conducting the study in each school, the study team met with the school management committee and the school director to explain the study and the rights of the pupils and to obtain permission to conduct the study. Parents of children at participating schools were invited to hear about the study and asked for their written consent to allow their children to participate. On the day of the study, study staff members visited grade 3-6 classrooms and explained the study and the rights of the participants to the pupils as a group. Staff members obtained verbal assent from each selected pupil in a private setting prior to the start of data collection activities.

3.7. Data Analysis

Data was entered into MS Excel and analyzed using SPSS version 21. A total of eight scores for six cognitive tests were calculated. Scores were considered as missing in situations where pupils did not understand instructions well enough to complete the test according to instruction. Pearson correlations were used to determine the relationship between hydration measures. Independent samples t-tests were used to compare cognitive test scores by gender, by condition (water v. control), and by hydration status (U_{SG} above/below 1.010). Linear regression was used to compare hydration level to cognitive test score across the two study conditions.

4. Results

4.1. Field hydration assessment

We tested three field hydration measures: Urine specific gravity (U_{SG}) measured by a portable refractometer, urine color, and self-reported thirst. During the piloting period, we found that the self-reported thirst scale would not be feasible. Uniform results across all participants suggested that either the students did not understand the scale or they did not feel comfortable answering honestly. After trying other scales, we decided that self-report would not be a useful measure for hydration status.

The measures of U_{SG} and color were highly correlated in both the morning and afternoon sessions (Table 2). This indicates that the two measures are comparable for field measurement of hydration status. In practice, field staff found that the refractometer was a more objective measurement. In this analysis, only U_{SG} was used as it has been shown to correlate well with urine osmolality.

Table 2. Correlation between U_{SG} and urine color, morning and afternoon

Time period	n	Mean U_{SG}	Mean Color	Pearson correlation	p-value
Morning	290	1.018	4.1	0.779	**<0.001**
Afternoon	279	1.014	3.3	0.926	**<0.001**

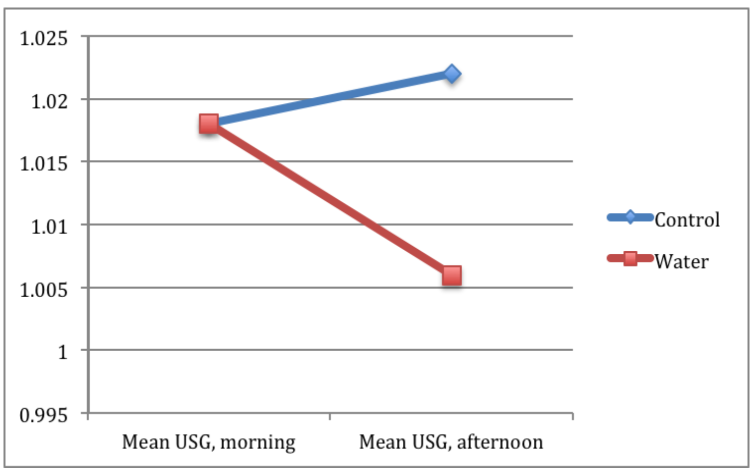
4.2. Hydration

At the time of the morning urine sample collection, 89% of pupils were mildly dehydrated or worse (U_{SG} $\geq$ 1.010) with both control and water groups showing an average U_{SG} of 1.018 (Table 3, Figure 1). At the afternoon urine sample collection, slightly fewer pupils in the control group were dehydrated but the average USG increased to 1.022. In the water group, dehydration decreased to 23.5% and average USG dropped to 1.006.

Table 3. Pupil hydration status in morning and afternoon, by study condition

Condition	n	Dehydrated in morning	Dehydrated in afternoon
Control	142	128 (89.5%)	124 (86.7%)
Water	149	130 (87.2%)	35 (23.5%)

Figure 1. Change in pupil urine specific gravity from morning to afternoon, by study condition



4.3. Cognitive test scores

We developed eight possible test scores for pupils based on the six cognitive tasks they performed. Scores were developed in such a way that higher test scores on all cognitive tests represented better performance. Each pupil took the test once. In some cases, scores were not included in the analysis if a pupil did not perform the task according to the instructions. Sample size, average score, and gender-stratified scores are reported in Table 4.

Table 4. Cognitive task scores of all study participants with valid tests (n=110) over two sessions

Task	N	Score mean (sd)			
		Total	Boys	Girls	p-value
Letter cancellation	275	20.7 (7.1)	20.3 (7.4)	21.0 (7.8)	0.434
Image difference, direct	265	2.1 (1.6)	2.3 (1.8)	1.9 (1.4)	0.076
Image difference, indirect	268	1.6 (1.9)	1.8 (2.0)	1.5 (1.8)	0.204
Line trace	279	18.7 (7.2)	19.6 (6.8)	18.0 (7.5)	0.055
Number recall total, forward	278	5.4 (1.3)	5.5 (1.3)	5.3 (1.2)	0.435
Number recall maximum digit span, forward	278	4.1 (0.7)	4.1 (0.7)	4.1 (0.7)	0.687
Number recall total, reverse	255	3.7 (1.5)	3.7 (1.5)	3.7 (1.4)	0.971
Number recall maximum digit span, reverse	255	3.2 (0.9)	3.2 (0.9)	3.2 (0.9)	0.759

Pupil comprehension was lowest in the reverse number recall task, and this was almost always due to pupils forgetting to reverse the number string before writing it down. We observed a borderline significant difference between boys' and girls' scores in the line trace task, and no significant difference between boys' and girls' scores on any other tests.

Scores stratified by study condition are reported in Table 5. Pupils who received water performed significantly better on the direct image comparison task. However, there were no clear among the other tests scores.

Table 5. Mean pupil cognitive test scores, water condition compared to control

Task	n	Water mean (sd)	Control mean (sd)	p-value
Letter cancellation	275	21.0 (7.5)*	20.4 (7.7)	0.514
Image difference, direct	265	2.3 (1.5)*	1.9 (1.6)	**0.049**
Image difference, indirect	268	1.5 (1.9)	1.7 (1.9)*	0.299
Line trace	279	19.0 (7.0)*	18.4 (7.5)	0.452
Number recall total, forward	278	5.4 (1.3)	5.4 (1.2)	0.560
Number recall maximum digit span, forward	278	4.1 (0.7)	4.1 (0.7)	0.896
Number recall total, reverse	255	3.7 (1.5)	3.8 (1.4)*	0.455
Number recall maximum digit span, reverse	255	3.2 (0.9)	3.2 (0.9)	0.366

**Higher score*

Table 6 shows test scores stratified by hydration status (with hydration considered as Usg of 1.009 or less), regardless of study condition. There is no clear trend in test results and there were no significant differences between groups for any of the test scores.

Table 6. Mean pupil cognitive test scores, hydrated compared to dehydrated

Task	n	Hydrated mean (sd)	Dehydrated mean (sd)	p-value

Letter cancellation	272	21.1 (7.9)*	20.4 (7.4)	0.409
Image difference, direct	262	2.1 (1.5)	2.1 (1.6)	0.917
Image difference, indirect	265	1.4 (1.9)	1.8 (1.9)*	0.097
Line trace	276	19.4 (7.1)*	18.3 (7.3)	0.210
Number recall total, forward	275	5.4 (1.4)	5.4 (1.2)	0.678
Number recall maximum digit span, forward	275	4.1 (0.7)	4.1 (0.7)	0.814
Number recall total, reverse	252	3.7 (1.5)	3.8 (1.4)*	0.712
Number recall maximum digit span, reverse	252	3.1 (0.9)	3.3 (0.9)*	0.296

**Higher score*

To further test the link between hydration measures and cognitive test scores, we tested the correlation between the eight cognitive test scores and afternoon U_{SG}. The correlation coefficient is a measure of the strength and direction of the linear relationship between two variables. The closer to one or negative one, the stronger the correlation. A value of zero signifies there is no correlation. Our expectation was that there is a negative correlation between U_{SG} and test score—that is, as U_{SG} increases (ie, a pupil is more dehydrated), the test score would decrease.

Table 7 reports the results of this test for correlation. Results do not show any clear trends and none of the results are significant, although there is a strong negative correlation with borderline significance for the letter cancellation test.

Table 7. Correlation between pupil's test score and afternoon U_{SG}

Task	n	Correlation coefficient	p-value
Letter cancellation	271	-1.776	0.079
Image difference, direct	261	-0.010	0.872
Image difference, indirect	264	0.081	0.187
Line trace	275	-0.044	0.468
Number recall total, forward	274	0.023	0.706
Number recall maximum digit span, forward	274	-0.041	0.495
Number recall total, reverse	251	0.014	0.829
Number recall maximum digit span, reverse	251	0.056	0.373

5. Conclusions and Next Steps

We documented that pupils in Chipata region in schools without a water point within 0.5km face a high degree of dehydration. Nearly 90% of pupils were dehydrated during morning testing. The provision of water during the day significantly increased the level of hydration among the pupils. In cases where schools have access to a water point, teachers should encourage pupils to drink water frequently during the school day. In cases where schools do not have a water point, pupils should be encouraged to bring a container of water from home or from a neighboring water point during the day.

We found that two inexpensive field measures of hydration status were comparable: urine specific gravity (Usg) as measured by a handheld refractometer, and urine color as measured by a verified color card. Although the color card was less expensive, study staff found that the refractometer offered a more objective and easier to use measure of hydration.

This is the second trial of the effect of supplemental water on cognitive tests scores among schoolchildren in water-scare areas. In the first trial, conducted in Mali, we found some evidence that supplemental water increased performance on cognitive tests that measure visual attention, visual memory, short-term memory, and visuomotor skills. However, it appeared that the methodology of the trial may not have been ideal. The cognitive tests used in the trial had been widely validated in other contexts, but they were novel to pupils in rural Mali. The design of the study had pupils take the test two times, once on a day where they had water and once without, and results were compared between the two days. The study found that the effect of taking the test a second time, and therefore becoming more familiar with the test, produced a large increase in test score that masked any change related to whether the test had been taken on a day with or without supplemental water.

For the Zambia trial, we focused on developing instructions that helped pupils understand how to complete the tests. We also changed the methodology of the study to eliminate the confounding effect of repeated testing. In this trial, pupils only took the test one time and mean scores were compared between the pupils who had received water and those who did not. However, despite the improved methodology we did not see any clear differences in test scores between the water and control groups, or between pupils who were hydrated versus pupil who were dehydrated.

There could be several reasons for the lack of observing an association between increased water access and cognitive test scores. The cognitive tests that were used had been thoroughly validated for use with children in developed contexts and pupils in Zambia completed them correctly. However, it is possible that they are not the best measures of cognitive function in this population. There may have been too much variability within each of the study groups to see trends across the groups. Further analysis that controls for potential confounding factors may reveal hidden trends. Additionally, it may be that providing water for the length of a morning is insufficient to see improvements in cognitive function, and there may be a need to provide water consistently for a longer period of time to see improvements.