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Prevalence of Dehydration among School-Aged Children in Eastern Province, Zambia and Sikasso, Mali with an Analysis of Hydration and Cognition Measures

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An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University

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Abstract

Prevalence of Dehydration among School-Aged Children in Eastern Province, Zambia and Sikasso, Mali with an Analysis of Hydration and Cognition Measures

By Kaleb Price

Background: Dehydration has serious detrimental effects on physical and cognitive health in children. This study was conducted to estimate prevalence of dehydration among African children as well as analyze methods for measuring hydration and cognition.

Methods: We obtained urine specimens on 110 children in Mali and 293 children in Zambia and measured urine specific gravity and urine color, both measures of hydration status. We also administered a battery of cognitive tasks to assess cognitive performance among these children.

Results: We found that 78% of children in Mali and 93% of children in Zambia were dehydrated during the day. We also found strong correlation between our two measures of hydration status (r^2=0.73-0.90). We found only weak correlation between cognitive tasks (r^2=-0.02-0.45). Boys and girls performed similarly on the cognitive tasks.

Conclusion: Our data showed that a large number of children in Eastern and Southern Africa are dehydrated during the school day. Because of the detrimental effect dehydration has on cognitive performance, efforts must be made to provide safe water to school children. We also found that urine color approximates urine specific gravity and can be used to cheaply and easily assess hydration status when more advanced methods are unavailable.

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Chapter I: Background

Dehydration is associated with a variety of adverse health and educational outcomes in school children. Despite this, there is a dearth of evidence on the prevalence of dehydration in children. There are also few non-clinical signs of dehydration that can be evaluated during the school day.

Effects of dehydration

While the effects of dehydration have been well studied in adults, less research has been done in children. Most research on dehydration has been done in adult athletes who have been voluntarily dehydrated.

Popkin et al note that the effects of dehydration are often divided into categories of physical and cognitive effects (1). Physical effects at mild levels of dehydration include "reduced endurance, increased fatigue, altered thermoregulatory capability, reduced motivation, and increased perceived effort" in athletes. The authors mention that children are likely at an increased vulnerability to these effects.

The physical performance effects of dehydration on athletes can be observed when 1% of total body weight is decreased through fluid loss (2). Kleiner notes that a 2% decrease in body weight corresponds roughly to a 20% decrease in physical performance in a healthy athlete. As with the Popkin study, Kleiner mentions that children are at a higher risk for dehydration when exercising.

Limitations of the reported physical effects in both of these studies are their study populations and non-biometric measures of dehydration. Dehydration studies are typically carried out in healthy athletic populations in Western settings where water is easily available. It is difficult to apply the results of these studies to children in arid environments who may not have such ready access to water. Because these studies take place in athletes who are typically only briefly dehydrated due to exercise or sport, they provide no information on the possible physical effects of chronic dehydration.

These studies also use change in body weight as a metric of dehydration. This is useful in athletic settings where participants can be weighed before and after activity. Such metrics are less useful in school settings where routinely measuring the weight of all attending children would be problematic. Chronic dehydration is also easily missed using this method. A child's weight may not drop very between weighing sessions because he or she was already dehydrated at the first weigh session.

Of particular interests to our work is the effect of hydration status on cognitive function. A larger number of students world-wide do not have access to safe water during the school day. This is important because decreased cognitive function due to poor hydration can result in decreased educational outcomes for students.

Popkin lists reduced concentration, alertness, and short-term memory in children and adults as side-effects of mild dehydration. He also found reduced arithmetic ability, visuomotor tracking, and psychomotor control as side-effects of moderate to severe dehydration (1).

Experimental research on the cognitive effects of dehydration has been done using children. Edmonds conducted a trial using 23 children (14 females, 9 males) recruited from a class of 6-7 year old (3). 11 children received a drink of water between baseline and second testing and 12 did not receive a drink. Participants were given paper based tests of visual attention, visual search, visual memory, and visuomotor performance. Edmonds found statistically significant differences in the water and control groups' performance on the visual attention and visual search tests. Additionally, self-reported mood showed a greater increase in the water group.

Benton et al conducted a similarly designed experiment testing the effect of water consumption on memory using children 40 children 8 year old children in South Wales (4). They recruited 18 males and 22 females. In Benton's design, children were tested on two separate days. On one day they received 300mL of water 20-30 minutes before testing began and on the other day they did not receive water. The difference in memory test scores between the water and no water days was statistically significant (P=0.03).

These studies show that having a drink of water does improve cognitive performance in children. Neither of these studies, however, measured hydration levels of children. In fact, it is likely that few of the participants were dehydrated prior to consumption of the water. While it is helpful to know that having a glass of water can improve a child's mood and cognitive performance, it offers little insight into the actual effects of dehydration on cognition.

Prevalence of dehydration

Despite the demonstrated negative effects of dehydration on physical and cognitive health, few studies has quantified prevalence of dehydration in an arid, non-Western setting and none of those studies were done in Africa. Bar-David used urine osmolality to measure voluntary dehydration in school children in the Negev region of Israel (5). 441 children age 8-10 were recruited from 5 schools. A single urine sample was collected from all children at noon on a school day in the first week of June. The authors found that 93% of children exhibited mild dehydration or greater with 67.3% having moderate or severe dehydration.

Bar-David previously carried out a similarly designed study in which hydration prevalence was a secondary research question (6). In this study, in which data collection again occurred in southern Israel, 58 10-12 year olds were recruited for participation. Morning and noon dehydration, measured by urine osmolality, were both found to be 63%.

There have been few studies have not been carried out in other regions. Sub-Saharan Africa has the lowest rates of water access in the world (7), yet no studies have examined the prevalence of dehydration in this region.

Measures of dehydration

Hydration status can be measured in a variety of ways. A common, safe measure of hydration status is body mass change (8). A difference in body mass of 2% or greater after accounting for food and beverage intake and urine and fecal output is indicative of dehydration.

Biomarkers of dehydration include plasma osmolality, urine osmolality, and urine specific gravity (9). All of these methods measure concentration of solutes in body fluids. Plasma osmolality and urine osmolality require laboratory testing. Due to the increased cost, time, and technical skills needed and the lack of portability, these methods are not suitable as field measures of hydration despite being considered sensitive methods for determining hydration status. Urine specific gravity can be performed using an analog refractometer, a small portable device that requires little technical training to accurately use. Urine specific gravity has been found to strongly correlate with urine osmolality making it an ideal field measure of hydration (10).

Urine color is the cheapest, easiest to measure metric of hydration status. As hydration level diminishes, urine becomes more concentrated resulting in a darker color. Armstrong found that urine color has a strong correlation with urine specific gravity (r^2=0.77-0.96). While measuring urine color is not as objective as other methods, it can be used as a simple, approximate measure of hydration status.

Other methods to measure hydration include 24-hour urine volume, salivary flow rate, bioelectrical impedance spectroscopy, urine conductivity, and thirst level (9, 11). None of these methods are easily measured in field settings except thirst level. Thirst level is highly subjective, particularly at low levels of dehydration and has not been found to be an accurate measure of hydration.

Measures of cognition

Because dehydration can have negative effects on cognitive and academic achievement in children, it is important to develop measures of cognitive performance. Due to differences in learning style and culture, cognitive measures must be adapted to local contexts making it difficult to identify tasks appropriate for wide ranging use.

Bangirana et al, found that memory, visual spatial skills, and learning were correlated with academic performance in reading and arithmetic (12). Specifically, memory (r^2=0.36) and learning (r^2=0.06) were positively correlated with reading (P<0.05) and visual spatial skills were positively correlated with arithmetic (r^2=0.15, P<0.05). Bangirana's team used the Kauffman Assessment Battery for Children (KABC-II) which uses 18 subtests to assess a child's cognitive ability. While the KABC-II has been validated for use in Ugandan children (13), it requires trained staff to administer the battery to a single child and is not suitable for group testing.

To address the challenges associated with administering cognitive tests to a group setting, Edmonds and Burford developed a battery of tests that can be administered a number of children at once (14). Their tests included a letter cancellation task, a find the differences image task, and an additional indirect find the difference image tasks that was performed from memory; these tasks were designed to measure attention. The indirect image difference task also measured memory. Finally, a line tracing task measure visuo-motor skills. These tasks performed well in their research in the United Kingdom, but they have not been validated for use in other countries.

Fadda also developed a cognitive performance battery to be used in a group setting (15). Fadda's battery consisted of a symbol cancellation task, number addition, auditory number recall, verbal analogies, and a pattern recognition task. As with Edmonds and Burford's work, these tasks have not been validated outside of Europe.

There is a need for validated cognition measures that can be easily used in African settings. As research on the effects of dehydration on cognitive performance advances, low cost, simple field measures of both cognition and hydration will be needed.

Chapter II: Manuscript

Introduction

Access to safe drinking water is a basic human right that can have significant health benefits. Because of this, many public health campaigns have been launched to increase the availability of water to school children, and UNICEF has made access to safe water, sanitation, and hygiene (WASH) facilities in all schools a global priority (21). Multiple studies have found positive effects on pupil health and school attendance due to increased water access and improved WASH conditions (22-25).

Water is the largest constituent of the human body and is necessary for cellular function and homeostasis (16). Dehydration, excessive loss of body water, has been linked to many adverse health outcomes such as decreased kidney function, diabetes, and poor physical and cognitive performance (1, 2, 17). Water volume varies from person to person but composes approximately 60% of total body weight in school-aged children (18). Hydration status is determined by the balance of water intake and water output (19), and can vary over a day due to factors such as amount of water and food that is consumed, illness, physical activity, and environmental factors such as temperature (20). Approximately 20-30% of water intake comes from food while the remainder comes from drinking water and other beverages. Water is typically lost through renal output (urine), perspiration, and feces (20).

Because access to safe drinking water is a basic human right that can have significant health benefits, many public health campaigns have been launched to increase the availability of water to school children, and UNICEF has made access to safe water, sanitation, and hygiene (WASH) facilities in all schools a global priority (21). Multiple studies have found positive effects on pupil health and school attendance due to increased water access and improved WASH conditions (22-25).

Due to their focus on cognition and education outcomes, particularly important to school based WASH programs are additional studies which have found evidence of decreased cognitive performance in pupils due to mild dehydration and lack of drinking water (3, 4, 6, 26). These studies show improved hydration leads to better attention and memory performance, skills linked to positive outcomes in reading and arithmetic (12).

Despite the evidence showing improved health and educational outcomes due to improved hydration, only one study has assessed prevalence of dehydration in children in dry, arid conditions (5). This study, done in Israel, found that 93% of participants were in some state of dehydration with 67.5% being in a state of moderate to severe dehydration. Additionally, while medical risk factors for dehydration have been identified in older adults (27), no studies have developed risk models for dehydration using variables that can be evaluated in children during the school day.

Sub-Saharan Africa has the lowest rates of safe water access of any region in the world with less than half of schools, on average, in Eastern and Southern Africa having access to adequate water and sanitation facilities (7). In Zambia, more than 25% of primary schools are without access to clean water (28). This study was conducted in Eastern Province, Zambia during the region’s dry season when temperatures are highest and there is little to no precipitation.

Hydration status of Zambian school children was assessed using urine analysis to determine dehydration prevalence in this population. In addition to determining prevalence of hydration status, we were interested in examining methods of hydration status and cognitive performance to determine their performance in the field.

Our primary research objective was to determine the prevalence of dehydration among rural school children in Eastern Province, Zambia and Sikasso, Mali. We also developed four secondary research objectives. The first was to identify risk factors for dehydration in school children and develop a predictive model for determining morning and afternoon dehydration in the pupils in Zambia. We also aimed to assess field measures for hydration and cognitive performance in children. Finally, we sought to compare cognitive performance scores across age and gender for the populations in this study.

Methods

Study locations

Data were collected in 5 primary schools located in Chipata District, Eastern Province, Zambia during September 2013. This analysis is a nested part of a larger trial examining the relationship between hydration status and cognitive function in school children. We partnered with Schools Promoting Learning Achievement through Sanitation and Hygiene (SPLASH), a five-year program by FHI360 to improve WASH conditions in schools, to identify eligible schools and collect data. Schools were eligible for inclusion if there was no water point within 0.5 kilometers from school grounds. All data collection occurred on school grounds during the school day.

Data were also collected at 2 schools in Sikasso, Mali during January and March, 2013. Data was collected in partnership with Save the Children. Schools were eligible if there was no water access point within 0.5 kilometers from school grounds and the school was located within 1.5 hour drive from Bamako, Mali.

Study population

Using the results of previous cognition studies in children, we calculated a needed sample size of 300 pupils using OpenEpi (v3.01) (6, 29). Pupils were eligible for inclusion if they were in grades 3-6 and in attendance at a participating school on the day of data collection regardless of gender or age. Students were also required to write a string of numbers dictated to them in order to participate. A total of 293 students were randomly selected to participate among those pupils who were eligible for inclusion and for whom parental consent and pupil assent were obtained. Pupils were randomly allocated to either the water or control group.

In Mali, 120 pupils were recruited from grades 5 and 6. 30 pupils from each grade were selected randomly from a class roster list at each school. A crossover design was used in Mali so data on all pupils was collected under water and control conditions.

Ethical Considerations

The protocol for the study in Zambia was approved by the Institutional Review Boards of Emory University, and the ERES Ethics Review Converge of Zambia. The study was deemed exempt by our partner organization FHI360. Written consent to perform the study in Chipata District schools was obtained from the District Education Board Secretary as well as the director of each school that was visited. Parents of children in grades 3-6 were invited to the schools and asked to provide written consent for their children to be enrolled following an explanation of the study. Pupils' whose parents provided consent to participate were added to a master list where they were randomly assigned to either the water or control group. Among students whose parents consented, verbal assent was obtained and recorded from those willing to participate.

The protocol for the study in Mali was approved by the Institutional Review Board of Emory University and the CAP and AE local government representatives responsible for education in the area where the study was conducted. At each school, permission for pupil participation was provided by the school director and school management committee. Prior to conducting the study in each school, the study team met with the CGS and school director to explain the study and the rights of the pupils and to obtain the permission of the CGS to conduct the study. Once consent was obtained, study staff members visited grade 5-6 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.

Data collection

In Zambia, on the day of data collection, pupils were called individually and, in a private area, asked if they would like to participate. Students who did not assent returned to their normal class. Following assent to participate, pupils were individually given an oral survey on risk factors for dehydration, between 9:30-12:00pm. They were then given a sterile urine collection container purchased from a local pharmacy and asked to provide a urine sample in a private location. Pupils returned the filled urine container and were provided with soap and water for hand washing.

Pupils were individually randomized to intervention and control groups. The intervention group received a 1L bottle of supplemental water after the morning urine collection procedure and was instructed to drink throughout the day. Study staff would refill a pupil's bottle if he or she requested more water. The control group was provided with a bottle of water at the end of the school day after all data collection was completed. No participants were denied water or discouraged from drinking anything normally available to them.

At the end of the school day in the afternoon, between 2:30-3:30 pm, an additional oral survey was administered and the same urine collection procedure was followed to collect a second urine sample.

The same data collection schedule was followed in Mali. The study design differed in Mali, however, because a crossover design was used over two days of data collection at each school. On the control day, no participants were provided with supplemental water. On the water day, all pupils were provided with a 1L bottle of supplemental water.

Cognitive tasks

Following the morning urine collection, pupils were given a cognitive performance test immediately following morning urine collection. The test was paper based, and pupils were provided with pens to use during the testing sessions. All testing was carried out in a group setting. The test included six cognitive performance tasks measuring memory, visual attention, and psychomotor skills. Prior to each task, a study staff member would read instructions to the whole class in the local language then perform an example at the front of the room. Pupils were then given the chance to do an example in their testing booklet. Testing occurred again in the afternoon just prior to afternoon urine collection using the same procedures. Two versions of the test were developed: A and B. Half the students at each school received version A in the morning and B in the afternoon while the other students completed B in the morning and A in the afternoon.

The following tasks were adapted from previous work by Edmonds and Burfurd(14). The letter cancellation and direct image difference tasks measure visual attention. The indirect image difference and number recall tasks measure memory, and the line trace task measures psychomotor 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 number 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 was recorded.

5. Reverse number 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 was recorded.

6. Line tracing task. Pupils were presented with two curved parallel lines 0.5 cm apart. 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.

Urine analysis

All urine analysis was conducted on school grounds and samples were disposed of on site. While there is no agreed upon "gold standard" for assessing hydration, plasma osmolality is often considered the best available measure (9). Laboratory testing for plasma osmolality, however, is expensive and not feasible for use in field settings. Other non-biometric methods such as self-reported thirst or urine color are often used instead. Urine specific gravity (USG) has been identified as a simple, low cost measure of hydration that is strongly correlated with urine osmolality (r^2=0.96) and was chosen as the standard measure of hydration for our study (8). We also chose to measure urine color on an 8 point scale to compare its correlation with USG to assess the utility of urine color as a measure of hydration status.

Urine specific gravity (USG) - Urine specific gravity for each urine sample was measured by two different study staff members, each using a different hand-held, analog refractometer. Concordant measures were recorded. If the two readings differed, the refractometers were recalibrated and measured again until concordance was reached. We used the National Athletic Trainers' Association widely accepted cutoffs of USG <1.010 as hydrated, 1.011-1.020 as mildly dehydrated, 1.021-1.030 as moderately dehydrated, and >1.030 as severely dehydrated (30, 31).

Urine color - Two staff members recorded the color of the urine samples using an 8-point color scale previously validated for hydration measures (32, 33) and purchased from hydrationcheck.com. If the two readings differed by more than 1 point, a third staff member was consulted. The three conferred to reach agreement on the reading. If the readings were within ±1, then an average of the two scores was taken.

Data Analysis

Data were entered into Microsoft Excel and analyzed using SAS v9.3. A significance level of 0.05 was used for all analyses. Paired t-tests were used to compare afternoon hydration to morning hydration levels within each study group (water vs control groups). Independent samples t-tests were used to compare hydration levels across study groups.

Identification of variables associated with hydration status

The associations between sex, grade, morning fluid consumption, breakfast consumption, and illness in the previous two weeks and morning and afternoon dehydration status were evaluated using Chi-square tests using an alpha of 0.05. The associations between age and time traveled to school in minutes and morning and afternoon dehydration status were evaluated using one-way ANOVA.

Finally, we assessed all potential confounders for the relationship between afternoon dehydration and study arm using logistic regression. The odds ratio for the effect of study arm on dehydration in a model containing only study arm as an independent variable was compared to the odds ratio for study arm in a model containing the potential confounders. A change in estimate of 10% or more for the odds ratio was used as an indicator for the presence of confounding.

Correlation of urine hydration measures

Spearman correlation coefficients were calculated to examine the relationship between morning USG and morning urine color as well as afternoon USG and afternoon urine color. Spearman correlation coefficients were chosen over Pearson due to the non-normal distribution of urine color.

Cognitive task performance by gender and age

Independent sample t-tests were used to compare the difference in means for boys and girls on the cognitive tasks. One-way ANOVA was used to compare cognitive performance across three age categories with Scheffe's test used for post-hoc analysis. Participants were categorized into three age categories (<12 years, 12-14 years, and 15+ years) based on results of previous studies showing improved performance on cognitive tasks beginning around ages 12 or 13(34).

Results

Pupil dehydration in Sikasso, Mali

One hundred and ten participants were recruited from grades 5-6. 48 (44%) of the participants were female. Ages ranged from 9-15 with a median age of 12 (Table1). 109 participants provided urine samples on the control day while 108 provided urine samples on the water day.

We observed that 28 (25.7%) participants were dehydrated during the morning on the control day while 34 (31.5%) were dehydrated in the morning on the water day.

On the control day, the number of dehydrated participants increased to 85 (78%) at the time of afternoon urine collection. The number of dehydrated pupils increased to 49 (45.4%) on the water day.

On the control day, mean morning urine specific gravity was 1.007 and increased to 1.0014, indicating an increase in dehydration, by time of the afternoon data collection (P<0.001). On the water day, mean urine specific gravity increased from 1.008 to 1.010 (P=0.002) showing an increase in dehydration. While average hydration status worsened for participants on both days, the greater increase was observed on the control day.

During the morning urine collection on both the water and control days, mean urine specific gravity did not significantly differ between boys and girls. In the afternoon, boys had higher mean urine specific gravity on both days (Table 8).

There was no significant difference in mean urine specific gravity when participants were stratified by grade (Table 10). There were only weak correlations between morning urine specific gravity and afternoon urine specific gravity (Table 13).

The correlation between specific gravity and urine color were strongly positive in both the morning and afternoon urine collections. Morning measures showed a correlation coefficient of 0.78 and afternoon measures had a correlation of 0.73, both of which were statistically significant (P<0.0001) (Table 7).

<u>Pupil Dehydration in Eastern Province, Zambia</u>

A total of 293 participants were recruited from grades 3-6. 154 (52.5%) of the participants were female. Participant ages ranged from 8-18 with a median age of 13

(Table 2). 291 participants provided urine in the morning and 280 provided urine in the afternoon.

Mild dehydration or greater (USG ≥ 1.010) was observed equally in both the water and control group (87.8% and 89.5%, respectively) during the morning urine collection. Dehydration prevalence was lower during the afternoon urine collection among the water group while remaining approximately the same in the control group (Table 3).

Mean urine specific gravity increased from USG 1.018 (SD=0.006) in the morning to 1.022 (SD=0.008) in the afternoon for the control group. These students experienced normal conditions during data collection meaning hydration status worsened during the school day for most students. Mean USG decreased by 0.012 points from morning to afternoon in the water group (P<0.0001) and increased by 0.004 points from morning to afternoon in the control group (P<0.0001) (Table 4). There was one severely dehydrated participant (USG ≥ 0.030) during afternoon urine collection in the water group compared to 21 severely dehydrated participants in the control group. Morning and afternoon showed a statistically significant, but weak correlation, r^2=0.21 (P=0.003). Morning hydration status was not predictive of afternoon hydration status.

When pupils were stratified by sex, there were significant differences in mean urine specific gravity between males and females in the morning although this difference was no longer seen in the afternoon. Males had an average USG 0.002 points higher than females during the morning for both the water and control groups. In the afternoon, the difference decreased to 0.001 for both groups (Table 9).

Girls were more likely to perform household chores in the morning before school while boys were more likely to have play before school. Girls were also more likely to have an illness in the previous two weeks than boys (Table 12).

Mean urine specific gravity was approximately the same across grades for morning and afternoon urine collection in both the water and control groups (Table 11).

Age, grade, , morning fluid consumption, breakfast consumption, travel time to school, previous illness, and activities during the school day were considered as potential risk factors during the analysis, but none of these variables showed a statistically significant association with either morning or afternoon dehydration meaning they were not effect modifiers for change in hydration status (Table 12). None of these variables led to a change in estimate for the odds ratio of dehydration comparing the water and control arms in a logistic model by more than 10% so they were not considered confounders for the effect of water provision (Table 6). Because none of the potential risk factors showed an association with dehydration status, a risk model using these variables was not developed.

There was weak correlation between morning and afternoon urine specific gravity in the water group, but moderate correlation in the control group (Table 13). Control group participants who were more dehydrated in the morning were still more dehydrated in the afternoon.

The correlation between specific gravity and urine color were strongly positive in both the morning and afternoon urine collections. Morning measures showed a correlation coefficient of 0.78 and afternoon measures had a correlation of 0.93, both of which were statistically significant ($P<0.0001$) (Table 7).

Cognitive performance measures in Sikasso, Mali

Correlation coefficients for the cognitive tasks ranged from -0.016 to 0.445 (Table 14). The strongest correlation was between the direct and indirect image comparisons ($r^2=0.445$, $P<0.0001$). A negative correlation of -0.016 was observed between the line trace and reverse number recall, but this correlation was not significant ($P=0.91$). The letter cancellation task was strongly correlated with all other tasks except the reverse number recall tasks ($r^2=0.10$, $P=0.30$). The indirect image comparison had weak to moderate correlations with the other memory task, forward number recall ($r^2=0.30$) and reverse number recall ($r^2=0.132$). The correlation between the number recall was moderate and significant ($r^2=0.370$, $P<0.0001$).

Boys and girls performed the same on all cognitive performance tasks except the indirect image difference tasks where the boys' average score (2.36) was 0.55 points higher than the average girls' score (1.81) (Table 16).

There were no significant differences in any of the cognitive tasks across age categories (Table 17).

Cognitive performance measures in Eastern Province, Zambia.

Correlation coefficients between the various cognitive tests ranged from 0.09 to 0.36. The lowest correlation was between the direct image difference and line trace tasks while the highest correlation was between the letter cancellation and reverse number recall tasks. The number recall tasks had a correlation coefficient of 0.36. The image difference tasks had a correlation coefficient of 0.32. The indirect image tasks had a correlation coefficient of 0.32 and 0.26 with the other memory tasks, direct image recall and indirect image recall, respectively. The letter cancellation tasks was weakly correlated with the other attention tasks, direct image comparison ($r^2=0.15$) and indirect image comparison ($r^2=0.27$). All correlations were significant at a 95% confidence limit ($P<0.05$) except for the correlation between the direct image difference task and the line trace task (Table 15).

Boys and girls performed the same on all task except for the direct image difference task. The average boys' score (2.71) was 0.55 points higher than the average score for girls (2.16, $P=0.001$). The mean boys' score (2.65) was higher in the indirect image difference and the line trace tasks compared to girls (2.32), but these results were not significant (Table 16).

Older children consistently did better on the cognitive tasks than the younger children. Children in both the 12-14 category performed better than children younger than 12 in all tasks except reverse number recall where there was no significant difference in scores. Children 15 and older did better than children younger than 12 on all tasks except the line trace where there was no significant difference in scores. Finally, children 15 and older performed better on the number cancellation task than children 12-14. This was the only task with a significant difference in scores between these two age categories (Table 18) suggesting performance levels out around ages 12-14.

Discussion

Hydration status

To our knowledge, this is the first study to assess dehydration among school children in sub-Saharan Africa. We found that 88% of pupils in our sample in Zambia were in some level of dehydration upon arriving at school in the morning. Among students in the control arm, 91.9% were dehydrated during the afternoon urine collection. While the number of dehydrated students remained approximately the same, the significant increase in average USG means students' hydration status deteriorated throughout the day. This is important because the negative physical effects of dehydration become more pronounced as dehydration becomes more severe.

In Mali, we observed lower rates of dehydration during the morning with an overall prevalence of 28.6%. Unlike in Zambia, the number of dehydrated pupils increased under both control and water conditions although the greater increase occurred on the control day. The severity of dehydration was lower in Mali as well. The mean urine specific gravity in the mornings (1.007 and 1.008) was similar to the afternoon mean urine specific gravity for the Zambian water group (1.006). Mean afternoon specific gravity was lower under control conditions in Mali (1.014) than in Zambia (1.022). A smaller portion of pupils in Mali was dehydrated and the dehydration was less severe. Less data on pupil activities was collected in Mali so it is difficult to identify factors that differ across the two populations. The refractometers used in each country were produced by different manufacturers and might account for some of the difference although such a difference is expected to be small as all refractometers used function based on the same principles.

These rates of dehydration in Zambia are similar to the prevalence of 93% found by Bar-David in Israel (5). The significant drop in dehydration among the water group (from 88% to 23%) shows that access to water at school is necessary for students to improve their hydration status while at school.

We did not find any variables had a significant association to dehydration status in the Zambian pupils. While this prevents the development of a complex risk model to predict which pupils are at greatest risk of dehydration, it does show the importance of schools providing access to water during the day. Pupils who received a supplemental 1L of water showed significant improvement in hydration status over those who did not receive supplemental water. Pupils who attend schools without water access are at significant risk of dehydration.

Because Zambian boys had higher mean urine specific gravity when arriving at school, we looked at factors that may account for this difference. Boys were more likely than girls to play games before school than girls were, likely because girls were busy with household chores and did not have the opportunity for play. The chores the girls performed were likely to require less physical exertion compared to the outdoor games boys would play.

Despite differences in hydration between boys and girls in the morning, by the afternoon hydration status between the two was almost the same. While pupils in the control group became more severely dehydrated overall, girls saw a greater increase in urine specific gravity than boys. Having an extra drink of water upon reaching school may be especially beneficial to boys, but all pupils should be encouraged to drink throughout the day.

In contrast to Zambia, boys and girls in Mali had the similar urine specific gravity scores when they arrived at school in the morning. Boys had more severe hydration in the afternoon than girls. Because data was not collected on pupil activity during the school day, we do not know if there were differences in school activities between the boys and the girls. In both Mali and Zambia, participants' mean urine specific gravity did not differ across grades. Regardless of grade, pupils in dry, hot settings are at risk of becoming dehydrated during the school day.

Surprisingly, morning urine specific gravity was only weakly correlated with afternoon urine specific gravity. While pupils who are dehydrated in the morning are likely to stay dehydrated through the day, severity of afternoon dehydration cannot be predicted by morning levels of dehydration. As our other results have shown, all pupils should be encouraged to drink water while at school regardless of morning hydration status.

Our study is limited by the population and geographic area in which it was conducted. While our results are similar to those found by Bar-David (2009), additional studies are needed to determine the prevalence of dehydration in climates that are not as hot or arid as Israel or Eastern and Sothern Africa.

This was a convenience sample of schools near Chipata town with limited access to water supply. We do not have any information on pupil hydration status at schools that do have water available. Simply providing water does not guarantee that pupils will drink (35, 36). Because of this, it is not possible to estimate the prevalence of dehydration of pupils in schools where water is provided, but it could be just as high as in our study population.

We also did not measure how much water was consumed by pupils in the water group for either country. Without this data, we were unable to assess how much water must be consumed in order to improve hydration status. While, in theory, the refractometers used in both countries should provide similar readings despite being produced by different manufacturers, because we did not compare their results on the same samples, we are unable to account for any differences that may exist between them.

We found that there is strong positive correlation between the measures of hydration status. Our correlation coefficients fall within the ranges found by Armstrong (r^2=77-96) (8). This is further evidence that urine color is an acceptable estimator for more accurate biometric measures of hydration. Visual inspection of urine is the quickest, cheapest method of hydration assessment and can be used by researchers in the field. Teachers can also use these results to instruct pupils to drink more water if they notice their urine is becoming darker.

Teachers and school staff should encourage pupils to drink regularly throughout the day. Schools that do not have water available on their premises should encourage pupils to bring water from home or their normal water source in order to have something to drink during the school day. Additionally, both the public and private sectors must continue to make access to safe water in schools a global priority in an effort to reduce pupil dehydration.

Cognitive performance measures in Eastern Province, Zambia

While nearly all correlation coefficients were statistically significantly different from 0 in Zambia, none of the r^2 values were particularly high. It may be that while these tasks measure similar cognitive skills, children perform these skills using different cognitive processes resulting in low correlation between the tasks. There were fewer significant correlations between tasks in the Mali data although there were still relatively high correlations between the image comparison tasks and between the number recall tasks in both countries.

Because the letter cancelation, direct image comparison, and indirect image comparison tasks were designed to measure visual attention, it was expected they would be more highly correlated with each other than with the other tasks (37). The letter cancellation task did not appear to be any more highly correlated with these tasks than with the others; in fact, its lowest correlation was with the direct image comparison. The image comparison tasks had an r^2 of 0.33, the highest correlation for each of these tasks.

The number recall and indirect image comparisons all measured short-term memory suggesting pupil results on these tasks would be highly correlated (37). The number recall tasks had an r^2 of 0.36 which was the highest correlation for any of the tasks. The indirect image comparison task did not seem to be any more highly correlated with these tasks than with the others.

We observed only one statistically significant difference in task scores between boys and girls in both countries. The mean score for boys on the direct image difference task was higher than the mean score for the girls. While there is some evidence that females perform better than males in tasks of visual attention, there is no prior evidence in gender differences in the image comparison task used for this study (38). The consistency between the results from Mali and Zambia suggests that there may be a true difference in the performance of boys and girls on direct image difference tasks. Further study is needed to bolster this finding and examine the cognitive process that might account for this difference.

Finally, in Zambia, children 12 years and older tended to do better than children younger than 12 in all tasks. Children 15 years and older performed better than 12-14 year olds only in the letter cancelation task. This suggests that children's performance on these cognitive tasks increases with age before leveling out around age 12. This is consistent with Gur et al's, findings that performance on cognitive tasks tends to show great improvement around ages 12-13 (34). While Gur's study used computerized testing in American children, it suggests that important cognitive development occurs around the early teen years. As such, it may be appropriate to stratify across age group during analysis of cognitive performance studies.

Children in Mali did not show any differences in performance on the cognitive tasks across age categories. This could be because Zambian children are more familiar with these or similar cognitive performance measures and so improve with age while children in Mali are unfamiliar with these tasks and the skills necessary for success on them.

The particular tasks used in this study are, in fact, the biggest limitation of this study. While these tasks have been used in previous research in Europe and the United States, they have not been validated for use in Africa. Due to differences in culture and the education systems in Africa, these tasks may not adequately measure cognitive function in African children. Future researchers should work with African teachers and researchers to develop tasks that are more appropriate for measuring attention, memory, and psychomotor skills in African children.

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Tables

Table 1. Mali study population by sex, school grade, and age, n=110

Characteristic	Water day, n=108	Control day, n=109
Female	47	48
Male	62	61
Grade		
5	59	60
6	50	49
Age		
9-10	14	14
11-12	53	52
13-14	28	28
15-16	5	5

Table 2. Study population by sex, school grade, and age, n=293

Characteristic	Water group, n=149	Control group, n=144	Total	Overall
Female	85	69	154	291
Male	63	74	137	
Grade				
3	37	35	72	293
4	32	29	61	
5	41	40	81	
6	39	40	79	
Age				
8-10	22	20	42	291
11-12	40	43	83	
13-14	60	58	118	
15-18	25	23	48	

Table 3. Participant hydration status in morning and afternoon by study arm

	Dehydrated, morning, n (%)	Dehydrated, afternoon, n (%)
Mali		
Water day	34 (31.5%)	49 (45.4%)
Control day	28 (25.7%)	85 (78.0%)
Zambia		
Water group	130 (87.8%)	35 (2.3%)
Control group	128 (89.5%)	125 (91.9%)

Table 4. Mean urine specific gravity (USG), by study group

	Morning USG, mean	Afternoon USG, mean	Change in mean	p-value
Zambia				
Water group	1.018	1.006	-0.012	<.0001
Control group	1.018	1.022	0.004	<.0001
Mali				
Water day	1.008	1.010	0.003	0.0022
Control day	1.007	1.014	0.007	<.0001

Table 5. Association of selected variables with dehydration using Chi-Square tests and one-way ANOVA separately for morning and afternoon hydration

		Morning			Afternoon		
Variable	n	Chi-Square	df	p-value	Chi-Square	df	p-value
Sex	291	2.6136	1	0.11	2.1009	1	0.15
Grade	293	0.5951	3	0.90	1.5875	3	0.66
Ate breakfast	292	1.0541	1	0.30	0.397	1	0.53
Illness in past 2 weeks	293	3.1901	1	0.07	0.0148	1	0.90
Had a drink before school	292	0.2515	1	0.61	3.2101	1	0.07
	n	F-value	df (df_n/df_d)	p-value	F-value	df (df_n/df_d)	p-value
Age*	291	0.31	10/280	0.98	0.41	10/280	0.94
Time to school*	292	0.77	18/273	0.73	0.71	18/273	0.80

*Analyzed using one-way ANOVA

Table 6. Odds ratios for the effect of study arm on afternoon dehydration with and without potential confounders*

	Study arm only	Study arm + potential confounders	Difference in estimate
Odds ratio (95% CI), water arm vs control arm	0.0467 (0.0253, 0.0862)	0.044 (0.023, 0.084)	0.003**

*Potential confounders include sex, age, grade, morning fluid consumption, breakfast consumption, and illness in previous two weeks
**<10% change in estimate

Table 7. Spearman correlation coefficients comparing urine specific gravity and urine color

Zambia

	Urine color, am	Urine color, pm	p-value
Urine specific gravity, am	0.79376	-	<0.0001
Urine specific gravity, pm	-	0.902056	<0.0001

Mali

	Urine color, am	Urine color, pm	p-value
Urine specific gravity, am	0.77752	-	<0.0001
Urine specific gravity, pm	-	0.73424	<0.0001

Table 8. Mean morning and afternoon urine specific gravity in Mali stratified by sex and study arm

	Male	Female	Difference	p-value
Control Day				
Morning USG, mean	1.0077	1.0059	0.00187	0.08
Afternoon USG, mean	1.015	1.0126	0.00239	0.03
Water Day				
Morning USG, mean	1.0081	1.0068	0.00126	0.27
Afternoon USG, mean	1.0116	1.0075	0.0041	0.01

Table 9. Mean morning and afternoon Urine Specific Gravity in Zambia Stratified by Sex and Study Arm

	Male	Female	Difference	p-value
Control group				
Morning USG, mean	1.0188	1.0163	0.00252	0.01
Afternoon USG, mean	1.0222	1.0211	0.00108	0.44
Water Group				
Morning USG, mean	1.0193	1.0168	0.00246	0.02
Afternoon USG, mean	1.0065	1.0059	0.000588	0.68
Water and Control groups				
Morning USG, mean	1.019	1.0166	0.00245	0.0007
Afternoon USG, mean	1.0149	1.0125	0.00241	0.07

Table 10. Mean Urine Specific Gravity Stratified by Grade and Study Arm in Mali

	Grade		
	5	6	p-value
Control Day			
Morning USG, mean	1.0068	1.007	0.89
Afternoon USG, mean	1.014	1.0139	0.94
Water Day			
Morning USG, mean	1.0073	1.0077	0.73
Afternoon USG, mean	1.0100	1.0098	0.92

Table 11. Mean Urine Specific Gravity Stratified by Grade and Study Arm in Zambia

	Grade				
	3	4	5	6	p-value
Control group					
Morning USG, median	1.018	1.018	1.017	1.018	0.98
Afternoon USG, median	1.022	1.022	1.021	1.022	0.86
Water group					
Morning USG, median	1.019	1.017	1.018	1.018	0.62
Afternoon USG, median	1.007	1.005	1.005	1.008	0.41

Table 12. Association of risk factors for morning dehydration for sex using Chi-Square test

	Girls	Boys	p-value
Illness in previous 2 weeks	35	17	0.02
Ate breakfast	61	54	0.99
Had something to drink this morning	57	40	0.17
Morning Activity			<0.0001
Chores	77	13	
Playing	9	52	
Farming	2	14	

Table 13. Correlation of morning urine specific gravity with afternoon urine specific gravity in Zambia and Mali

	Correlation coefficient	p-value
<u>Zambia</u>		
Water Group	0.27641	0.0008
Control Group	0.51742	<0.0001
Water and Control Group	0.24924	<0.0001
<u>Mali</u>		
Water Day	0.33313	0.0004
Control Day	0.22037	0.02
Water and Control Days	0.24268	0.0003

Table 14. Spearman correlation coefficients for comparing all cognitive performance tasks in Mali

	Letter Cancelation	Image Difference, Direct	Image Difference, Indirect	Number Recall, forward	Number Recall, reverse	Line Trace
Letter Cancelation	1	0.19315	0.26249	0.23634	0.10007	0.37497
p-value		0.04	0.01	0.01	0.30	<0.0001
n	109	109	109	109	109	107
Image difference, direct	0.19315	1	0.44517	0.16213	0.08958	0.19968
p-value	0.04		<0.0001	0.09	0.35	0.04
n	109	109	109	109	109	107
Image difference, indirect	0.26249	0.44517	1	0.29809	0.13192	0.15973
p-value	0.01	<0.0001		0.0016	0.17	0.10
n	109	109	109	109	109	107
Number recall, forward	0.23634	0.16213	0.29809	1	0.36933	0.01135
p-value	0.01	0.09	0.0016		<0.0001	0.91
n	109	109	109	109	109	107
Number recall, reverse	0.10007	0.08958	0.13192	0.36933	1	-0.0157
p-value	0.3	0.35	0.17	<0.0001		0.87
n	109	109	109	109	109	107
Line trace	0.37467	0.19968	0.15973	0.01135	-0.0157	1
p-value	<0.0001	0.04	0.1	0.91	0.87	
n	107	107	107	107	107	107

Table 15. Spearman correlation coefficients for comparing all cognitive performance tasks in Zambia

	Letter Cancelation	*Image Difference, Direct*	*Image Difference, Indirect*	*Number Recall, forward*	*Number Recall, reverse*	*Line Trace*
Letter Cancelation	1	0.15394	0.27189	0.25709	0.35399	0.25167
p-value		0.01	<0.0001	<0.0001	<0.0001	<0.0001
n	277	265	267	277	255	277
Image difference, direct	0.15394	1	0.32571	0.22743	0.19752	0.08957
p-value	0.01		<0.0001	0.0002	0.0019	0.14
n	265	267	263	267	245	267
Image difference, indirect	0.27189	0.32571	1	0.32289	0.26006	0.18431
p-value	<0.0001	<0.0001		<0.0001	<0.0001	0.0024
n	267	263	270	270	248	270
Number recall, forward	0.25709	0.22743	0.32289	1	0.36019	0.15598
p-value	<0.0001	0.0002	<0.0001		<0.0001	0.01
n	277	267	270	280	257	280
Number recall, reverse	0.35399	0.19752	0.26006	0.36019	1	0.2089
p-value	<0.0001	0.0019	<0.0001	<0.0001		0.01
n	255	245	248	257	257	257
Line trace	0.25167	0.08957	0.18431	0.15598	0.2089	1
p-value	<0.0001	0.14	0.0024	0.01	0.0008	
n	277	267	270	280	257	280

Table 16. Mean cognitive task scores for boys and girls in Zambia and Mali

	n	Mean score, boys	Mean score, girls	Difference	p-value
Zambia					
Letter cancelation	275	20.28	21.03	-0.75	0.42
Image difference, direct	265	2.71	2.15	0.55	0.001
Image difference, indirect	268	2.65	2.32	0.33	0.07
Number recall, forward	278	5.45	5.35	0.1	0.50
Number recall, reverse	255	3.71	3.71	0	0.98
Line trace	278	21.64	20.15	1.49	0.12
Mali					
Letter cancelation	109	22.97	23.17	-0.2	0.89
Image difference, direct	109	2.36	1.81	0.55	0.05
Image difference, indirect	109	2.44	1.98	0.46	0.07
Number recall, forward	109	5.44	5.02	0.42	0.16
Number recall, reverse	109	3.38	2.92	0.46	0.19
Line trace	107	20.47	18.62	1.85	0.20

Table 17. Pairwise comparison of age categories for cognitive test scores with 95% confidence intervals in Zambia

	<12	12-14	15+	12-14 v. <12	15+ v. <12	15+ v. 12-14
Letter cancellation						
Mean score	22.65	22.93	20.00			
Mean difference				0.29	-2.65	-2.93
Mean difference CI				-2.38, 2.95	-8.73, 3.44	-8.96, 3.09
Significant (P<0.05)				No	No	No
Image difference, direct						
Mean score	2.04	2.41	1.90			
Mean difference				0.38	-0.51	-0.14
Mean difference CI				-0.13, 0.89	-1.66, 0.64	-1.30, 1.03
Significant (P<0.05)				No	No	No
Image comparison, indirect						
Mean score	2.13	2.47	2.90			
Mean difference				0.34	0.77	0.43
Mean difference CI				-0.14, 0.83	-0.34, 1.88	-0.67, 1.52
Significant (P<0.05)				No	No	No
Number recall, forward						
Mean score	5.20	5.26	5.30			
Mean difference				0.06	0.10	0.04
Mean difference CI				-0.48, 0.60	-1.14, 1.34	-1.19, 1.27
Significant (P<0.05)				No	No	No
Number recall, reverse						
Mean score	3.41	3.57	2.80			
Mean difference				0.16	-0.77	-0.61
Mean difference CI				-0.47, 0.78	-2.18, 0.64	-2.03, 0.81
Significant (P<0.05)				No	No	No
Line trace						
Mean score	17.40	16.47	16.10			
Mean difference				-0.94	-1.3	-0.37
Mean difference CI				-3.97, 2.09	-8.16, 5.56	-7.15, 6.41
Significant (P<0.05)				No	No	No

Table 18. Pairwise comparison of age categories for cognitive test scores with 95% confidence intervals in Zambia

	<12	12-14	15+	12-14 v. <12	15+ v. <12	15+ v. 12-14
Letter cancelation						
Mean score	16.13	21.58	25.69			
Mean difference				5.45	9.56	4.1
Mean difference CI				3.10, 7.81	6.46, 12.66	1.31, 6.90
Significant (P<0.05)				Yes	Yes	Yes
Image difference, direct						
Mean score	2.04	2.55	2.57			
Mean difference				0.51	1.18	0.02
Mean difference CI				0.01, 1.00	-0.13, 1.18	-0.57, 0.61
Significant (P<0.05)				Yes	No	No
Image difference, indirect						
Mean score	2.01	2.63	2.72			
Mean difference				0.62	0.70	0.09
Mean difference CI				0.11, 1.12	0.03, 1.37	-0.52, 0.69
Significant (P<0.05)				Yes	Yes	No
Number recall, forward						
Mean score	4.84	5.56	5.83			
Mean difference				0.72	1.99	0.28
Mean difference CI				0.30, 1.14	0.45, 1.55	-0.22, 0.78
Significant (P<0.05)				Yes	Yes	No
Number recall, reverse						
Mean score	3.31	3.80	4.04			
Mean difference				0.49	0.73	0.24
Mean difference CI				-0.023, 1.02	0.06, 1.41	-0.36, 0.84
Significant (P<0.05)				No	Yes	No
Line trace						
Mean score	18.8	21.75	21.54			
Mean difference				2.95	2.74	-0.20
Mean difference CI				0.24, 5.65	-0.83, 6.32	-3.43, 3.03
Significant (P<0.05)				Yes	No	No

Chapter III: Summary and Future Directions

Summary

We found that around 90% of pupils in Zambia were dehydrated throughout the school day. In Mali, around 30% of pupils were dehydrated upon arriving to school, but this increased to 78% under control conditions. In both countries, the severity of dehydration increased for pupils in the control group. This is an important finding because the control condition represents the typical experience for these children. Without access to water at school, pupils are at increased risk for the negative physical and mental effects of dehydration.

When we examined the correlation of field measures for hydration status, we found that urine color has a strong correlation with urine specific gravity. This result provides support for using urine color assessment as an approximate measure of dehydration. As urine color becomes darker, children are becoming more dehydrated. Both field researchers and school staff can use urine color as a safe, inexpensive, easy-to-use measure for monitoring the hydration of children.

We also examined the correlation of field measures of cognition and found that the cognitive tasks used in this study were only weakly correlated. Because the low correlation could be due to the tasks measuring different cognitive processes, we suggest that researchers continue to use a variety of cognition measures to measure cognitive functions such as memory, attention, and psychomotor skills. The biggest limitation of this study is that the measures used have not been validated for use in non-Western contexts meaning they may not have been suitable for our work in Africa.

Future Directions

Further research is still needed on the relationship between hydration status and cognitive effects on children. Additional research is especially needed in Africa as, to the best of our knowledge, our two studies are the first to be carried out there. Our studies did not quantify how much water participants consumed during the day. This leads to additional questions that can be explored further. The first, 'how much water does a child need to consume in order to move from hydrated to dehydrated, and is there a linear relationship between amount consumed and urine specific gravity ?' The next question is 'does the amount of water consumed have an effect on cognitive performance scores?' These questions could be answered using a similar design to our Mali and Zambia studies by including a method to track consumption such as measuring the amount of water remaining in a participant's bottle at the end of the study period.

Another area for further study is the development of cognitive measures that have been validated for use in African countries. Researchers must work with local educators to develop measures that include tasks that measure the cognitive functions typically required of pupils in African countries as well as ensuring these tasks are culturally appropriate.