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 in the presence of external stimuli. Heat may 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 effects of temperature on executive function behavior and tests scores. I find that higher UTCI heat index temperatures significantly decrease children's executive function, as measured by assessments made by the assessor administering the one-on-one test to the child. I also find that, at hotter temperatures, children are more likely to be rated "never attentive". The paper also finds that poorer children's executive function is more affected under heat. There is no effect on test scores, which may reflect both skills and effort. These findings have implications for children's behavior in everyday classroom settings, and suggest global warming will make it more difficult to learn.

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

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1 Introduction

The number of high temperature days grows each year. People in developing countries are at the greatest risk: poorer countries are hotter, and people have less capacity to protect themselves against the harm of heat. This can have dire implications for children's development and learning, where learning outcomes are already extremely low. Indeed, despite rapidly increasing school enrollment in Sub-Saharan African countries, the learning gains are limited. While 80% of primary school aged students are enrolled, less than 30% achieve the minimum proficiency level in reading according to the SDG "Quality Education" report on African countries (Team, Africa, and Union 2022; Evans and Mendez Acosta 2021). Adeniran, Ishaku, and Akanni (2020) and Bold et al. (2017) show evidence of low learning in numeracy as well. What are the implications of more hot days on learning in developing country classrooms?

I thus explore heat as a potential driver for low learning in Sub-Saharan Africa. This paper studies the effect of heat on cognitive functioning, measured as executive function behavior, for children in the southern region of Ghana, the Greater Accra Region. Executive function behavior, or the capacity to pay attention and attention shift, is part of a set of executive function processes 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), and developing countries, where there is little to no adaptation strategies to heat, including evidence Brazil, China and India (Graff Zivin et al. 2020; Garg, Jagnani, and Taraz 2020; Li and Patel 2021). However, all those studies on developing countries focus more on adults and how low performance due to heat could affect their long-term outcomes. Less is known about how heat affects children's performance or functioning in a developing countries, which matters for long run learning under expected increases 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 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. Park et al. (2020) shows a decrease in PSAT score for PSAT test retakers a year after heat exposure in US schools. Graff Zivin, Hsiang, and Neidell (2018)

finds no effect of heat on human capital accumulation both for accumulated heat exposure between two tests, and for lifetime (from birth to day of test) accumulated exposure. Graff Zivin et al. (2020) argues that the null results imply that parents are substantially offsetting the decrease in human capital expected if we consider the short run effect of heat on scores. Those ex post compensatory behaviors, however, could be costly and 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's executive function behavior. Secondly, this paper add to the limited evidence using within individual variation to study exposure to external conditions and learning (Graff Zivin, Hsiang, and Neidell 2018; Park et al. 2020). 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 in Ghana, as well as their test scores in math and literacy. Thirdly, this paper contributes to the limited evidence on heat and children's functioning in Sub-Saharan Africa, a previously unstudied setting. Previous work has studied the effect of heat on agricultural productivity (Emediegwu, Wossink, and Hall 2022) and on productivity of adults (LoPalo 2023) in Sub-Saharan Africa. But the effect of heat has not been studied on children in Sub-Saharan Africa. Sub-Saharan Africa is an important context 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. 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. my specification uses 3° C UTCI temperature bins and a non linear specification to allow for a non linear relationship between children's functioning and UTCI temperature.

Using data from all three survey-rounds jointly, I find that a deviation from the reference UTCI 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 UTCI 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 UTCI 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. my 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 4 describes data and construction of key measures and presents summary statistics. Section 5 describes the estimation strategy. Section 6 presents and interprets the main results. Section 7 concludes.

2 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.

3 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 air 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.

This paper used a longitudinal data collected on children from the Greater Accra Region. Figure 1 shows the Greater Accra Region on the map of Ghana. The Greater Accra

Region 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.

4 Data

To estimate the effects of exposure to heat on children functioning, I take advantage of a longitudinal data in Ghana following a study called "Quality for Pre-school for Ghana" (hence, QP4G). 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. 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) which is a heat index as temperature.

4.1 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. Figure D.4 shows the dispersion of different schools in my sample. As the figure shows, 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 executive function behavior throughout the interview and at the end of the interview. These assessments are made possible thanks to one-on-one testing.

4.1.1 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 my 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 my 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 they 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 the Overall Child EF rating, and of the the Overall Child EF rating. In average, students are often attentive during the test.

I construct 3 dummy variables related to my main outcome to understand how chil-

dren'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 my 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 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.

4.1.2 Other variables

Age. Children in my 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, 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. I later construct a variable ''Young" which a dummy for children aged

2 to 5 years old. This allows me to perform an heterogeneity analysis based on age groups. The hypothesis is that younger children might perform differently because they are still at an early developmental stage. According to Table 2 45% of the sample respect my definition of ''Young''

Poverty Measure. I construct a proxy for poverty and socioeconomic status using the question asking the type of toilet that is used in a given child household.[1] The dummy is for household with no private toilet or households who have to use a public toilet. The last panel of Table 2 shows that about 51% of the children have a poor socioeconomic background, per the selected question. This dummy will be used to assess whether the effect of heat differs for different socioeconomic group. The hypothesis is that wealth is protective and allows for better health and more cognitive activities practices.

4.2 UTCI Temperature Data

4.2.1 UTCI

In my analysis, temperature is the Universal Thermal Climate Index. The UTCI is a heat index that combines air temperature, humidity, wind speed, and radiant heat and is a proxy for temperature perceived 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 real-time. The precision is: $0.25° \times 0.25°$ spatial resolution (~31 Km).

4.2.2 UTCI Thresholds

There are different thresholds of UTCI temperature that define different levels of heat stress and the human body experiences heat stress starting from a UTCI temperature of 26 °C. In detail, from 26 °C to 32 °C the human body experiences 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. 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

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

counterpart in colder countries. The link between acclimatization and heat stress is not documented to the best of my knowledge, and believed threshold of heat stress could be different in tropical countries such as Ghana.

Ghana as a tropical country is hotter in average and according to its Climate Risk Country profile by the World Bank the annual mean temperature is 27.3 °C. Giving such a high annual mean temperature, one might hypothesize that individuals in Ghana and similar countries are acclimatized to hot temperatures. Acclimatization to heat, if there is any, should be reflected in the results of the current study. If there is acclimatization to heat, there will be very small to no effect of heat on children's outcomes.

In my analysis, I define 3 °C UTCI 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 UTCI temperature bins defined for my analysis. Using UTCI temperature bins allows for a non-linear relationship between UTCI and children outcomes. I define the average daytime UTCI temperature as the average of all hourly UTCI temperature from 8 am to 5 pm considering that outside those hours, children are not in school.

4.3 Merging UTCI Data into QP4G Data

The UTCI is linked to three (03) survey-rounds of QP4G using location information on one side and date of survey information on the other. Students were interviewed in schools. I first aggregate the school's longitude and latitude information to the nearest $0.25° \times 0.25°$. Then I merge the QP4G data to the UTCI temperature data using the school aggregated location information as well as the date of test or interview information. Interviews were done on tablets and the date of surveys were collected automatically on the tablet. Survey start time, survey end time and survey submission time were also collected. The start and end time describe the duration 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.

4.4 Sample

My Analysis sample is restricted to children with at least 2 survey rounds of data and non-missing data on age. This corresponds to approximately 2700 unique children and 8173 obser-

vations for the different analyses. Figure D.1 shows the proportion of children in each district. 45% of my observations were interviewed in Ga South and Ledzokuku-Krowor schools. In each other district about 15% of students were interviewed.

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.

Figure D.6 and Table 1 shows the within and between survey round variation of UTCI 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 UTCI temperature bins. Between rounds, we see that children are exposed to different (or the same) temperature bins. These movements show that there is within individual variation, as some children shift from one temperature bin to the other across survey round. Those shift are important to identify the effect of heat on children outcomes.

Figure 3 shows the within survey round variation of UTCI temperature by district. Each panel represents a district. At first glance there is within and across survey round variation in UTCI. 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. No district seem to be hotter than the other.

5 Empirical Strategy

To estimate the effects of heat stress on child functioning on the day of test, I exploit a within child variation (or an across time variation). Intuitively, the strategy compares the same individual taking the test on different days, one day hotter than the other. Because of the longitudinal nature of my data, I observe the same individual multiple times, and while some individuals might always be exposed to the same UTCI temperature bin throughout the three survey-rounds, some individuals will switch from a hotter UTCI temperature to a colder UTCI temperature or vice versa. This methodology is used in Graff Zivin, Hsiang, and Neidell (2018) and Park et al. (2020).

I use the following specification to estimate the effect of heat exposure on child out-

comes:

$$\begin{aligned} y_{i,r(t)} =& \beta_1 UTCI_{27-30^\circ} + \beta_2 UTCI_{30-33^\circ} + \beta_3 UTCI_{33-36^\circ} + \beta_4 UTCI_{>36^\circ} \\ &+ \alpha_i + \delta_{r(t)} + \sigma_a + \epsilon_{i,r(t)}, \end{aligned} \tag{5.1}$$

where $UTCI_{27-30^\circ}$ is a dummy for UTCI temperature between 27°C and 30°C (excluded), $UTCI_{30-33^\circ}$ is a dummy for UTCI temperature between 30°C and 33°C (excluded), $UTCI_{33-36^\circ}$ is a dummy for UTCI temperature between 30°C and 33°C (excluded), and $UTCI_{>36^\circ}$ is a dummy for UTCI temperature greater than 36°C. The omitted UTCI temperature bin in my analysis is $[24°C, 27°C)$. The parameters of interest are β_1, β_2, β_3, and β_4. The parameters of interests are estimates of the expected change in children's outcomes of a hotter UTCI temperature relative to the omitted UTCI temperature bin $[24°C, 27°C)$. For example, β_1 is the expected change in children's outcomes when those children are performing cognitive activities under the temperature bin $[27°C, 30°C)$ instead of the temperature bin $[24°C, 27°C)$. The UTCI temperature is measured at the school $\times$ day-of-test level and school location information are aggregated at the $2.5° \times 2.5°$ precision level to be merged with the UTCI temperature data.

The subscript 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. Each survey round denotes a different season of the year. $y_{i,r(t)}$ 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, α_i , in my specification is the source of causal identification and solves potential biases. It particularly allows to control for individual background characteristics such as innate skills or intrinsic ability, tolerance to (heat) stress, family wealth and parental support of the child. It also controls any selection related to location choice by children's parents. For example, there could be situations were low socioeconomic households sort into hotter or less hot places compared to high socioeconomic households.

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, σ_a, because in my 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.

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.

Wealth might be protective because it offers better health and more cognitive activities practices. I allow for the effect of heat to differ by socioeconomic background of the child:

$$\begin{aligned} y_{i,r(t)} =& \beta_1 UTCI_{27-30^\circ} + \gamma_1 UTCI_{27-30^\circ} \times Poor + \beta_2 UTCI_{30-33^\circ} + \gamma_2 UTCI_{30-33^\circ} \times Poor \\ &+ \beta_3 UTCI_{33-36^\circ} + \gamma_3 UTCI_{33-36^\circ} \times Poor + \beta_4 UTCI_{>36^\circ} + \gamma_4 UTCI_{>36^\circ} \times Poor \\ &+ \alpha_i + \delta_{r(t)} + \sigma_a + \epsilon_{i,r(t)}, \end{aligned} \tag{5.2}$$

where Poor represents a dummy variable which is 1 when the child belongs to a poor family, or more specifically, if the child's family uses public toilets.

I additionally allow the effect of heat to differ by age. Indeed, less is known about very young children, who could respond differently to heat because their brains are at an early developmental stage. Specifically, in the second heterogeneity analysis, I estimate:

$$\begin{aligned} y_{i,r(t)} =& \beta_1 UTCI_{27-30^\circ} + \gamma_1 UTCI_{27-30^\circ} \times Young + \beta_2 UTCI_{30-33^\circ} + \gamma_2 UTCI_{30-33^\circ} \times Young \\ &+ \beta_3 UTCI_{33-36^\circ} + \gamma_3 UTCI_{33-36^\circ} \times Young + \beta_4 UTCI_{>36^\circ} + \gamma_4 UTCI_{>36^\circ} \times Young \\ &+ \alpha_i + \delta_{r(t)} + \sigma_a + \epsilon_{i,r(t)}, \end{aligned} \tag{5.3}$$

where Young is defined as as children between the age of 2 and 5 (included).

6 Estimation Results

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

6.1 Temperature and Child Executive Function Behavior Rating

Table 3 presents the results from estimating Eq. 5.1. The first seven outcome variables in the table correspond to the seven questions in the assessor report at the end of each test. Figure D.2 lists the 7 questions. The last outcome is the overall child executive behavior rating by the assessor which is the average of those seven questions. The omitted UTCI temperature bin is the least hot UTCI temperature. It ranges from 24 to 27 °C. All coefficients are interpreted relatively to the least hot UTCI temperature bin.

Overall the results shows that for each question on the report, and for the average of all questions on the report, exposure to a relatively hotter temperature decreases child executive

function behavior. In other words, children lose their ability to stay focus or a cognitive task when it gets hotter. The results also show that moderate heat stress (27 °C to 32 °C in our sample) is harmful to children and that, the effect increases as children get exposed to strong (32 °C to 38 °C), and very strong (38 °C to 46 °C) heat stress in average on the day of test.

In column 8 of Table 3, the first point estimate which corresponds to β_1 indicates a decrease in child executive function behavior by 0.05 point on a scale of 1 to 4. This corresponds to about a 2% decrease of children executive function behavior from the omitted group average which is 3.11. Particularly, the child becomes less careful (β_1 in column 4) and less motivated (β_1 in column 6). The following coefficient corresponds to β_2 and indicates that the child executive function behavior decreases by 0.1 point on a scale of 1-4 which corresponds to about a 4% decrease from the omitted group average. Particularly, all aspect of the report are statistically significantly affected by hotter temperatures. β_3 indicates that the child executive function behavior decreases by about 0.2 point on a scale of 1-4 which corresponds to about a 6% decrease from the omitted group average. β_4 shows a decrease of 0.1 point as well which corresponds to a decrease of 4% from the omitted group average. The smaller value of β_4 compared to β_3 may suggest limited statistical power to detect an effect at the highest temperature bin.

To understand how large or small the previous estimates are, and to know at which point of the scale children are affected, 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 shows the dummy for which the overall rating is 4.

The estimates in the first column of Table 4 show an increase 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 that a child becomes "almost never attentive" or inattentive from being "sometimes", "often" or "almost always" attentive under hotter temperatures. The word "attentive" stands for the 7 aspects on which the assessor or interviewer rates the child. Quantitatively, there is an increase of up to 1.6 percentage points in the likelihood of a child becoming inattentive under heat. This implies that as the world becomes hotter, there will be more and more students who become inattentive in classrooms.

The estimates in the second column of Table 4 show an increase in the likelihood of

moving from a rating of 4, or 3, to a rating of 2, or 1. In other words there is an increase in the likelihood that a child becomes "almost never" or "sometimes " attentive from being "often" or "almost always" attentive under hotter temperatures. Quantitatively, there is an increase of up to 6 percentage points in the likelihood of a child becoming "less attentive" under heat.

Column 3 of Table 4 shows an increase in the likelihood of moving from a rating of 4 to a rating of 3, 2, or 1. In other words, children move from being attentive to being "sometimes", "often", or "almost never" attentive. Or else, there is a decrease in the likelihood of being "almost always" attentive. This is a decrease of up to 10 percentage points. The implication is that heat is affecting the most attentive children and, as global warming continue rising, more and more children will learn less in classrooms.

6.2 Temperature and Child Executive Function Behavior Rating: Earlier vs Later Parts of Test

The previous results show that children have lower executive function under hotter temperatures. In this section, we utilize the intermediates rating by assessor of student executive function. An example of such report is found on Figure D.3. This intermediate report is smaller in terms of number of questions. In addition each question is a dummy, and is not on a scale from 1-4 as the question in the overall report. Investigating those intermediates outcomes allows to comment on the behavior of children throughout the test.

Table 5 shows the results of the investigation. The first 4 columns shows the effect of heat on the executive function behavior of children related to the 6^{th} item of the test. Item 6 is the number sense exercise which is a math exercise, and the math section is one of the first section. Column 1, 2 and 3 show the results for each question in the report. Column 4 shows the results for the average of those 3 questions. Columns 5 to 8 shows the effect of heat on the executive function behavior of children related to the 24^{th} item of the test. Item 24 is the oral comprehension exercise which is a literacy exercise, and the literacy section is one of the last section.

The estimates in column 4, even though negative, are not statistically and significantly different from 0. This means that all children start fresh and children exposed to hotter temperatures have enough cognitive resources to overcome initial discomfort from the heat; therefore they don't behave differently than the omitted children in the omitted category. Column 8 shows that there is up to a 6 percentage point decrease in children executive function behavior

under heat for the oral comprehension exercise. The implication is that, even though children start fresh at all temperature ranges, prolonged exposure to heat affect reduces children's cognitive processes and affect their behavior.

6.3 Temperature and Test Scores

So far, the results show that children's cognitive functioning declines as temperature rise. A key question now is whether children perform differently on cognitive tasks under heat. One possibility is that children exert more effort to counteract the adverse effects of heat, potentially requiring more time to complete tasks. Assessors, too, may compensate by providing more detailed explanations. This is feasible when the exam or test is not timed, as in our case, where there are no skipping patterns in the math and literacy sections and all questions are answered.

Table 6 presents 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. While the estimates are negative, indicating possible adverse effects, I find no statistically significant impact of heat on test scores. I propose two hypotheses. First, as it gets hotter, children and assessors take longer than normal (duration under omitted bin 24 to 27 °C) to complete tasks, leading to longer test duration. Second, it is possible that the true effect might be so small that the current study is underpowered to detect it. This is consistent with comments in Park et al. (2020) which states that the effect on test score is small and that they are able to estimate such effect because of a large sample size.

6.4 Heterogeneous Effects of temperature on Child Executive Function Behavior Rating

Socioconomic Background. The effect of heat on children's executive function might vary by socioeconomic status. High socioeconomic households might exposed their children to more cognitive activity practices. Also, wealth offers better health and better construction materials to children. This might lead to a difference in behavior under heat. The first column of Table 7 shows the heterogeneity analysis results by socioeconomic status background of children executive function behavior under heat. Columns 2, 3 and 4 presents the results for the different margins. The estimated equation is Eq. 5.3. The upper panel shows the results for the children with a low socioeconomic backgrounds. The lower panel shows the differential effect for children with a high socioeconomic status backgrounds.

The first column of the upper panel indicates that the executive function behavior of

children with a low socioeconomic background decreases when they are exposed to hotter UTCI temperatures (relative to 24-27). The lower panel of the same column indicates that children with a high socioeconomic background behave in a better way. The third column indicates 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 UTCI temperature could worsen the learning gap between socioeconomic groups in a day to day setting, which have potential long term implications.

Age Group. The effect of heat on children's executive function might vary by age groups. Younger children are at an early developmental stage, including development of their brain. Table 8 shows the heterogeneity analysis results by age group of children using the overall child executive function behavior and the 3 dummies of each one of its margin. The estimated equation is Eq. **??**. The upper panel shows the results for the youngest children (<6 years old). The lower panel shows the differential effect for older children.

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

7 Conclusion

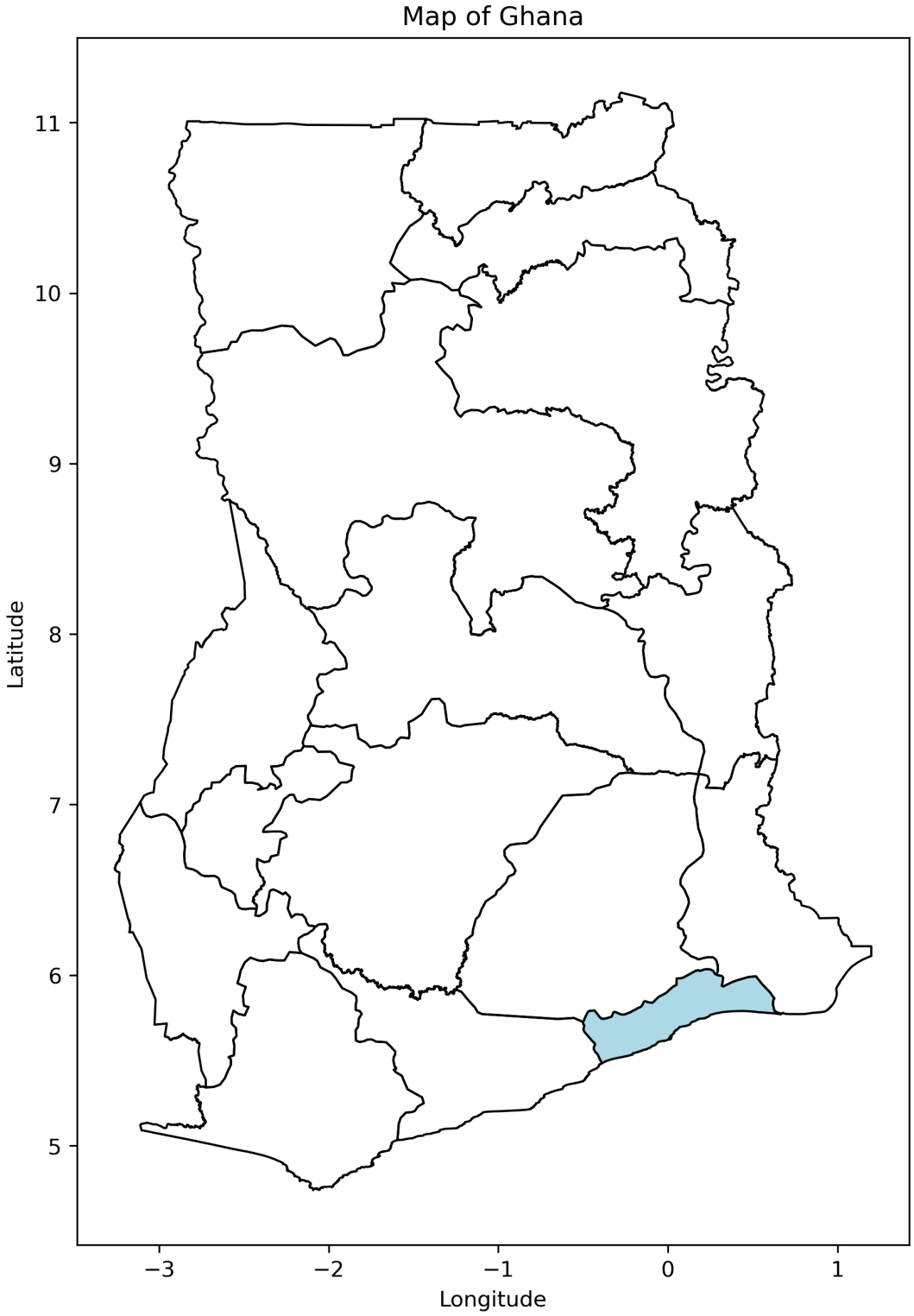
The number of high UTCI temperature days continues to grow each year. Individuals living in developing countries are the greatest risk: poorer countries are hotter, and individuals have less capacity to protect themselves against the harm of extreme heat. This has implications for children's development 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 linked UTCI temperature data and children's outcomes data, I find that a deviation from the reference UTCI 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). I find as much as a 1.6 pp increase in the likelihood of becoming inattentive under heat, and a 10 pp decrease in the likelihood of being almost always attentive I found evidence that the decrease in attentiveness is pronounced at the end of the test. Nevertheless, at the beginning of the test I find that the estimates are negative but not statistically significant. This is consistent with a story where children start fresh and are able to overcome the adverse effects of heat, but as they are doing more and more activities under heat, they lose their attention. I found no effect on test scores. This could be indicative of extra efforts by children and assessors to overcome the adverse effects of heat. In fact, the interviews are not timed and are administered for one child at a time and duration could increase under heat. This papers also explores whether children from low socioeconomic backgrounds perform differently than children from high socioeconomic backgrounds. The paper finds that low socioeconomic children are less attentive under heat compared to their richer counterparts. This could exacerbate the learning gap by socioeconomic status under rise in temperature level and increase in the number of heat days within a year. The paper also explores whether the effect of heat differs for different age group. The paper find no evidence of a difference between age groups heat.

Overall, the results in this paper have some implications for classroom learning. There will be an increase in less attentive students as global warming continues. The learning gap by socioeconomic status will worsen. Developing countries are particularly vulnerable because they have less resources to adapt.

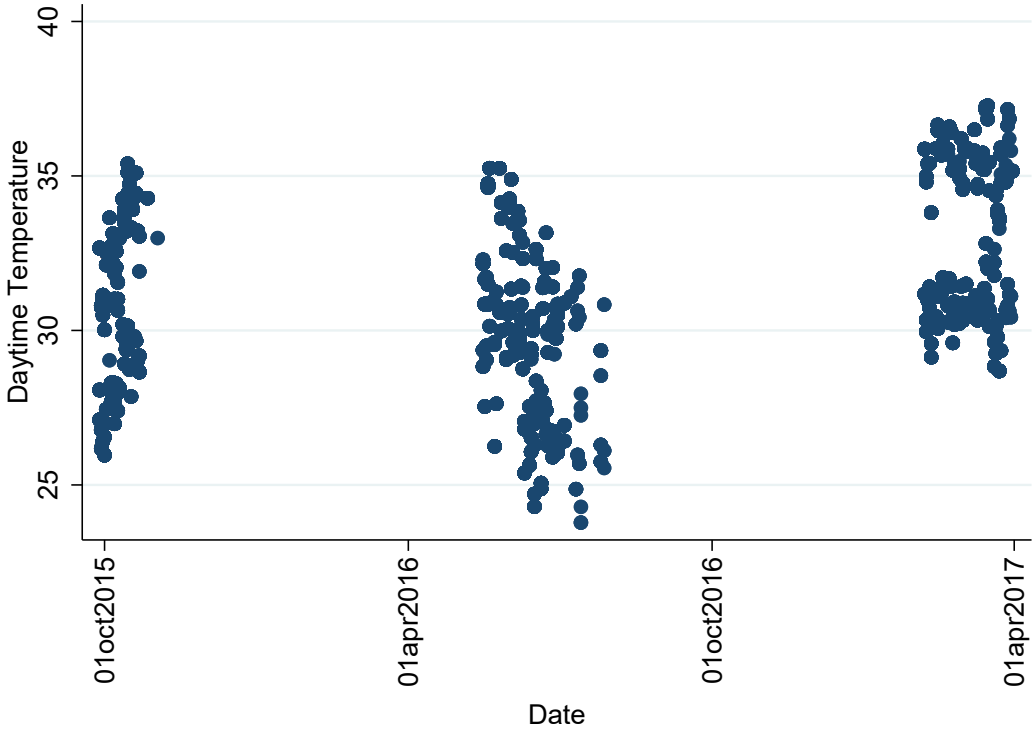
Tables and Figures

Fig. 1. Map of Ghana



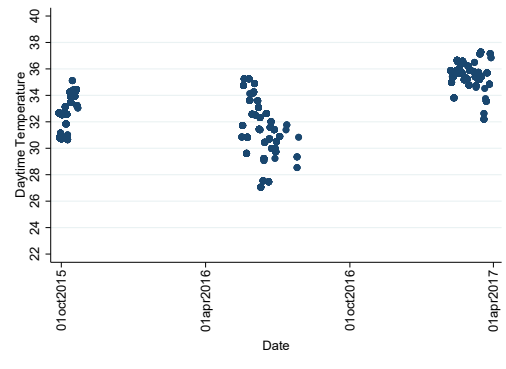
Note: The figure illustrates the map of Ghana. The blue area depicts the Greater Accra region where the data used in this paper was collected.

Fig. 2. Temperature Variation by Wave

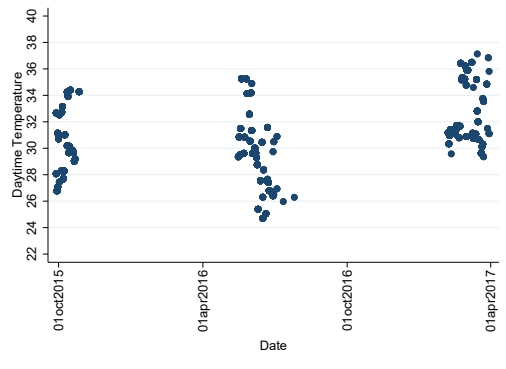


Note: The figure illustrates the temperature variation for each survey-round. The figure shows that the third survey-round is in average hotter than the first two survey-rounds. Temperature here stands for UTCI which is a proxy of the perceived temperature by the body.

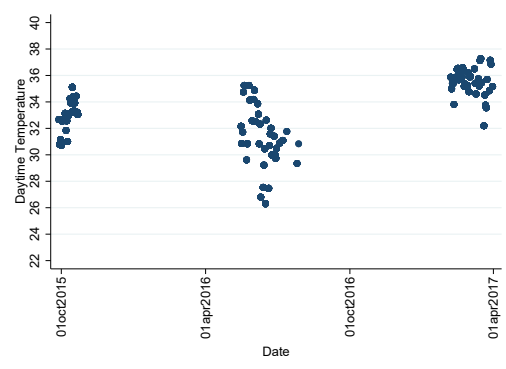
Fig. 3. UTCI Temperature Distribution by Districts



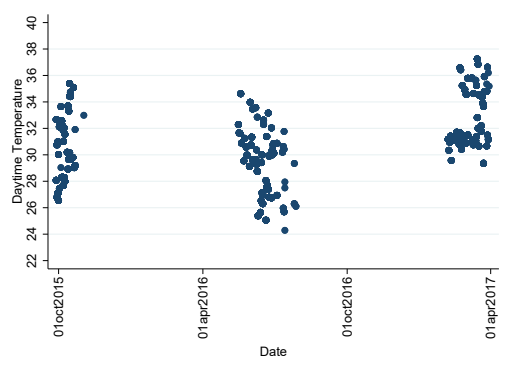
(a) District of Adentan.



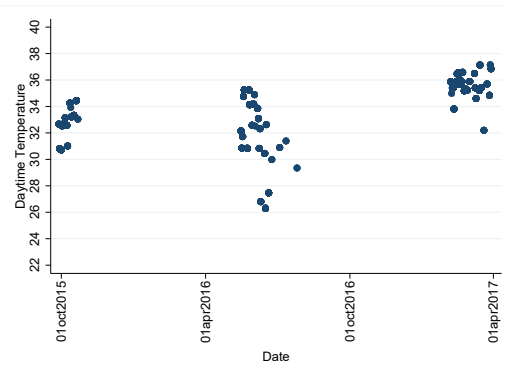
(b) District of Ga Central.



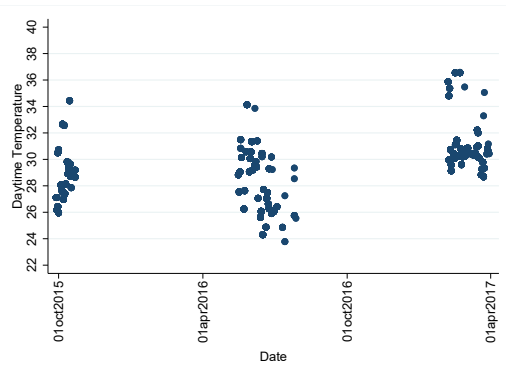
(c) District of Ga East.



(d) District of Ga South.



(e) District of La-Nkwantanang-Madina.



(f) District of Ledzokuku-Krowor.

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. 5.1 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. 5.1 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	−0.017	−0.041	−0.008	−0.004	−0.017	−0.010
	(0.007)	(0.015)	(0.011)	(0.026)	(0.012)	(0.020)	(0.016)	(0.013)
$30°C \leqslant$ Temp $< 33°C$	0.006	−0.024	−0.017	−0.035	−0.034***	−0.019	−0.021	−0.025*
	(0.008)	(0.015)	(0.011)	(0.027)	(0.013)	(0.022)	(0.018)	(0.014)
$33°C \leqslant$ Temp $< 36°C$	0.021**	−0.027	−0.029*	−0.036	−0.047***	−0.064**	−0.060***	−0.057***
	(0.010)	(0.020)	(0.015)	(0.035)	(0.018)	(0.027)	(0.023)	(0.018)
Temperature $\geqslant 36°C$	0.029**	−0.024	−0.021	−0.016	0.005	−0.002	−0.025	−0.007
	(0.013)	(0.025)	(0.019)	(0.046)	(0.024)	(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	8173	8173	8173	8173	8173	8173	8173	8173

Notes: Table reports results from estimating Eq. 5.1 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

Omitted Bin: $< 27°C$	(1) Section 1 Math Score (% Correct)	(2) Section 3 Literacy Score (% Correct)
$27°C \leqslant$ Temp $< 30°C$	-0.002	-0.007
	(0.005)	(0.006)
$30°C \leqslant$ Temp $< 33°C$	-0.003	-0.005
	(0.005)	(0.007)
$33°C \leqslant$ Temp $< 36°C$	-0.000	-0.005
	(0.007)	(0.008)
Temperature $\geqslant 36°C$	-0.003	-0.011
	(0.010)	(0.011)
Child FE	Yes	Yes
Survey Round FE	Yes	Yes
Age FE	Yes	Yes
Observations	8173	8173

Notes: Table reports results from estimating Eq. 5.1 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. 5.3 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. **??** 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.

References

Adeniran, Adedeji, Joseph Ishaku, and Lateef Olawale Akanni. 2020. "Is Nigeria Experiencing a Learning Crisis: Evidence from Curriculum-Matched Learning Assessment." *International Journal of Educational Development* 77 (September): 102199. https://doi.org/10.1016/j.ijedudev.2020.102199.

Ahmed, Ishita, Lily Steyer, Noelle M. Suntheimer, Sharon Wolf, and Jelena Obradović. 2022. "Directly Assessed and Adult-Reported Executive Functions: Associations with Academic Skills in Ghana." *Journal of Applied Developmental Psychology* 81 (July): 101437. https://doi.org/10.1016/j.appdev.2022.101437.

Araujo, M. Caridad, Pedro Carneiro, Yyannú Cruz-Aguayo, and Norbert Schady. 2016. "Teacher Quality and Learning Outcomes in Kindergarten *." *The Quarterly Journal of Economics* 131, no. 3 (August): 1415–1453. https://doi.org/10.1093/qje/qjw016.

Bold, Tessa, Deon Filmer, Gayle Martin, Ezequiel Molina, Brian Stacy, Christophe Rockmore, Jakob Svensson, et al. 2017. "Enrollment Without Learning: Teacher Effort, Knowledge, and Skill in Primary Schools in Africa." *Journal of Economic Perspectives* 31, no. 4 (November): 185–204. https://doi.org/10.1257/jep.31.4.185.

Di Napoli, Claudia, Christopher Barnard, Christel Prudhomme, Hannah L. Cloke, and Florian Pappenberger. 2021. "ERA5-HEAT: A Global Gridded Historical Dataset of Human Thermal Comfort Indices from Climate Reanalysis." *Geoscience Data Journal* 8 (1): 2–10. https://doi.org/10.1002/gdj3.102.

Diamond, Adele. 2013. "Executive Functions." *Annual review of psychology* 64:135–168. https://doi.org/10.1146/annurev-psych-113011-143750.

Emediegwu, Lotanna E., Ada Wossink, and Alastair Hall. 2022. "The Impacts of Climate Change on Agriculture in Sub-saharan Africa: A Spatial Panel Data Approach." *World Development* 158 (October): 105967. https://doi.org/10.1016/j.worlddev.2022.105967.

Evans, David K, and Amina Mendez Acosta. 2021. "Education in Africa: What Are We Learning?" *Journal of African Economies* 30, no. 1 (January): 13–54. https://doi.org/10.1093/jae/ejaa009.

Garg, Teevrat, Maulik Jagnani, and Vis Taraz. 2020. "Temperature and Human Capital in India." *Journal of the Association of Environmental and Resource Economists* 7, no. 6 (November): 1113–1150. https://doi.org/10.1086/710066.

Graff Zivin, Joshua, Solomon M. Hsiang, and Matthew Neidell. 2018. "Temperature and Human Capital in the Short and Long Run." *Journal of the Association of Environmental and Resource Economists* 5, no. 1 (January): 77–105. https://doi.org/10.1086/694177.

Graff Zivin, Joshua, Yingquan Song, Qu Tang, and Peng Zhang. 2020. "Temperature and High-Stakes Cognitive Performance: Evidence from the National College Entrance Examination in China." *Journal of Environmental Economics and Management* 104 (November): 102365. https://doi.org/10.1016/j.jeem.2020.102365.

Hocking, Chris, Richard B Silberstein, Wai Man Lau, Con Stough, and Warren Roberts. 2001. "Evaluation of Cognitive Performance in the Heat by Functional Brain Imaging and Psychometric Testing." *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 128, no. 4 (April): 719–734. https://doi.org/10.1016/S1095-6433(01)00278-1.

Hyde, Dale, John R. Thomas, John Schrot, and W. F. Taylor. 1997. *Quantification of Special Operations Mission-Related Performance: Operational Evaluation of Physical Measures:* technical report. Fort Belvoir, VA: Defense Technical Information Center, February. https://doi.org/10.21236/ADA381211.

Li, Xiaoxiao, and Pankaj C. Patel. 2021. "Weather and High-Stakes Exam Performance: Evidence from Student-Level Administrative Data in Brazil." *Economics Letters* 199 (February): 109698. https://doi.org/10.1016/j.econlet.2020.109698.

LoPalo, Melissa. 2023. "Temperature, Worker Productivity, and Adaptation: Evidence from Survey Data Production." *American Economic Journal: Applied Economics* 15, no. 1 (January): 192–229. https://doi.org/10.1257/app.20200547.

Moffitt, Terrie E., Louise Arseneault, Daniel Belsky, Nigel Dickson, Robert J. Hancox, HonaLee Harrington, Renate Houts, et al. 2011. "A Gradient of Childhood Self-Control Predicts Health, Wealth, and Public Safety." *Proceedings of the National Academy of Sciences* 108, no. 7 (February): 2693–2698. https://doi.org/10.1073/pnas.1010076108.

Owusu, George, and Samuel Agyei-Mensah. 2011. "A Comparative Study of Ethnic Residential Segregation in Ghana's Two Largest Cities, Accra and Kumasi." *Population and Environment* 32, no. 4 (June): 332–352. https://doi.org/10.1007/s11111-010-0131-z.

Park, R. Jisung, Joshua Goodman, Michael Hurwitz, and Jonathan Smith. 2020. "Heat and Learning." *American Economic Journal: Economic Policy* 12, no. 2 (May): 306–339. https://doi.org/10.1257/pol.20180612.

Team, Global Education Monitoring Report, Association for the Development of Education in Africa, and African Union. 2022. "Spotlight on Basic Education Completion and Foundational Learning in Africa, 2022: Born to Learn — Policy Commons."

Wolf, Sharon, J. Lawrence Aber, Jere R. Behrman, and Edward Tsinigo. 2019. "Experimental Impacts of the "Quality Preschool for Ghana" Interventions on Teacher Professional Well-Being, Classroom Quality, and Children's School Readiness." *Journal of Research on Educational Effectiveness* 12, no. 1 (January): 10–37. https://doi.org/10.1080/19345747.2018.1517199.

APPENDIX
Exposure To Heat and Student Cognitive Functioning

Yabo Gwladys Vidogbena

A Additional QP4G Data Details

A.1 Survey implementation and background

The Republic of Ghana offers a context to study the issue of rising temperature and its adverse effects on children's outcomes. 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). 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 and 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.1.1 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 according to (Wolf et al. 2019). The survey round were collected at different seasons throughout the years. Indeed, the first survey round of data was collected in September and October 2015. The second round of data was collected in May and June 2016 and the last survey round used in this study was collected in May and June 2017.

A.2 School and Child sample

School sample 240 schools were selected As shown in Figure D.4. All schools in the six districts were identified using the Ghana Education Service Educational Management Information Sys-

tem (GES-EMIS) database, which lists all registered schools in the country. There are 120 public schools and 490 private schools. All public schools were included in the sample, and private schools were selected within a districts. 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. 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. Figure D.1 shows the proportion of children surveyed per districts and Figure D.5 show the number of children surveyed per day for each survey round. Those children are distributes across 240 schools and in each school, an average of 15 students were randomly selected (eight from KG1, and seven from KG2) and assessed. In case there is only one KG classroom in the school, 15 children were selected. In addition, there was also a reserve list where a child is replaced by the assessor after three attempted interviews.

A.3 Survey timing

The survey dates are decided by the supervisor team and a contract is made to the team of assessors. Therefore date are not chosen by the assessor, nor by the school. The timing of the survey is related to the time interval when schools are open and children are in school. This allow to argue that the date and timing are neither correlated with temperature, nor correlated with assessor characteristics. In fact, assessors move in groups and interview children almost simultaneously such that the decision is not assessor dependent.

A.4 Questions on Executive function and behaviors

Executive function behaviors are a component of executive functions and measure how an individual can stay focus in the presence 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. Reports on individual by assessors or by an external person over

a range of question allow to assess the executive function behavior of that individual. In this setting, Figures D.2 and D.3 show an example of set of questions for a report to assess executive function behavior of children during a test.

B Additional Heat Exposure Data Details

B.1 Universal Thermal Climate Index

B.1.1 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). This may be written in mathematical terms as

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

The UTCI temperature is associated with heat stress in the following way:

- Moderate heat stress: 26°C to 32°C
- Strong heat stress: 32°C to 38°C
- Very strong heat stress: 38°C to 46°C
- Extreme heat stress: above 46°C

B.2 UTCI temperature calculations

In a given day d, UTCI temperature is measured at each hour h. For a given interval of time starting at τ^{start} and finishing at τ^{end} the mean temperature is expressed as follow:

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

Different temperature measures are used for robustness checks. It include the maximum temperature on a given day such that:

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

It also include using the average of the minimum and the maximum temperature in a day. The minimum temperature is written as follow:

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

and the average of the minimum and maximum temperature is written as follow:

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

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

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

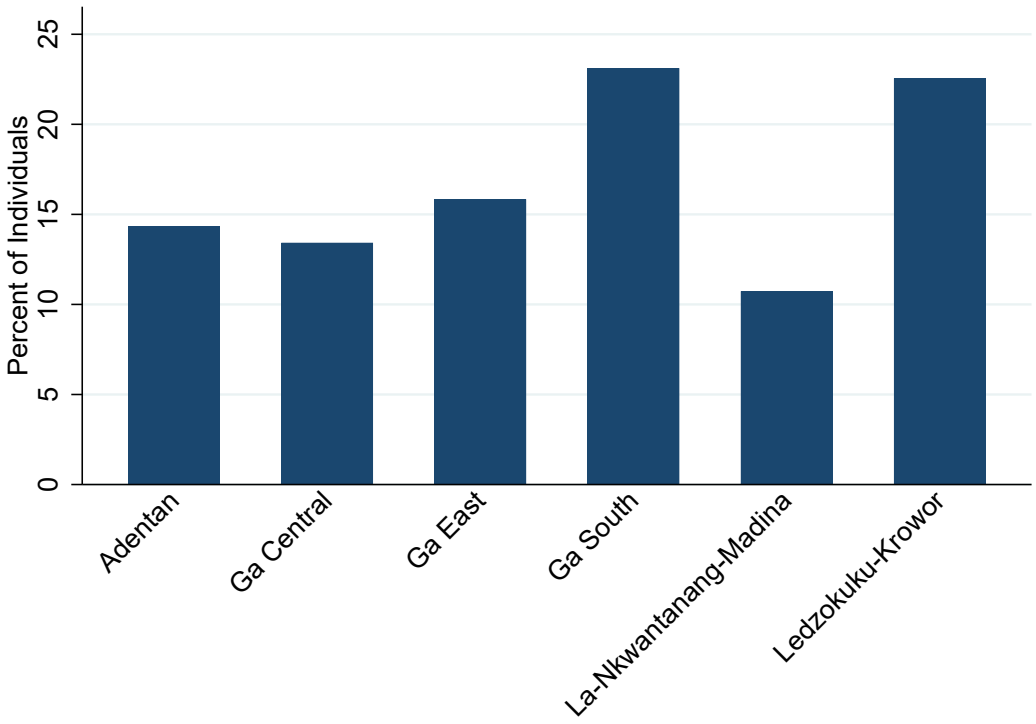
such that we compute both the daytime average temperature and the daily average temperature.

B.3 Distribution of UTCI statistics

We show variations in average, maximum and minimum temperature in Figure D.6. The last survey round is hotter than the first 2 but the average temperature is almost the same for the 3 survey round.

C 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.

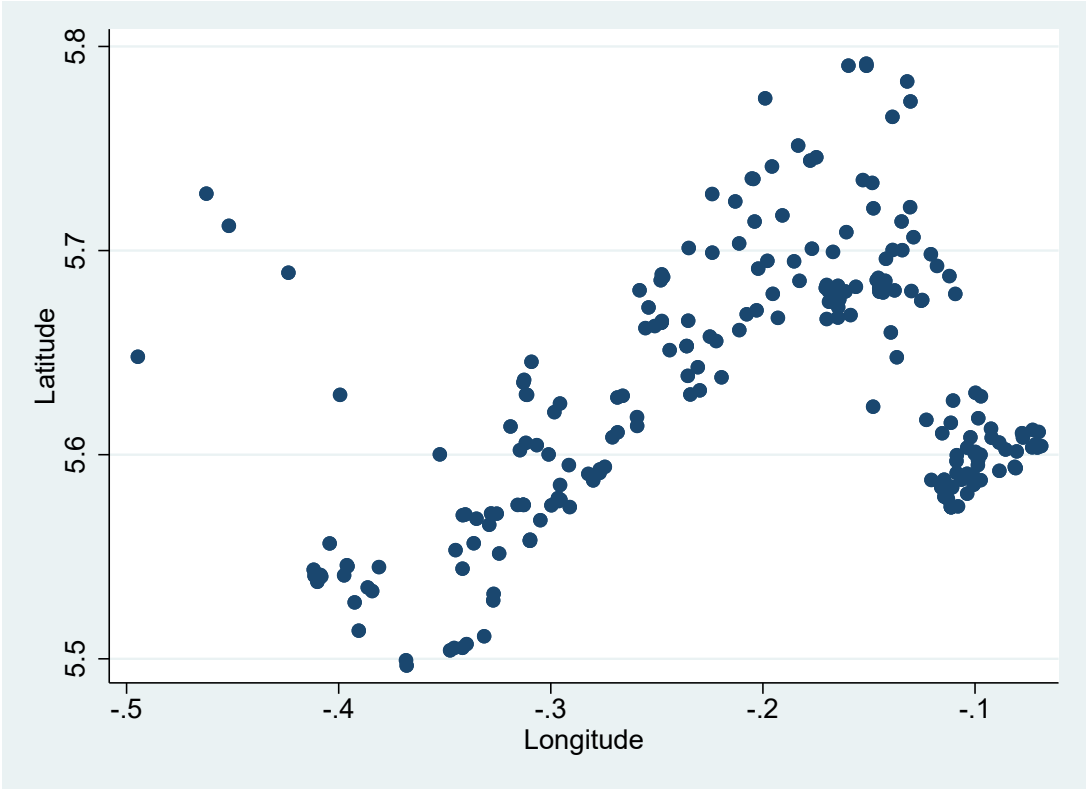
Fig. D.2. Overall Report Questions

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

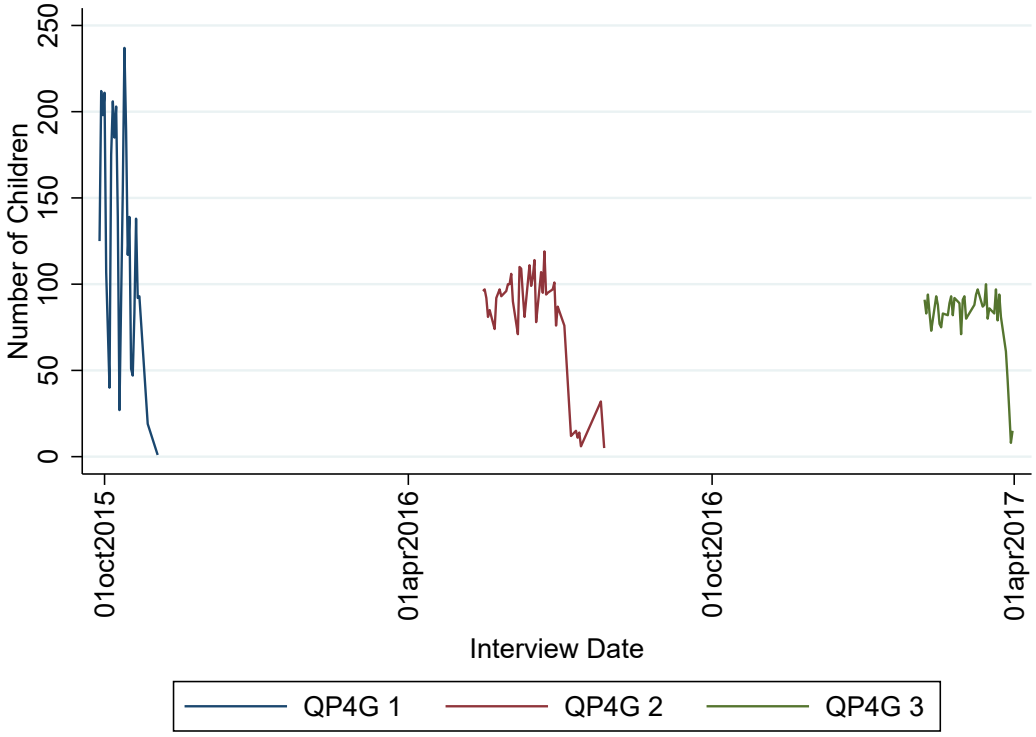
SCORING					
	Scoring categories	*Scoring options*			
Item No.	**Comprehension**	Correct (1)	Incorrect (0)	No response (-99)	Doesn't know (-88)
2401.	**"Who stole the cat's hat?"** (the mouse)	[ ]	[ ]	[ ]	[ ]
2402.	**"What is the color of the hat?"** (red)	[ ]	[ ]	[ ]	[ ]
2403.	**"Why did the cat chase 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



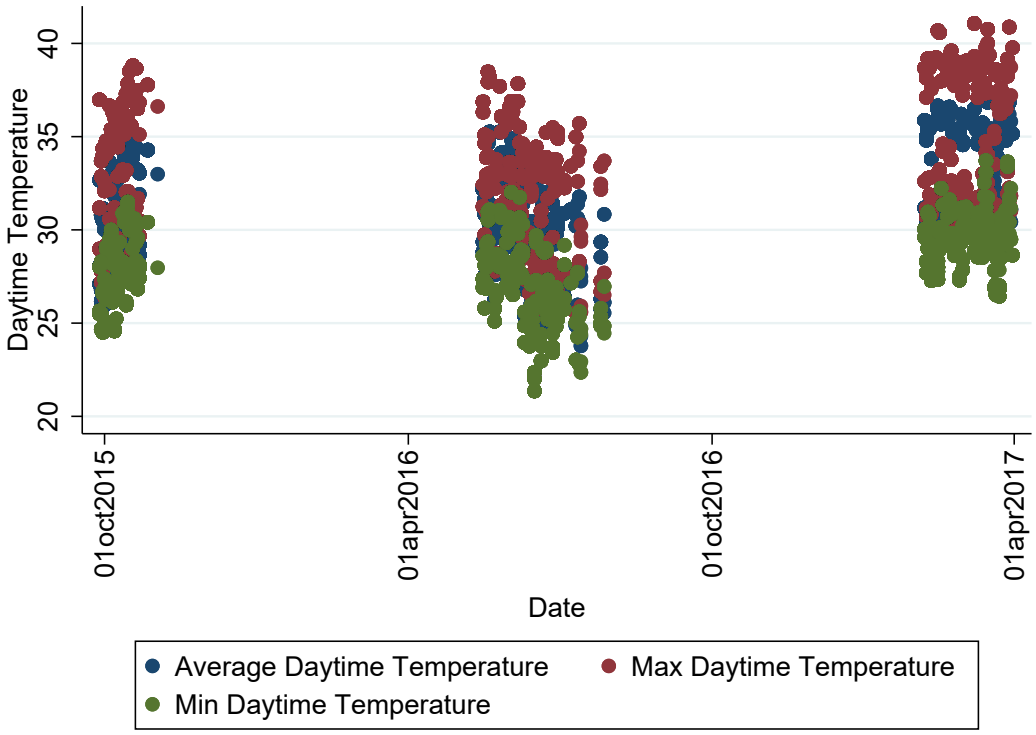
Note: The figure illustrates the dispersion of the schools using their longitude and latitude information.

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.