Exposure To Heat and Student Cognitive Functioning

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Abstract

This paper examines the effect of heat on children's executive function behavior in Ghana. Executive function behavior reflects the ability to stay focused regardless of external stimuli. Heat may act as a stimulus and affect executive function behavior through changes in brain chemistry and functioning, leading to decreases in attention, memory, information retention and processing. Using rich longitudinal data on children, this paper estimates child fixed-effects models to obtain the contemporaneous effect of temperature on executive function behavior and tests scores. The results suggest that a deviation from the reference temperature bin (24-26°C) decreases children's executive function. Specifically, at 33-35°C, these results correspond to an increase in the likelihood of being never attentive. The paper also finds that relatively poorer children are more affected. There is no effect on test scores, but since exam are not timed, test scores could reflect both skills and effort in this context.

JEL: I21, I24, Q54
Keywords: Learning, Inequality, Low Income, Global Warming

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Introduction

The number of high temperature days continues to grow each year. Individuals living in developing countries are the greatest risk: poorer countries are hotter, and individuals have less capacity to protect themselves against the harm of heat. This has dire implications for children's development and learning, where learning outcomes are already extremely low. Indeed, despite increasing school enrollment in Sub-Saharan African countries, the learning poverty rate [1] is estimated at 86% before the global pandemic of 2020 and 89% after the pandemic (Team, Africa, and Union 2022). Specifically, while, according to the SDG "Quality Education" report on African countries, 80% of primary school aged students are enrolled, less than 30% achieve the minimum proficiency level in reading (Evans and Mendez Acosta 2021). Adeniran, Ishaku, and Akanni (2020) and Bold et al. (2017) show evidence of low learning in numeracy as well. Those documented two facts led to wonder what the implications of more hot days are on learning in developing country classrooms.

I thus explore heat as a potential driver for low learning in Sub-Saharan Africa. Specifically, this paper studies the effect of heat on cognitive functioning for children in the southern region of Ghana called the Greater Accra Region. Learning is proxied by executive function behavior. Executive function behavior, also called the capacity to pay attention or attention shifting is part of a set of processes called executive function and which measure a child's ability to regulate thoughts, actions, and emotions, all of which are central to the learning process. Indeed, hot temperatures changes the brain chemistry and functioning, and decreases attention, memory, information retention and processing (Hocking et al. 2001; Hyde et al. 1997). Hot temperatures are proven to decrease children's performance in the short run in developed countries (Graff Zivin, Hsiang, and Neidell 2018). The setting of developing countries, where there is little to no adaptation strategies to heat, is also studied and studies include evidence in Brazil, China and India (Graff Zivin et al. 2020; Garg, Jagnani, and Taraz 2020; Li and Patel 2021). However, all those studies focus the most on adults and how low performance due to heat could affect their long-term outcomes. Not much is known about how heat affect children performance or functioning in a developing countries, which matters for long run learning under expected rise in temperature. Another strand of the literature studies the effect of heat on learning in the long run, where long run is defined either as one year before the exam date

1. The learning poverty rate is the proportion of children who are unable to read a simple text with comprehension by age 10. Learning poverty combines schooling and learning.

or from birth to the exam date. Studies include Graff Zivin, Hsiang, and Neidell (2018) and Park et al. (2020) in the context of developed countries. While the latter found that heat does decrease learning, Graff Zivin et al. (2020) found no long run effects. Graff Zivin et al. (2020) argues that the null results could be due to post-strategies set up to counter the effect of heat on learning. Those post strategies, however are costly and are not necessarily affordable to developing countries.

This paper makes three contributions. It is the first paper to look at the effects of temperature on children executive function behavior. Executive function behaviors are a component of executive functions and measure how an individual can stay focus regardless of stimuli or shocks received from the immediate environment (Araujo et al. 2016). Executive function behaviors are found to be predictive of how students perform on cognitive tasks (Ahmed et al. 2022) and low executive functions are predictive of low later life outcomes (Moffitt et al. 2011). In fact, they are predictive of how much a student can learn in a usual classroom and have implications on how they can perform during high stakes exams. Secondly, this paper add to the limited evidence using within individual variation. This is possible because of the longitudinal nature of a data on student tests in Ghana. I thus build on the previous literature to analyze how heat affects the executive function behavior of children's in Ghana, as well as their test scores in math and literacy. Thirdly, this paper contributes to the limited evidence of study on children's functioning and add a new setting which is the Sub-Saharan African context. There are 2 components to this point, the geographic location of the study and the demographic group targeted. As stated previously, there is evidence of children performance in developed countries (Graff Zivin, Hsiang, and Neidell 2018). However, nothing is known about children in the sub-Saharan African context. In fact, sub-Saharan Africa matters because by 2050, 40% of children in the world will live on the African continent and this is a continent deeply affected by a warming planet. But the implications for young children are not fully understood yet. On the other side, there is evidence on agricultural productivity Emediegwu, Wossink, and Hall (2022) and on physical (labor) productivity LoPalo (2023) in Africa. While the importance of knowing about workers and agricultural productivity is not disputable, the importance of children's productivity in learning is more subtle but also as important. In fact, if children's functioning is hindered by heat, then children are not learning on hot days. This could accumulate over time and generate the overall persistent low learning trend observed in Africa.

I link the Universal Thermal Climate Index (temperature perceived by the body) data to an early childhood survey with similar survey instruments measuring cognitive and non-cognitive development outcomes for children—Quality Preschool for Ghana (QP4G). In particular, I used the average daytime UTCI. QP4G has a panel with 8 survey-round over 8 years. It is a school based intervention aiming at improving children's school readiness in the Greater Accra region in Ghana. Children were in two grades of preprimary school, enrolled in grades pre-primary 1 or pre-primary 2 at baseline in 2015 and were followed until 2022. Different outcomes were regularly measured. For the first three years, the International Development and Early Learning Assessment (IDELA hereafter) was used to evaluate the children. For the last 5 data collections, various assessments were used including the Early Grade Reading Assessment (EGRA) and the International Social and Emotional Learning Assessment (ISELA). Consequently, in this paper, I will exploit the first three survey-rounds (2015-2017) to avoid any variation coming from the difference in the testing materials. IDELA is a rich instrument which include a measure of executive function behavior, both throughout the test and at the end of the test. To measure children executive function behavior, the assessor makes a report on how the child is behaving throughout the survey. The report is possible because the test is administered to one child at a time. Interviewers are professionals and additionally trained by psychologists to administer those tests and being able to report accurately on the children's behaviors. IDELA includes emergent math, and emergent literacy as well.

I identify the effects of temperature on child performance on survey instruments by exploiting variations within an individual. This is possible because of the longitudinal nature of the dataset. This methodology is rare in the literature given the lack of longitudinal datasets using the same assessment over several waves, particularly in sub-Saharan Africa. The thought experiment is comparing the same individual taking the test on a day when it is relatively cold to a day when it is relatively hot. This solves many potential biases related to the selection of families into location and holds fixed any individual unobserved time-invariant characteristics. Fist, location is not randomly assigned to families, so there is a likelihood that temperature is correlated with certain background characteristics of children such as wealth. Secondly, comparing the same individual hold innate ability constant, as well as any other individual specific attributes that remain constant over time. I control for time-varying characteristics such as seasons using a survey round fixed effect. I also include age fixed effects to adjust for any learning that happens between tests, that might allow older children to be better test takers. Our specification uses 3° C temperature bins and a non linear specification to allow for a non linear relationship between children's functioning and temperature.

Using data from all three survey-rounds jointly, I find that a deviation from the reference temperature bin (24°C and 26°C) decreases the attentiveness of children. Specifically, attentiveness decreases by respectively 0.05, 0.11, 0.18 and 0.13 points as it gets hotter (i.e. 27°C–29°C; 30°C–32°C; 33°C–35°C; 35°C–41°C). At a temperature bin of 33–35°C, these results correspond to a 20% decrease in the likelihood of being almost always attentive and a 2% increase in the likelihood of being almost never attentive. I found evidence that the decrease in attentiveness is observed both at the beginning and toward the end of the test. I found no effect on test scores. This could be indicative of extra efforts by children to overcome the adverse effects of heat. In fact, the interviews are not timed and are administered for one child at a time.

It is argued that climate related change are exacerbating the inequality between children from relatively wealthy families and children from relatively poor families. I thus conduct an heterogeneity analysis by socioeconomic background. I find that the attention of children of low socioeconomic background decreases significantly with higher temperatures. On the other hand, wealthier children perform significantly better, on the margin of going from often and always attentive to sometimes and never attentive. Our sample include very young children, as young as 2 years old. Very young children have a smaller body and are more sensitive to heat. I verify that hypothesis by doing an heterogeneity analysis by age group. I found that young children (< 6 years old) become inattentive as it gets hotter and there is no difference between older children and younger children.

The rest of this paper is organized as follows. Section 3 describes data and construction of key measures. Section 5 presents summary statistics. Section 4 describes the estimation strategy. Section 6 presents and interprets the main results. Section 7 concludes.

1 Conceptual Framework

Heat affects performance through changes in brain chemistry and functioning as indicated by Hocking et al. (2001). This further results in a decrease in attention, memory, information retention and processing as mentioned by Hyde et al. (1997). In other words, heat might act as an external stimuli that forces children to use more than their instinct or intuition when exposed to it. There are implications for individuals in general and children in particular.

Children might have worse executive function behavior. Executive functions behaviors are also called executive control or cognitive control and refer to a family of top-down mental processes needed when you have to concentrate and pay attention (Diamond 2013). Executive functions make possible mentally playing with ideas; taking the time to think before acting; meeting novel, unanticipated challenges; resisting temptations; and staying focused (Diamond 2013). Core executive functions are inhibition, working memory, and cognitive flexibility (Diamond 2013; Ahmed et al. 2022). Executive function behaviors are the application of executive function skills in everyday contexts and researchers measure such behaviors via observation and ratings of children's abilities to pay attention, stay engaged, and inhibit impulses (Ahmed et al. 2022).

Children might get lower scores on test or might exert higher effort to attain the same score. Heat acts as a stimuli and requires children to exert more effort to stay focused. A child who decide not to make some efforts to overcome the harm of heat might get a lower score. A child can choose to make an effort which leads to a test score that reflects his accumulated knowledge. The choice of making effort could be determined by children's characteristics.

The effect of heat on children's functioning might differ by their family's social-economic status. Indeed, wealth is protective because it offers better health, and expose children to more cognitive practices. Therefore, children from relatively wealthier families might perform better than the children from relatively poorer families, and additionally could be unaffected by heat. This could increase inequality in learning between wealthier and less wealthy students. The effect of heat on children's functioning might also differ by age groups. Young children could respond differently to heat because their brains are at an early development stage.

2 Background

The Republic of Ghana is a tropical country located in western Africa. Tropical countries are in average hot and Ghana has an historical (1901-2020) annual mean temperature of 27.3°C according to its World Bank's climate risk profile. In Ghana, the annual mean temperature has risen by 1°C since 1960 and the number of very hot days (defined as temperatures over 35°C) have increased by 13% per year and hot nights (defined as temperature over 26°C) have increased by 20% each year. While northern Ghana is hotter and dry, southern Ghana is more humid. February to April are the hottest month with a mean temperature between 28 and 29°C and June to September are the coldest in average with a mean temperature of 25-26°C.

The academic year runs from September to July and therefore children are in school during the hottest month.

In terms of education profile, Ghana has among the highest net enrollment rates in Africa (UNESCO, 2015) and the government has been investing in two years of universal pre-primary education since 2007. Nevertheless, there are concerns about low learning and educational inequality according to UNESCO (Spotlight on basic education completion and foundational learning: Ghana, UNESCO 2022). In fact, the country is divided into regions and regions are divided into districts. Specifically, Ghana is divided into 16 regions and the Greater Accra region is the most developed region and is located in southern Ghana. It has the smallest proportion of socioeconomically-disadvantaged citizens compared to all the regions (Owusu and Agyei-Mensah 2011). However, the 29 districts of the Greater Accra region are unequal in terms of basic services delivery such that the districts Ga South, Adenta, Ledzokuku-Krowor, Ga Central, La Nkwantanang-Madina, and Ga West are rated the most disadvantaged districts by the 2014 UNICEF District League Table. Inequality within those districts is high across inhabitants.

This paper used a longitudinal data collected on children from Ga South, Adenta, Ledzokuku-Krowor, Ga Central, La Nkwantanang-Madina, and Ga West. The data is collected on children in pre-primary in 2015, on their caregivers, on their schools and on their teachers. Tablets are used for the data collection and date and time are collected automatically as part of the process.

3 Data

To estimate the effects of exposure to heat on children functioning, I take advantage of a longitudinal data spanning 3 years in Ghana following a study called ”Quality for Pre-school for Ghana” (hence, QP4G). I link the first three survey-rounds of QP4G to the fifth generation of the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalyses of the global climate, the ERA5-HEAT dataset (Di Napoli et al. 2021). I particularly use the Universal Thermal Climate Index (hence, UTCI) to represent temperature.

3.1 QP4G Data

The data on children’s outcomes and characteristics is from the QP4G intervention. The intervention aims at improving classroom quality and develop Ghanaian children’s school readiness. The intervention was done in the Greater Accra region, in the southern part of Ghana, in 6 districts, namely Adentan, Ga Central, Ga East, Ga South, La-Nkwantanang-Madina, and Ledzokuku-Krowor. The intervention is school-based and included children aged 2 to 10 years old in the first year. The children were followed for 8 years, from 2015 to 2022. Figure D.4 shows the dispersion of different schools in our sample. The geographic dispersion is not large. At baseline, 3435 children were included in the study. There is attrition overtime of about 9% from the first survey year.

For the first three survey rounds, the surveys were done in school and include tests administered to kindergarten children. Fifteen children were randomly selected in kindergarten class rosters and were individually surveyed. The date of the surveys are decided in advance given that it is a contract between the surveyors and the evaluator team. Therefore there is no selection of date by students.

To assess or measure children readiness, the International Development and Early Learning Assessment (IDELA) was used for the first three survey rounds. IDELA is a set of items, where each item test a different skill which could be cognitive or non cognitive. For example, the children reading comprehension and vocabulary skills were tested, as well as their ability to add, subtract, multiply and divide. Non cognitive tests include personal awareness. One specificity about the dataset is that there are surveyors' assessments of the student attentiveness related to some items or exercises (e.g,: listening comprehension exercise), as well as an overall assessment related to the whole test.

3.2 Merging UTCI Data and QP4G Data

In our analysis, temperature is The Universal Thermal Climate Index. The UTCI is an index that combines air temperature, humidity, wind speed, and radiant heat and is a proxy of temperature felt by the body. The ERA5-HEAT dataset offers estimated hourly UTCI data expressed in degrees Celsius. The data is publicly available from January 1940 to near realtime. The precision is: $0.25° \times 0.25°$ spatial resolution (~31 Km). In our our QP4G data, there are six cells. The districts Ga East and La-Nkwantanang-Madina are separately located in one cell. Other districts (Adentan, Ga Central, Ga South, and Ledzokuku-Krowor) are found in multiple cells. Ga South is the most spread out district.

The UTCI is linked to three (03) survey-rounds of QP4G using on one side the longitude and latitude of each survey locations, and on the other side the date and time of the survey. The date and time of the survey were collected automatically on a tablet. For the timing, specifically, survey start time, survey end time and survey submission time were collected. The start and end time accurately described the length of the survey or the time span within which each child answered the test questions. The submission time here refers to the time when the surveyor submitted the survey, which could be different than the end time of the survey.

There are different thresholds that define different level of heat stress. From 26°C to 32°C the human body experience moderate heat stress. From 32°C to 38°C the human body experiences strong heat stress. From 38°C to 46°C the human body experiences very strong heat stress. UTCI above 46°C causes the human body to experience extreme heat stress. These thresholds do not account for acclimatization and do not say anything about acclimatization. Ghana is a tropical country and unlike countries in the northern hemisphere, Ghana is in average hotter over the year. This raises the question of acclimatization and how this could change the UTCI heat stress thresholds for that side of the world.

4 Estimation Strategy

To estimate the effects of heat stress shock on child functioning on the day of the test, I mainly exploit two types of variations. The first one is a within survey-round variation in temperature. Indeed, in each survey-round individuals are assigned a daily average temperature. Also, children are usually interviewed over the course of 2 months. This implies that within a survey-round children are likely exposed to different temperature ranges. The second and main variation that I exploit is a within child variation (or an across time variation). Because of the longitudinal nature of our data, I observe the same individual multiple times, and while some individual might always be exposed to the same temperature bin throughout the three survey-rounds, some individuals will switch from a hotter temperature to a colder temperature or vice versa. Intuitively, the within child variation (or across time variation will compare the same individual taking the test at different point in time, one when the individual is exposed to hotter temperature and one when the individual is not. This methodology is used in Graff Zivin, Hsiang, and Neidell (2018) and Park et al. (2020) only to the best of our knowledge. Other papers including Garg, Jagnani, and Taraz (2020), Graff Zivin et al. (2020), Li and Patel (2021), Park (2022) use a different identification where they compare the individuals within the same location. I discussed why this might be an issue and how being able to observe the same individual at multiple periods helps resolve those issues.

Following the subsection 5.2 I define the omitted temperature bin as $24-26°C$. The specification used is:

$$y_{i,r(t)} = \sum_{c=1}^{5} \beta_c \mathbb{1}_{T_{L(i),t} \in [l_c, u_c]} + \delta_i + \delta_{r(t)} + \delta_a + \epsilon_{i,r(t)}, \tag{4.1}$$

where $[l_{\{c=1\}}, u_{\{c=1\}}] = [24°C, 27°C[$ is the first temperature bin. The omitted temperature bin in our analysis is $[l_{\{c=1\}}, u_{\{c=1\}}]$. i represents a child, t represents a year and $r(t)$ stands for survey-round which embed the concept of time as a year and the concept of seasonality.Indeed, each survey round denotes a different seasons of the year. L represents location which is a cell of $2.5° \times 2.5°$. $y_{i,r(t)}$ is the outcome of child i interviewed in survey round $r(t)$. The error term $\epsilon_{i,r(t)}$ is clustered at the individual level.

The child FE, δ_i , in our specification solves omitted variable bias problems. It specifically allows to control for individual background characteristics such as innate skills or intrinsic ability, tolerance to stress, family wealth and parental support. I control for other yearly invariant characteristics, $\delta_{r(t)}$, such as seasonal variations, education policies, or the timing of the academic year [2]. I control for age, δ_a, because in our dataset, children are aged 2-11 years old, which is a wide range of age and each age implies different cognitive maturity as well as different adaptation to heat stress for example. There could be a correlation between age and heat if children take the test during a hot period when they are old and during a cold period when they are young and vice versa. I do not need to control for humidity because as discussed previously, the UTCI measures embeds humidity. The third source of variation is the spatial variation. Temperature is assigned at the cell level and individual are distributed across 6 cells in our dataset.

I explore inequality in different socio-economic background by doing an heterogeneity analysis using a SES indicator. The equation used for this analysis is the following:

$$y_{i,r(t)} = \sum_{c=1}^{4} \beta_c \mathbf{1}_{T_{L(i),t} \in [l_c, u_c]} \times Poor + \delta_i + \delta_{r(t)} + \delta_a + \epsilon_{i,r(t)}, \tag{4.2}$$

where $Poor$ represents a dummy variable which is 1 when the child belongs to a poor family, or more specifically, if the construction material of his parent's house in of poor quality.

2. The survey-round FE is actually a survey-round $\times$ a dummy for intervention FE. The data used in this analysis is from a one year intervention done in 2015 in the Greater Accra region of Ghana. The objective of the intervention is to improve the readiness of kindergarten children for primary schools. The intervention was both at the teacher and at the parents level.

5 Sample and Summary Statistics

5.1 Sample

I use the first three survey rounds of QP4G spanning the years 2015 to 2017. There are 3435 students in 2015, 3500 in 2016 and 3126 students recorded in 2017. From 2015 to 2016, 367 students leave the study and were replaced by 432 students on the initial wait list of selected students. From 2015 to 2017, there was an attrition rate of about 9%. Table 2 shows that the average child age is 5.8 years for all 3 survey-rounds, but 5.2 years old for the first survey-round. The distribution of age is quite large, but concentrated around 3-6 years of age at the first survey-round. In fact, 87% of the children are aged 3-6 years old. Figure D.1 shows the proportion of children in each district. Specifically, Ga South and Ledzokuku-Krowor have about 45%. Other disticts have from 13 to 17% of children.

The date of birth of children as well as the age at last birthday were collected throughout the survey-rounds and from different sources within the same survey-round. The main source is the caregiver. Those two variables allow us to construct a reasonable and decent age variable. It is worth noting that there are some inconsistencies of the variable date of birth from a survey-round to the other.

5.2 UTCI Measure

In Section 3.2, I highlighted that the the UTCI combines air temperature, humidity, wind speed, and radiant heat and is a measure of the perceived temperature. The human body experience heat stress starting from a UTCI of 26°C. There could be acclimatization for individuals living in a tropical area, meaning that, the human body could adapt and function relatively well, even under hotter temperatures. The human body in these areas could tolerate up to 3.5°C more than their counterpart in colder countries. The link between acclimatization and heat stress is not documented to the best of my knowledge, but believed threshold of heat stress could be different in tropical countries such as Ghana.

In our analysis, I define 3°C temperature bins. While the commonly used bin size in the literature is the 2°C, defining 3°C temperature bins guarantee enough observations in each temperature bin. Table 1 shows the different temperature bins defined for our analysis. Using temperature bins allows for a non-linear relationship between UTCI and children outcomes. I define the average daytime temperature as the average of all hourly temperature from 8 am to

5 pm. From 8 am to 5 pm, children are in school.

Figure D.6 and Table 1 shows the within and between survey round variation of temperature. The first thing to notice is that the surveys do not run the same months each year. The third survey round is hotter than the first 2 survey rounds, as the interviews happened during a dry and hot season called harmattan. Within one survey-round, individuals are exposed to different temperature bins. Also, there is movement across survey rounds, meaning, children are being exposed to different temperature bins for the 3 time periods they are observed in our sample.

Figure 2 shows the within survey round variation of temperature by district. Each panel represents a district. At first glance there a broad variation across all districts and within each survey-round. Ga Central, Ga South and Ledzokuku-Krowor experience the coldest average daytime UTCI. The figure confirms that the survey-round 3 is the hottest, and it is the case in all districts.

5.3 Outcomes Variables

To assess student functioning, I use assessor's rating of students behavior throughout the survey, and at the end of the survey, as our main outcomes. Secondly, I construct a math and literacy test score, respectively based on all questions related to the math section and to the literacy section.

Child Executive Function Behavior Rating. Executive function behavior or attention according to Araujo et al. (2016) is the ability to focus and disregard external stimuli. It includes staying engaged, switching easily from a task to the other by staying concentrated (Ahmed et al. 2022). Executive functions are predictive of day-to-day learning and have important implications for later life outcomes (Moffitt et al. 2011). Also, Ahmed et al. (2022) provides evidence that executive function skills and behaviors are informative on how children perform in cognitive tasks. IDELA measures executive function behavior throughout the test or survey, and at the end of the test. Indeed, assessors or interviewers are asked to make a report on each child's behavior. This individual report is possible because the interviews or testing were done individually.

I define our main outcome using the overall report by assessors done at the end of each survey. Indeed, at the end of each survey, surveyor's are asked 7 questions and rated each child on a scale from 1 to 4, where 1 is the lowest rating and 4 is the highest rating. Figure

D.2 shows the 7 questions with the scale. I construct the Overall Child EF rating measure (1-4) by taking the average of the 7 questions. The first panel of Table 2 shows the mean and standard deviation of each component of our main outcome, and the main outcome. In average, students are often attentive during the test.

I construct 3 dummy variables related to our main outcome to understand how children's behavior are changing on each margin of the scale. To do so, I first construct dummy variables for each one of the 7 questions in the assessor report on each margin. Secondly I compute an average for each margin. I obtain 3 variables displayed in the second panel of Table 2. while 45% of the children are rated almost always attentive, 2% are rated almost never attentive.

As stated earlier, assessors make intermediate reports as well throughout the survey. Those reports, unlike the overall report are smaller in terms of number of questions. Figure D.3 shows an example of such report. The report is composed by 3 yes or no questions and therefore the scale is different from the overall report scale. Also, the intermediate reports are tied to a question or an item. In Figure D.3 the item is oral comprehension, and that specific report is made with respect to the behavior of the child for that particular exercise.

For our analysis, I consider the executive function behavior of the child related to two items: item 6 (Number sense (One-to-one correspondence) and item 24 (Oral comprehension). Item 6 is part of the emergent math section which is one of the earliest sections. Item 24 is part of the literacy section which is one of the latest sections. The analysis using those two variables will allow to do a comparison between how children behave early in contrast with how they behave later during the test. I thus construct two executive function behavior dummies related to item 6 of the test and item 24 of the test. The fourth panel of Table 2 show the average and standard deviation of the two outcomes. I notice that the average behavior decreases from early parts of the survey to later part of the survey.

Test Scores. I construct 2 test scores: the math score and the literacy score. The math score is the fraction of correct answers to the emergent math section for each child. The literacy score is constructed similarly with respect to the emergent literacy section. The fifth panel of Table 2 show the statistics related to those 2 outcomes. The average is higher for the math section.

5.4 Other variables

Age. Children in our sample as mentioned before are kindergarten students in 2015. However, the age range is wide and goes from 2 to 10 years old. The last panel of Table 2 shows the statistics related to the age variable. In fact, the average age for the 3 survey-rounds is 5.8 years old. 45% of the sample is below age 6 in all survey-rounds combined.

Poverty Measure. I construct a proxy for poverty using the question asking the type of toilet that is used in a given child household[3]. The dummy is activated when the household has access to a public toilet. The last panel of Table 2 shows that about 51% of the children have a poor socio-economic background, per the selected question.

6 Temperature and Children Functioning

In this section I discuss the results from our estimation equation on the various outcomes I have defined earlier.

6.1 Temperature and Child Executive Function Behavior Rating by Assessors

Table 3 presents the results from estimating Eq. 4.1. The first seven outcome variables in the table correspond to the seven questions in the assessor report at the end of each test. The last outcome is the overall child executive behavior rating by the assessor which is the average of those seven questions. The omitted temperature bin is the least hot temperature. It ranges from 24 to 27 ° C. All coefficients are interpreted relatively to the least hot temperature bin.

Results show that exposure to a relatively hotter temperature bin decreases a child executive function behavior. The results is consistent for each outcome in the table. In other words, children loose their ability to stay focus when it gets hotter. If I consider column 8, the estimate on the first line indicates a decrease in the rating by 0.05 point. This corresponds to a 2% decrease in attentiveness. The effect is the largest for the 33-35 temperature bin where the overall rating of the child drops by 6%. To understand how large or small the estimates are, I look at each margin of the previous outcome. Table 4 shows the results for the different margins. Column 1 shows the dummy for which the overall rating of the child executive function is either 2, or 3 or 4. Column 2 shows the dummy for which the overall rating is either 3 or 4. The last column show the dummy for which the overall rating is 4.

3. A better measure will be used in the future.

The estimates in the first column show a decrease in the likelihood of moving from a rating of 4, 3, or 2 to a rating of 1. In other words there is an increase in the likelihood of having the lowest rating (which is 1), or almost never paying attention. Specifically, exposure to a temperature bin 33-35 increases the likelihood of having the lowest rating by 2%. The estimates in the third column show a decrease in the likelihood of getting the highest rating which is 4. Particularly, when exposed to a 33-35 temperature bin, there is a decrease of 20% in the likelihood of being almost always attentive.

6.2 Temperature and Child Executive Function Behavior Rating by Assessors: Sooner vs Later Parts of Test

Table 5 is comparing children executive function behavior rating in the first part of the test to the same outcome later in the test. Columns 1-3, and 5-7 shows the individual rating outcomes related to each question in the report. Columns 4 and 8 show the average of the individual ratings respectively for the number sense exercise and for the oral comprehension exercise.

Overall, there is evidence of a decreased attention at hot temperatures (relative to 24-26) both at the beginning and later in the test. However earlier in the test, the difference is not significant. Later, there is a significant difference.

6.3 Temperature and Test Scores

Table 6 shows the results of test scores. The first column shows the results related to the math score and the second column shows the results related to the listening score.

I see a decrease in both math and literacy test scores when children are exposed to hotter temperature (compared to the temperature bin 24-26). While consistent with a loss of cognitive functioning when exposed to higher temperature, the differences observed are not significant. The results obtained could denote additional efforts made by the students. Indeed, the interviews are not timed and no questions are skipped in the emergent math and literacy section. Interviews duration varies from a child to the other and could denote extra efforts by the child to overcome the fatigue from being exposed to heat.

6.4 Heterogeneous Effects of temperature on Child Executive Function Behavior Rating by Assessors

Socio-Economic Background. Table 7 shows the heterogeneity analysis results by socio-economic status background of children using the overall Child Executive Function Behavior Rating and the 3 dummies on each one of its margin. The estimated equation is Eq. 4.2. The first panel shows the results for the children with a poor SES background. The second panel shows how different children with a rich SES background are attentive.

The first column of the first panel indicates that the executive function behavior of children with a poor background decreases when they are exposed to hotter temperatures (relative to 24-26). The second panel of the same column indicates that children with a rich SES background behave in a better way. The third column indicate that children with a rich SES background behave significantly better on the margin of going from a rating of 3 or 4 to a rating of 1 and 2. The direct implication is that increased temperature could worsen the learning gap in a day to day setting, which have long term implications.

Age Group. Table 7 shows the heterogeneity analysis results by age group of children using the overall Child Executive Function Behavior Rating and the 3 dummies on each one of its margin. The estimated equation is Eq. 4.2. The first panel shows the results for the youngest children (<6 years old). The second panel shows how different older children are attentive.

The first column of the first panel indicates that the executive function behavior of young children decreases when they are exposed to hotter temperatures (relative to 24-26). The second panel of the same column indicates that older children don't behave differently.

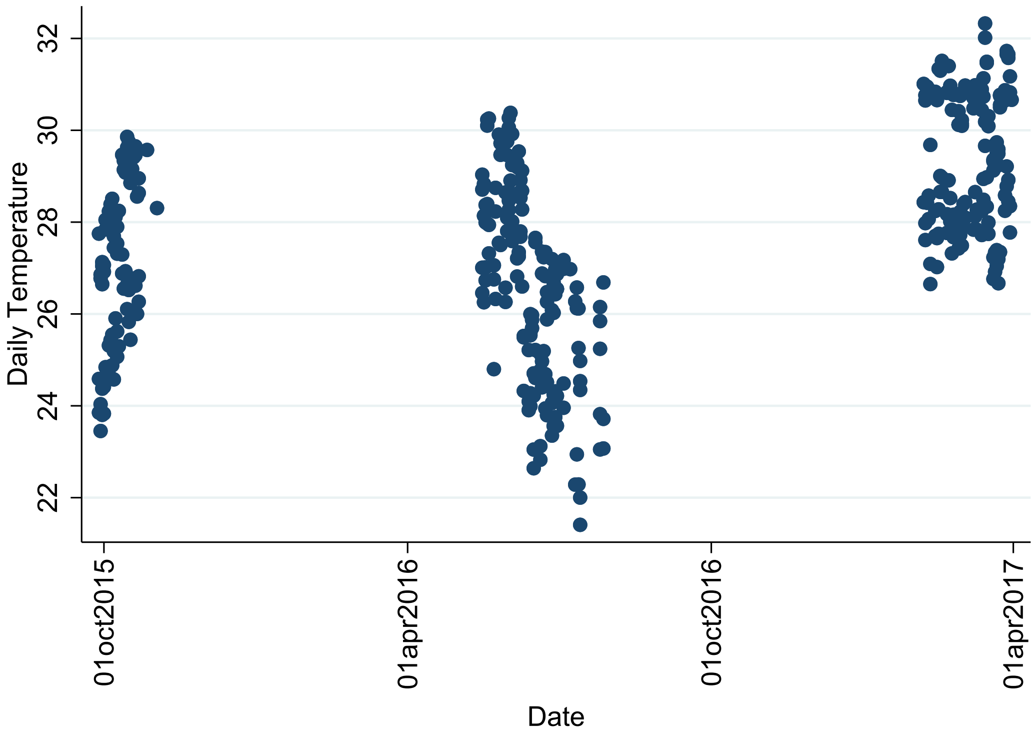
7 Conclusion

The number of high temperature days continues to grow each year. Individuals living in developing countries are the greatest risk: poorer countries are hotter, and individuals have less capacity to protect themselves against the harm of extreme heat. This has dire implications for children's development and learning, where learning outcomes are already extremely low. Indeed, the learning poverty rate is estimated at 86% for Sub-Saharan African countries before the global pandemic of 2020 and 89% after the pandemic (Spotlight on basic education completion and foundational learning in Africa: born to learn, UNESCO 2022). This paper explores heat as a potential driver for low learning. The mechanism is through changes in the brain chemistry and functioning, and decreases in attention, memory, information retention and processing. The paper contributes by providing a unique evidence on the contemporaneous effect of heat on children executive function using individual fixed effects in the context of a west African country.

Using data from all three survey-rounds jointly, I find that a deviation from the reference temperature bin (24°C and 26°C) decreases the attentiveness of children. Specifically, attentiveness decreases by respectively 0.05, 0.11, 0.18 and 0.13 points as it gets hotter (i.e. 27°C–29°C; 30°C–32°C; 33°C–35°C; 35°C–41°C). At a temperature bin of 33–35°C, these results correspond to a 20% decrease in the likelihood of being almost always attentive and a 2% increase in the likelihood of being almost never attentive. I found evidence that the decrease in attentiveness is observed both at the beginning and toward the end of the test. I found no effect on test scores. This could be indicative of extra efforts by children to overcome the adverse effects of heat. In fact, the interviews are not timed and are administered for one child at a time. This papers also explores whether inequality based on wealth accentuates due to heat. The paper explores this conducting an heterogeneous analysis by wealth on the main outcome. Results show that children from poorer background are less attentive compared to relatively richer kids, when exposed to heat.

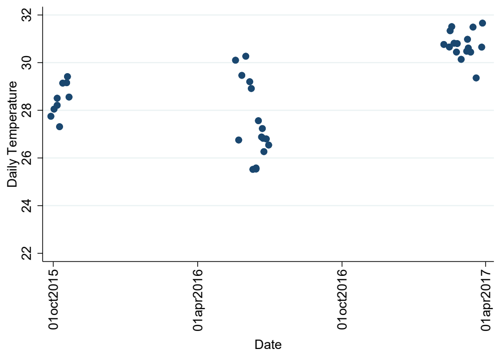
Tables and Figures

Fig. 1. Temperature Variation by Wave

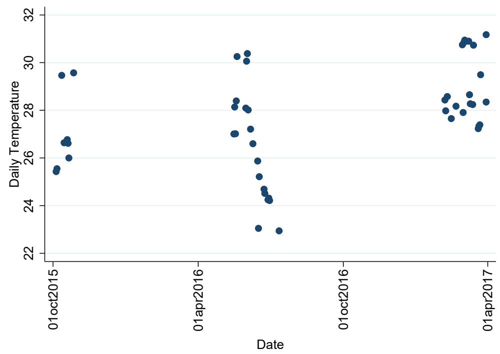


Note: The figure illustrates the temperature variation for each survey-round. The figure shows that the third survey-round is in average hotter than the first two survey-rounds. Temperature here stands for UTCI which is a proxy of the perceived temperature by the body.

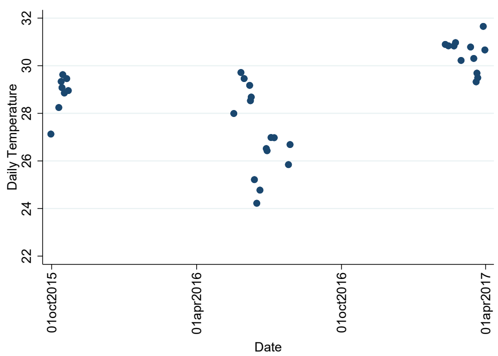
Fig. 2. Temperature Distribution by Districts



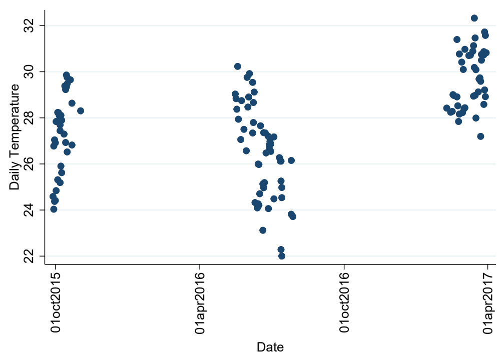
(a) Average temperature in the district Adentan by survey-round.



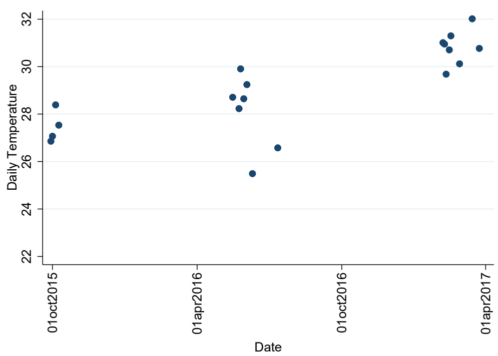
(b) Average temperature in the district Ga Central by survey-round.



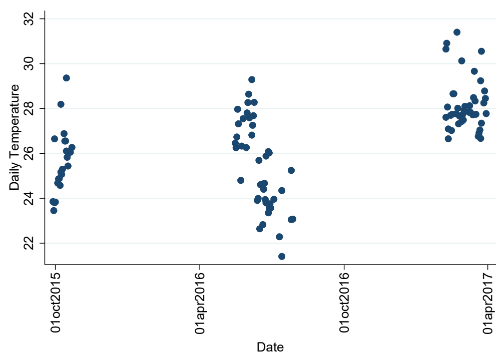
(c) Average temperature in the district Ga East by survey-round.



(d) Average temperature in the district Ga South by survey-round.



(e) Average temperature in the district La-Nkwantanang-Madina by survey-round.



(f) Average temperature in the district Ledzokuku-Krowor by survey-round.

Note: This figure shows the average temperature by districts in the Greater Accra Region in Ghana. There are 6 districts covered by the survey: Adentan, Ga Central, Ga East, Ga South, La-Nkwantanang-Madina, and Ledzokuku-Krowor

Table 1: Within and Between Survey-Round Temperature Variation

	Survey Round 1 (Sep, Oct 2015)	Survey Round 2 (May, Jun, Jul 2016)	Survey Round 3 (Feb, March 2017)	Pooled
Temperature $< 27°$C	0.07	0.19	0.00	0.09
$27°$C $\leqslant$ Temp $< 30°$C	0.32	0.28	0.07	0.23
$30°$C $\leqslant$ Temp $< 33°$C	0.33	0.37	0.36	0.36
$33°$C $\leqslant$ Temp $< 36°$C	0.27	0.16	0.43	0.28
Temperature $\geqslant 36°$C	0.00	0.00	0.15	0.05

Notes: The table shows ERA5-HEAT data for the sample.

Table 2: Summary Statistics

	Mean	SD	N
1. Assessor's EF Behavior Rating 1(lowest) to 4(highest)			
Child is Attentive	3.38	0.77	8173
Child is Confident	3.23	0.84	8173
Child is Concentrated	3.28	0.81	8173
Child is Careful	3.15	0.84	8173
Child Shows Pleasure	3.13	0.86	8173
Child is Motivated	3.27	0.79	8173
Child is Interested	3.06	0.90	8173
Overall Child EF Rating	3.21	0.70	8173
2. Assessor's EF Behavior Dummy if:			
Overall Child EF Rating is 4	0.45	0.42	8173
Overall Child EF Rating is 3 or 4	0.78	0.32	8173
Overall Child EF Rating is 2, 3, or 4	0.98	0.11	8173
3. Temperature			
Temperature $< 27°C$	0.09	0.28	8173
$27°C \leqslant$ Temp $< 30°C$	0.23	0.42	8173
$30°C \leqslant$ Temp $< 33°C$	0.35	0.48	8173
$33°C \leqslant$ Temp $< 36°C$	0.28	0.45	8173
Temperature $\geqslant 36°C$	0.05	0.22	8173
4. Assessor's EF Behavior Rating Related to Item 6 & 24			
Child EF Dummy For Item 6	0.95	0.17	8173
Child EF Dummy For Item 24	0.89	0.26	8173
5. Total Test Score			
Math Score (% correct)	0.60	0.26	8173
Literacy Score (% correct)	0.56	0.24	8173
6. Other Variables			
Age	5.81	1.42	8173
Young (Age < 6)	0.45	0.50	8173
Poor	0.51	0.50	7419

Notes: Data are from the first three rounds of the project Quality Pre-School for Ghana (QP4G). The first panel displays the main outcomes of this paper. At the end of each interview, the assessor makes a report about the behavior of the child during the interview. The report is composed of 7 questions found in appendix D.2. Those assessments questions are measured on a scale of 1-4 where 1 stands for almost never, 2 stands for sometimes, 3 stands for often and 4 stands for almost always. The overall Child EF rating is the average of the seven questions. The second panel displays the dummy versions of the Overall Child EF Rating outcome on each margin. The third panel shows 5 temperature bins and the proportion of children in each temperature bin over the three survey rounds. Panel 4 shows the assessor rating of the child EF behavior for item 6 and 24. Item 6 corresponds to the Number sense exercise, and item 24 corresponds to the oral comprehension exercise. Those ratings are the average of 3 questions found in appendix D.3. Panel 5 shows the math and literacy test scores which correspond to the percentage of correct answers to the math section and to the listening section. The last panel shows the age and socio-economic background composition of the sample. Young is dummy for children younger than 6 years old. Poor is a dummy for having public places as toilet rather than a private toilet.

Table 3: Impact of Temperature on Assessor's Report of Child Executive Function Behavior

Omitted Bin: $< 27°C$	(1) Child is Attentive	(2) Child is Confident	(3) Child is Concentrated	(4) Child is Careful	(5) Child Shows Pleasure	(6) Child is Motivated	(7) Child is Interested	(8) Overall Child EF Rating
$27°C \leqslant$ Temp $< 30°C$	-0.022	-0.042	-0.054	-0.082**	-0.064	-0.072*	-0.040	-0.054*
	(0.037)	(0.042)	(0.039)	(0.039)	(0.041)	(0.038)	(0.041)	(0.031)
$30°C \leqslant$ Temp $< 33°C$	-0.075*	-0.079*	-0.112***	-0.149***	-0.127***	-0.122***	-0.101**	-0.109***
	(0.038)	(0.043)	(0.041)	(0.040)	(0.044)	(0.041)	(0.044)	(0.033)
$33°C \leqslant$ Temp $< 36°C$	-0.131***	-0.170***	-0.198***	-0.223***	-0.193***	-0.213***	-0.142**	-0.182***
	(0.049)	(0.054)	(0.054)	(0.052)	(0.055)	(0.053)	(0.057)	(0.042)
Temperature $\geqslant 36°C$	-0.052	-0.145**	-0.113	-0.164**	-0.173**	-0.204***	-0.039	-0.127**
	(0.064)	(0.071)	(0.071)	(0.068)	(0.074)	(0.071)	(0.079)	(0.057)
Child FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8173	8173	8173	8173	8173	8173	8173	8173

Notes: Table reports results from estimating Eq. 4.1 using the sample described in Table 2. Robust standard errors clustered at individual level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Impact of Temperature on Different Margins of Child EF Behavior

Omitted Bin: $< 27°C$	(1) Child EF Rating $\geqslant 2$	(2) Child EF Rating $\geqslant 3$	(3) Child EF Rating $= 4$
$27°C \leqslant$ Temp $< 30°C$	0.002	0.003	-0.059***
	(0.005)	(0.016)	(0.019)
$30°C \leqslant$ Temp $< 33°C$	-0.011**	-0.021	-0.077***
	(0.005)	(0.017)	(0.020)
$33°C \leqslant$ Temp $< 36°C$	-0.016**	-0.059***	-0.107***
	(0.007)	(0.021)	(0.026)
Temperature $\geqslant 36°C$	0.007	-0.029	-0.106***
	(0.010)	(0.028)	(0.034)
Child FE	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes
Age FE	Yes	Yes	Yes
Observations	8173	8173	8173

Notes: Table reports results from estimating Eq. 4.1 using the sample described in Table 2. Robust standard errors clustered at individual level in parentheses. Reported are the estimates of the coefficient relative to the reference temperature bin of under 27° C *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Child EF Behavior: Sooner vs Later Parts of Test

	Item 6: Number Sense				Item 24: Oral Comprehension			
	(1) Child is Concentrated	(2) Child is Diligent	(3) Child is Motivated	(4) Average Child EF Dummy	(5) Child is Concentrated	(6) Child is Diligent	(7) Child is Motivated	(8) Average Child EF Dummy
Omitted Bin: $< 27°C$								
$27°C \leqslant$ Temp $< 30°C$	−0.003	−0.021	−0.018*	−0.042	−0.007	−0.007	−0.019	−0.011
	(0.007)	(0.015)	(0.011)	(0.025)	(0.012)	(0.020)	(0.016)	(0.013)
$30°C \leqslant$ Temp $< 33°C$	0.005	−0.024	−0.018	−0.037	−0.033***	−0.021	−0.023	−0.026*
	(0.007)	(0.015)	(0.011)	(0.027)	(0.013)	(0.022)	(0.018)	(0.014)
$33°C \leqslant$ Temp $< 36°C$	0.019**	−0.028	−0.031**	−0.040	−0.047***	−0.067**	−0.062***	−0.059***
	(0.010)	(0.020)	(0.015)	(0.035)	(0.018)	(0.027)	(0.023)	(0.018)
Temperature $\geqslant 36°C$	0.028**	−0.024	−0.024	−0.021	0.006	−0.004	−0.027	−0.008
	(0.013)	(0.025)	(0.019)	(0.046)	(0.023)	(0.035)	(0.029)	(0.023)
Child FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8207	8207	8207	8207	8207	8207	8207	8207

Notes: Table reports results from estimating Eq. 4.1 using the sample described in Table 2. Robust standard errors clustered at individual level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Test Scores and Temperature

	(1) Section 1 Math Score (% Correct)	(2) Section 3 Literacy Score (% Correct)
Omitted Bin: $< 27°C$		
$27°C \leqslant$ Temp $< 30°C$	-0.003	-0.007
	(0.005)	(0.006)
$30°C \leqslant$ Temp $< 33°C$	-0.002	-0.005
	(0.006)	(0.006)
$33°C \leqslant$ Temp $< 36°C$	-0.000	-0.006
	(0.007)	(0.008)
Temperature $\geqslant 36°C$	-0.002	-0.013
	(0.010)	(0.011)
Child FE	Yes	Yes
Survey Round FE	Yes	Yes
Age FE	Yes	Yes
Observations	8207	8207

Notes: Table reports results from estimating Eq. 4.1 using the sample described in Table 2. Robust standard errors clustered at individual level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Heterogeneity by SES: Poor vs Rich

Omitted Bin: $< 27°C$	(1) Overall Child EF Rating	(2) Child EF Rating $\geqslant 2$	(3) Child EF Rating $\geqslant 3$	(4) Child EF Rating $= 4$
$27°C \leqslant$ Temp $< 30°C$	-0.085**	-0.002	-0.035	-0.048*
	(0.043)	(0.006)	(0.022)	(0.027)
$30°C \leqslant$ Temp $< 33°C$	-0.177***	-0.013**	-0.070***	-0.095***
	(0.044)	(0.006)	(0.023)	(0.028)
$33°C \leqslant$ Temp $< 36°C$	-0.244***	-0.022***	-0.114***	-0.107***
	(0.058)	(0.008)	(0.029)	(0.036)
Temperature $\geqslant 36°C$	-0.267***	0.014	-0.129***	-0.152***
	(0.080)	(0.012)	(0.041)	(0.047)
$27°C \leqslant$ Temp $< 30°C \times$ Poor=0	0.060	0.007	0.078**	-0.026
	(0.063)	(0.009)	(0.031)	(0.040)
$30°C \leqslant$ Temp $< 33°C \times$ Poor=0	0.123**	0.004	0.093***	0.027
	(0.061)	(0.009)	(0.030)	(0.038)
$33°C \leqslant$ Temp $< 36°C \times$ Poor=0	0.101	0.010	0.095***	-0.004
	(0.070)	(0.010)	(0.034)	(0.045)
Temperature $\geqslant 36°C \times$ Poor=0	0.231**	-0.014	0.169***	0.076
	(0.094)	(0.015)	(0.046)	(0.057)
Child FE	Yes	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes	Yes
Age FE	Yes	Yes	Yes	Yes
Observations	7419	7419	7419	7419

Notes: Table reports results from estimating Eq. 4.2 using the sample described in Table 2. Robust standard errors clustered at individual level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Heterogeneity by Age Group: Young vs Old

Omitted Bin: $< 27°C$	(1) Overall Child EF Rating	(2) Child EF Rating $\geqslant 2$	(3) Child EF Rating $\geqslant 3$	(4) Child EF Rating $= 4$
$27°C \leqslant$ Temp $< 30°C$	-0.016	0.004	0.030	-0.050*
	(0.047)	(0.009)	(0.024)	(0.028)
$30°C \leqslant$ Temp $< 33°C$	-0.116**	-0.014	-0.024	-0.078***
	(0.048)	(0.010)	(0.024)	(0.028)
$33°C \leqslant$ Temp $< 36°C$	-0.225***	-0.024**	-0.063**	-0.139***
	(0.055)	(0.010)	(0.027)	(0.033)
Temperature $\geqslant 36°C$	-0.079	0.023	-0.017	-0.085
	(0.097)	(0.018)	(0.049)	(0.054)
$27°C \leqslant$ Temp $< 30°C \times$ Young (Age < 6)=0	-0.072	-0.004	-0.053*	-0.015
	(0.061)	(0.010)	(0.030)	(0.038)
$30°C \leqslant$ Temp $< 33°C \times$ Young (Age < 6)=0	0.030	0.009	0.007	0.015
	(0.061)	(0.011)	(0.030)	(0.037)
$33°C \leqslant$ Temp $< 36°C \times$ Young (Age < 6)=0	0.097	0.018*	0.006	0.073*
	(0.065)	(0.010)	(0.032)	(0.040)
Temperature $\geqslant 36°C \times$ Young (Age < 6)=0	-0.037	-0.015	-0.018	-0.004
	(0.108)	(0.019)	(0.054)	(0.061)
Observations	8173	8173	8173	8173
Child FE	Yes	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes	Yes
Age FE	Yes	Yes	Yes	Yes

Notes: Table reports results from estimating Eq. 4.2 using the sample described in Table 2. Robust standard errors clustered at individual level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

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APPENDIX

Exposure To Heat and Student Cognitive Functioning

Yabo Gwladys Vidogbena and Sharon Wolf

A Additional QP4G Data Details

A.1 Survey implementation and background

A.1.1 National and regional background

National setting The Republic of Ghana is a unique context to study these issues at the interface of developmental science, intervention science, and educational policy and practice (Wuermli, Tubbs, Peterson & Aber, 2015). The government has been investing in two years of universal pre-primary education since 2007, and Ghana has among the highest net enrollment rates in Africa (UNESCO, 2015). At the same time, levels of at-home stimulation provided to Ghanaian children are low. Compared to 13 other countries categorized as medium on the Human Development Index (a composite indicator of life expectancy, education, and income per capita), Ghana ranked 12th in terms of the levels of cognitive stimulation parents reported engaging in with their child (Bornstein & Putnick, 2012).

The Greater Accra Region The Greater Accra Region is the most developed region of Ghana among the 16 regions. It has the smallest proportion of socioeconomically-disadvantaged citizens compared to all the regions (Owusu & Agyei-Mensah, 2011). The Greater Accra region has 16 districts and 6 districts were selected for the intervention. The 6 district names are Ga South, Adenta, Ledzokuku-Krowor, Ga Central, La Nkwantanang-Madina, and Ga West. Those 6 districts are selected based on the 2014 UNICEF District League Table that provides a rank of regions and districts based on delivery of basic services including education, health, sanitation, and governance. The cited districts are rated the most disadvantaged districts in the Greater Accra region. Nevertheless there is a wide socioeconomic disparity within those districts.

A.1.2 Program design and RCT

The implementation and first-year evaluation of the QP4G intervention occurred between September 2015 and June 2016. 240 Schools were randomly assigned to treatment and control groups. The school year in Ghana begins in September and ends in July. The first survey round of data was collected in September-October 2015. The second round of data was collected in May-June 2016 and the last survey round used in this study was collected in May-June 2017.

A.2 School and Child sample

School sample 240 schools were selected As shown in Figure D.4.

School sample. All schools in the six districts were identified using the Ghana Education Service Educational Management Information System (GES-EMIS) database, which lists all registered schools in the country. Schools were then randomly sampled stratified by district, and within district by public and private schools. Eligible schools had to be registered with the government and have at least one KG class. A school listing was then conducted to confirm the presence of each school and to obtain information on each school's head teacher and proprietor. Because there were fewer than 120 public schools across the six districts, every public school was sampled. Private schools (490 total) were sampled within districts in proportion to the total number of private schools in each district relative to total for all districts. All KG teachers in the schools were invited to participate in the training. The majority of schools had two KG teachers, though the range was from one to five. If there were more than two KG teachers in the school, two teachers were randomly sampled per school for the evaluation (one from KG1 and one from KG2). Thirty-six schools only had one KG teacher, and in this case the one teacher was sampled. The final sample included 444 teachers / classrooms

Child sample. As shown in Figure D.1, Class rosters for KG classrooms were collected. An average of 15 children (eight from KG1, and seven from KG2) were randomly selected from each school roster to participate in direct assessments. If a school had fewer than 15 children enrolled across both classrooms, all children were selected. Assessors also randomly selected up to 10 additional children on the initial visit (a "reserve" list). If a selected child from the first 15 was not in school that day, assessors returned up to two times to assess the child. If the child was still not present on the third visit, a child from the reserve list replaced that child. For schools with only one KG classroom, 15 children were randomly sampled from the classroom. At baseline, the total sample of children was 3,435 children, with an average of 14.3 children per school (range = 4–15).

A.3 Survey timing

In Figure D.5, we show the number of children interviewed on different dates.

A.4 Questions on Executive function and behaviors

We show questions in Figures D.2 and D.3.

A.5

B Additional Heat Exposure Data Details

B.1 Universal Thermal Climate Index

B.1.1 Background on UTCI and temperature measurements

In 1999, the International Society of Biometeorology (ISB) established a Commission 'On the development of a Universal Thermal Climate Index UTCI'. The goal of this project was to derive a thermal index based on the most advanced thermophysiological model. Since 2005, these efforts have been reinforced by European COST (Cooperation in Science and Technical Development) Action 730, which has brought together leading experts in the areas of human thermophysiology, physiological modelling, meteorology and climatology, with a view to the Universal Thermal Climate Index, UTCI, being developed. In 2009, COST Action 730 was brought to a successful close, since the UTCI has been developed. This paper seeks to introduce the principles that underpin it, while this issue of Geographia Polonica also offers an example of the UTCI being applied in bioclimatic research.

Applications in human biometeorology require that there be thermophysiologically relevant assessments of the atmospheric environment. Although various models are available today, they are either not accepted generally, or deemed to be of restricted validity, due to the range of environmental conditions being limited. The general idea regarding UTCI deliverables was thus to entail goal-setting and attainment as regards: (1) thermo-physiological significance across the entire range of heat exchange. (2) applicability to whole-body calculations, but also local skin cooling (as in frost bite, for example). (3) validity in all climates and seasons, as well as on spatial and temporal scales from the micro through to the macro. (4) usefulness for key applications in human biometeorology, for example in the Public Weather Service, Public Health Service, precautionary planning and climate impact research. (5) representation as a temperature-scale index.

B.1.2 Definition of UTCI and air temperature

The UTCI is defined as the air temperature (Ta) of the reference condition causing the same model response as actual conditions. The offset, i.e. the deviation of UTCI from air temperature, depends on the actual values of air and mean radiant temperature (Tmrt), wind speed (va) and humidity, expressed as water vapour pressure (vp) or relative humidity (RH) (Fig. 1).

This may be written in mathematical terms as

$$
\begin{aligned}
\mathtt{UTCI} &= \mathtt{f}(\mathtt{Ta};\mathtt{Tmrt};\mathtt{va};\mathtt{vp}) \\
&= \mathtt{Ta} + \mathtt{Offset}(\mathtt{Ta};\mathtt{Tmrt};\mathtt{va};\mathtt{vp})
\end{aligned}
\tag{B.1}
$$

B.2 UTCI temperature calculations

WE compute this as the mean temperature:

$$
\mathrm{Avg}_d\left(\tau^{\text{start}}, \tau^{\text{end}}\right) = \sum_{h=\tau^{\text{start}}}^{\tau^{\text{end}}} \mathrm{UTCI}_{h,d} \tag{B.2}
$$

Then we compute:

$$
\mathrm{Max}_d\left(\tau^{\text{start}}, \tau^{\text{end}}\right) = \max\left\{\mathrm{UTCI}_{\tau^{\text{start}},d}, \mathrm{UTCI}_{\tau^{\text{start}}+1,d}, \ldots, \mathrm{UTCI}_{\tau^{\text{end}}-1,d}, \mathrm{UTCI}_{\tau^{\text{end}},d}\right\} \tag{B.3}
$$

Then we compute:

$$
\mathrm{Min}_d\left(\tau^{\text{start}}, \tau^{\text{end}}\right) = \max\left\{\mathrm{UTCI}_{\tau^{\text{start}},d}, \mathrm{UTCI}_{\tau^{\text{start}}+1,d}, \ldots, \mathrm{UTCI}_{\tau^{\text{end}}-1,d}, \mathrm{UTCI}_{\tau^{\text{end}},d}\right\} \tag{B.4}
$$

Then we compute:

$$
\mathrm{MaxMinAvg}_d\left(\tau^{\text{start}}, \tau^{\text{end}}\right) = \frac{\mathrm{Min}_d\left(\tau^{\text{start}}, \tau^{\text{end}}\right) + \mathrm{Max}_d}{2}\left(\tau^{\text{start}}, \tau^{\text{end}}\right) \tag{B.5}
$$

In in our implementation, we use two sets of τ^{start} and τ^{end}

$$
\left(\tau^{\text{start}}, \tau^{\text{end}}\right) \in \{(1, 24), (8, 17)\} \tag{B.6}
$$

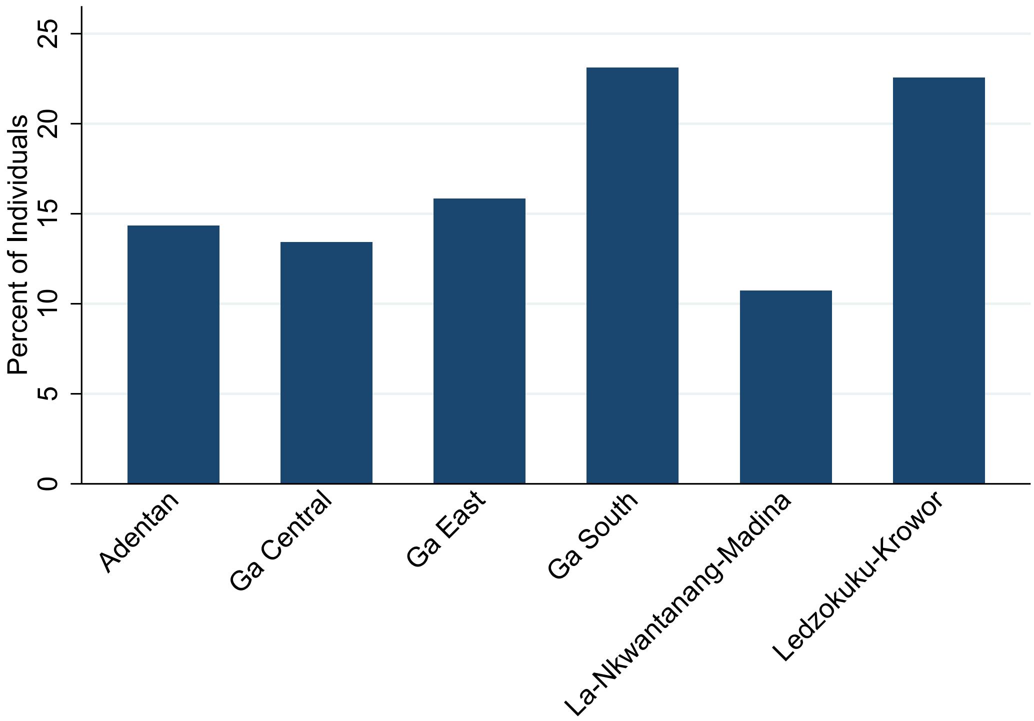
B.3 Distribution of UTCI statistics

We show variations in average, max and min in Figure D.6

C Discussions of Additional Estimation Results

D Appendix Figures and Table

Fig. D.1. Proportion of children by District



Note: The figure shows the proportion of children by district. All districts are located in the south of Ghana, in the Greater Accra region, which is a peri-urban region.

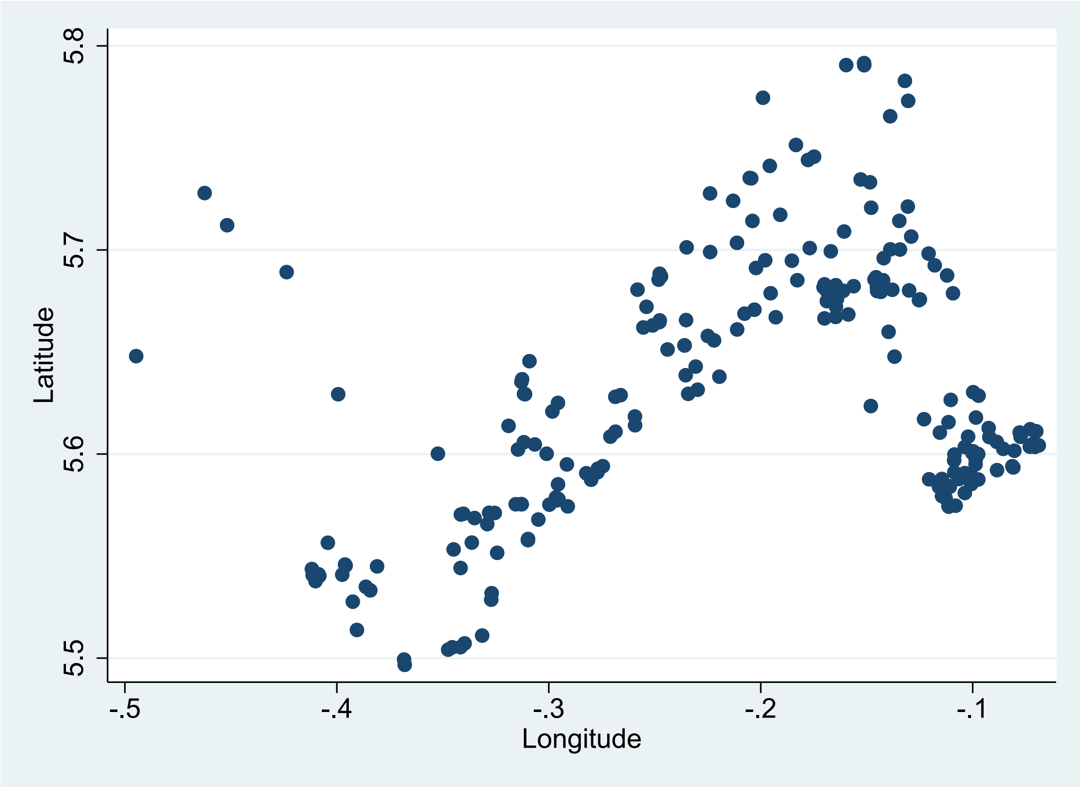
Fig. D.2. Overall Report Questions

SCORING					
Item No.		*Almost never (1)*	*Sometimes (2)*	*Often (3)*	*Almost always (4)*
2901.	Did the child pay attention to the instructions and demonstrations throughout the assessment?	[ ]	[ ]	[ ]	[ ]
2902.	Did child show confidence when completing activities; did not show hesitation.	[ ]	[ ]	[ ]	[ ]
2903.	Did the child stay concentrated and on task during the activities and was not easily distracted?	[ ]	[ ]	[ ]	[ ]
2904.	Was child careful and diligent on tasks? Was child interested in accuracy?	[ ]	[ ]	[ ]	[ ]
2905.	Did child show pleasure in accomplishing specific tasks?	[ ]	[ ]	[ ]	[ ]
2906.	Was child motivated to complete tasks? Did not give up quickly and did not want to stop the task?	[ ]	[ ]	[ ]	[ ]
2907.	Was the child interested and curious about the tasks throughout the assessment?	[ ]	[ ]	[ ]	[ ]

Fig. D.3. Intermediate Report Questions: Listening Comprehension

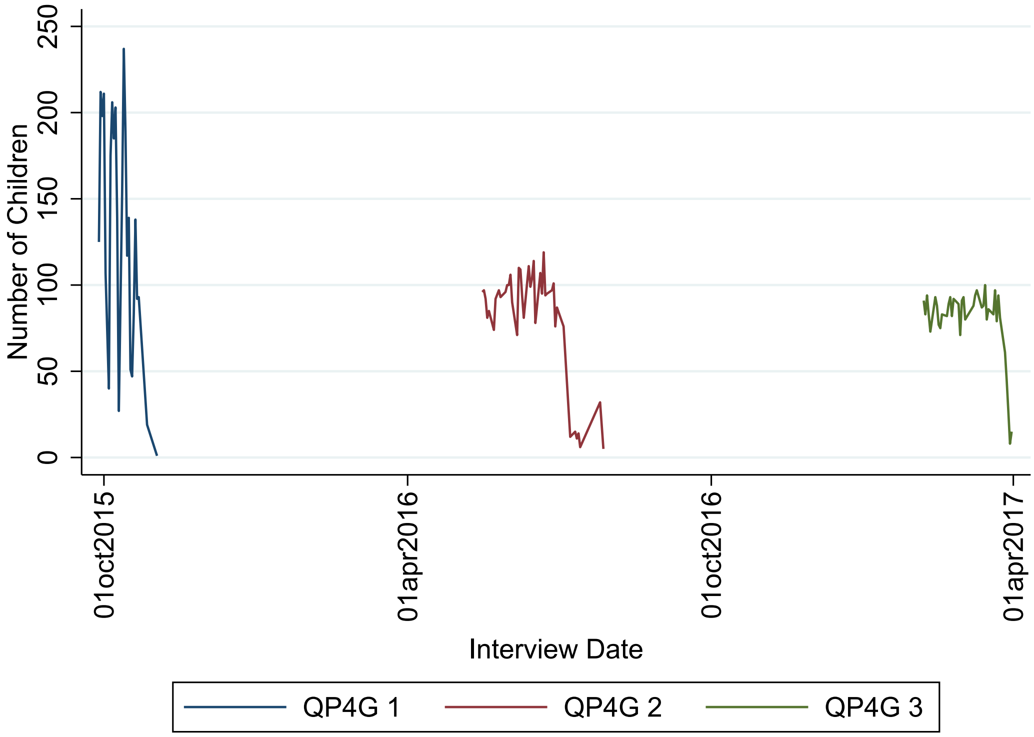
SCORING					
	Scoring categories	*Scoring options*			
Item No.	**Comprehension**	Correct (1)	Incorrect (0)	No response (-99)	Doesn't know (-88)
2401.	**"Who stole the cat's hat?"** (the mouse)	[ ]	[ ]	[ ]	[ ]
2402.	**"What is the color of the hat?"** (red)	[ ]	[ ]	[ ]	[ ]
2403.	**"Why did the cat chase the mouse?"** (because the mouse took/stole its hat)	[ ]	[ ]	[ ]	[ ]
2404.	**"Where did the mouse get trapped ?"** (under the table)	[ ]	[ ]	[ ]	[ ]
2405.	**"Why did the cat decide not to eat the mouse?"** (because the mouse gave back the hat)	[ ]	[ ]	[ ]	[ ]
	Persistence /Engagement	Yes (1)		No (0)	
2406.	Child stays concentrated on the task at hand; not easily distracted.	[ ]		[ ]	
2407.	Child is diligent/careful in their approach to the task.	[ ]		[ ]	
2408.	Child is motivated to complete task; does not want to stop the task.	[ ]		[ ]	

Fig. D.4. Geographical Distribution of Schools



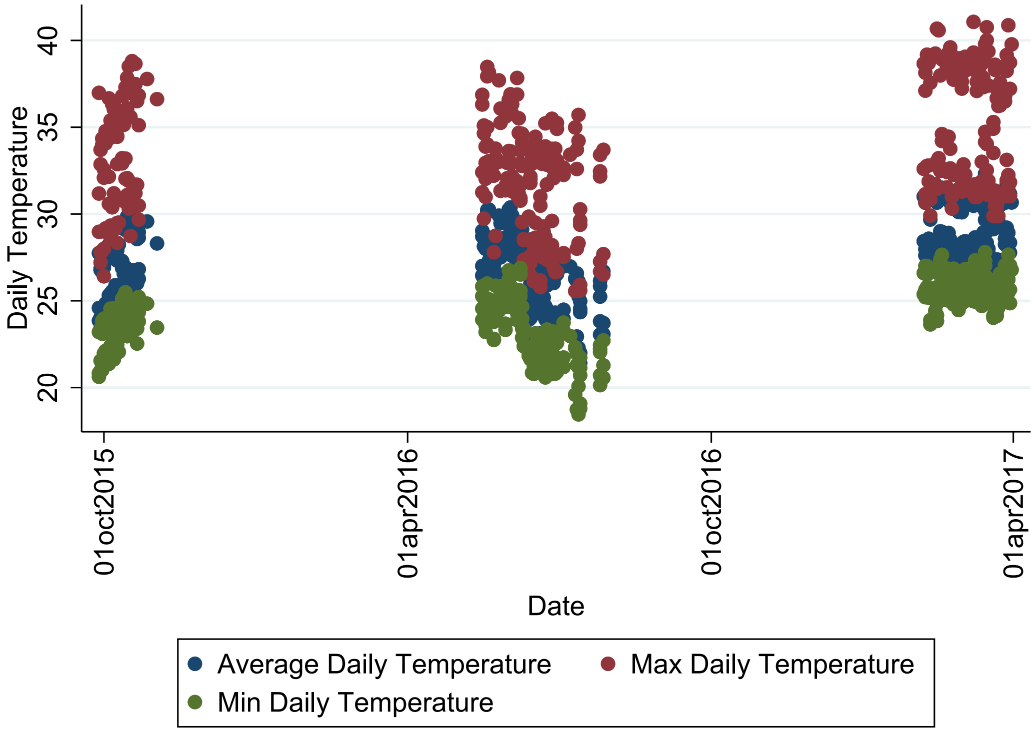
Note: The figure illustrates the dispersion of the schools using their longitude and latitude information.

Fig. D.5. Number of Students Interviewed per Day



Note: The figure illustrates the daily variation in the number of interviews conducted during the three first survey-rounds.

Fig. D.6. Temperature Variation by Wave



Note: The figure illustrates the temperature variation for each survey-round. The figure shows that the third survey-round is in average hotter than the first two survey-rounds. Temperature here stands for UTCI which is a proxy of the perceived temperature by the body.