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. The paper finds 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. It also finds 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?

We 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. We 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.

We 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, we 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, we 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.

We 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. First, 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 holds innate ability constant, as well as any other individual specific attributes that remain constant over time. We control for time-varying characteristics such as seasons using a survey round fixed effect. We 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 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, we 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. We found evidence that the decrease in attentiveness is observed both at the beginning and toward the end of the test. We 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. We 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. Our sample includes very young children, as young as 2 years old. Very young children have a smaller body and are more sensitive to heat. We verify that hypothesis by doing an heterogeneity analysis by age group. We 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 2 describes how heat affects performance, Section 3 describes the context of Ghana in details, 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, in turn, leads to decreases in attention, memory, information retention, and processing ability, as noted by Hyde et al. (1997). In other words, heat may act as an external stressor that challenges children to rely on more than instinct or intuition when exposed to it. These effects have implications for individuals broadly, and for children in particular.

Children might exhibit poorer executive function behavior. Executive function behaviors are also referred to as executive control or cognitive control and refer to a family of top-down mental processes required for concentration and attention (Diamond 2013). Executive functions enable individuals to mentally play 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 everyday application of executive function skills and researchers typically measure them through observation and ratings of children's abilities to pay attention, stay engaged, and inhibit impulses (Ahmed et al. 2022).

Children might receive lower scores on test or might exert higher effort to attain the same score. Heat acts as a stressor and requires children to exert more effort to stay focused. A child who chooses not to make the extra effort 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 both their effort and their knowledge. The choice of making effort could be determined by children's characteristics.

The effect of heat on children's functioning may vary by their family's socioeconomic status. Wealth can be protective, as it is associated with better health, and greater exposure to cognitively stimulating environments. Therefore, children from relatively wealthier families might perform better than those from poorer families, and additionally may be less affected 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 being at an earlier stage of development.

3 Background

The Republic of Ghana is a tropical country located in West Africa. Tropical countries are, on average, hot and Ghana has a historical (1901-2020) annual mean air temperature of 27.3°C according to the World Bank's climate risk profile. In Ghana, the annual mean temperature has risen by 1°C since 1960. While northern Ghana is hotter and drier, southern Ghana is more humid. February to April are the hottest months with a mean temperature between 28 and 29°C and June to September are the coolest months with an average temperature of 25-26°C. The academic year runs from September to July, meaning that children are in school during the hottest months.

In terms of education profile, Ghana has one of 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, concerns remain about low learning outcomes and educational inequality according to UNESCO (Spotlight on basic education completion and foundational learning: Ghana, UNESCO 2022).

This paper uses longitudinal data collected on children in 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's executive function, we take advantage of longitudinal data in Ghana following a study called "Quality for Pre-school for Ghana" (QP4G). The data was collected on children in pre-primary in 2015, on their caregivers, schools and teachers. Tablets were used for data collection and date and time were recorded automatically as part of the process. We 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). We specifically use the Universal Thermal Climate Index (UTCI) which is a heat index.

4.1 QP4G Data

The data on children's outcomes and characteristics come from the QP4G intervention. The intervention aims to improve classroom quality and enhance Ghanaian children's school readiness. It was implemented in the Greater Accra region, in the southern part of Ghana, across six districts, namely Adentan, Ga Central, Ga East, Ga South, La-Nkwantanang-Madina, and Ledzokuku-Krowor. The intervention is school-based and includes children aged 2 to 10 in the first year. Figure D.4 shows the distribution of different schools in the sample. As the figure demonstrates, the geographic dispersion is not large. At baseline, 3,435 children were included in the study. There was attrition of about 9% from the first survey year.

For the first three survey rounds, the surveys were conducted in schools and included tests administered to kindergarten children. Fifteen children were randomly selected from kindergarten class rosters and were individually surveyed. The dates of the surveys were decided in advance, as they were part of an agreement between the surveyors and the evaluation team. Therefore, students did not select the dates.

To assess children's readiness, the International Development and Early Learning Assessment (IDELA) was used for the first three survey rounds. IDELA is a set of items, each testing a different skill which may be either cognitive or non-cognitive. For example, children's reading comprehension and vocabulary skills were tested, as well as their ability to add, subtract, multiply and divide. Non-cognitive assessments include personal awareness. A unique feature of the dataset is that there are surveyors' assessments of the student's behavior throughout the interview and at the end of the interview. These assessments are made possible through one-on-one testing.

4.1.1 Outcomes Variables

To assess student functioning, we use assessors' rating of students' behavior throughout the survey and at the end of the survey, as the main outcomes. Secondly, we construct separate math and literacy test scores, based on all questions related to the math and literacy sections.

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 and switching easily from one task to the other while maintaining concentration (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). Additionally, Ahmed et al. (2022) provides evidence that executive function skills and behaviors are informative in predicting 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 report on each child's behavior. This individual report is made possible because the interviews or testing were conducted individually.

We define the main outcome based on the overall report by assessors completed at the end of each survey. Indeed, at the end of each survey, assessors are asked seven questions and they rated each child on a scale from 1 to 4, with 1 being the lowest rating and 4 the highest. Figure D.2 shows the seven questions with the scale. We construct the Overall Child EF rating measure (1-4) by taking the average of the seven questions. The first panel of Table 2 shows the mean and standard deviation of each component of the Overall Child EF rating, as well as for the Overall Child EF rating itself. On average, students are "often" attentive during the test.

We construct three dummy variables related to the main outcome to understand how children's behavior is changing on each margin of the scale. To do so, we first create dummy variables for each of the seven questions in the assessor report based on each margin. Secondly, we compute an average for each margin. The three resulting variables are displayed in the second panel of Table 2. While 45% of the children are rated as "almost always" attentive, 2% are rated as "almost never" attentive.

As stated earlier, assessors make intermediate reports as well throughout the survey. These intermediate reports, unlike the overall report contain fewer questions. Figure D.3 shows an example of such report. The report is composed of three 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 the report reflects the child's behavior during that particular exercise.

For the analysis, we focus on children's executive function behavior related to two specific items: item 6 (Number sense-One-to-one correspondence) and item 24 (Oral comprehension). Item 6 belongs to the emergent math section, which appears early in the test. Item 24 is part of the literacy section which is one of the final sections. The analysis using those two variables allows to do a comparison between how children behave early in contrast with how they behave later during the test. Accordingly, we construct executive function behavior dummies related to item 6 and item 24 of the test. The fourth panel of Table 2 presents the average and standard deviation of the two outcomes. We observe that average behavior decreases from the early to the later parts of the survey.

Test Scores. We construct two test scores: a math score and a 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 presents the summary statistics for both outcomes. On average, children perform better in the math section.

4.1.2 Other Variables

Age. Children in the sample are kindergarten students in 2015. However, the age range is wide, spanning from 2 to 10 years old. The last panel of Table 2 presents statistics related to the age variable. On average, across the three survey rounds, children are 5.8 years old, and 5.2 years old for the first survey-round. The age distribution is quite broad, but concentrated around ages 3 to 6 years at baseline. Specifically, 87% of the children are between 3 and 6 years old in the first round. We later construct a variable "Young" which is a dummy for children aged 2 to 5 years old. This allows us to perform a heterogeneity analysis based on age groups. The hypothesis is that younger children might perform differently because they are still in an early developmental stage. According to Table 2 45% of the sample respect the definition of "Young".

Poverty Measure. We construct a proxy for poverty and socioeconomic status using the question about the type of toilet used in the child's household.[1] The proxy is a dummy variable equal to 1 for households without a private toilet or households that rely on public toilets. The last panel of Table 2 shows that about 51% of the children come from a low socioeconomic background, based on this indicator. This variable will be used to assess whether the effect of heat differs across socioeconomic groups. The hypothesis is that wealth is protective, enabling better health and greater engagement in cognitively stimulating activities.

4.2 UTCI Temperature Data

4.2.1 UTCI

In the analysis, temperature is measured using the Universal Thermal Climate Index. The UTCI is a heat index that combines air temperature, humidity, wind speed, and radiant heat and serves as a proxy for the temperature perceived by the human body. The ERA5-HEAT dataset provides 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 (~31Km$\times$31Km).

4.2.2 UTCI Thresholds

There are different thresholds of UTCI temperature that define varying levels of heat stress. The human body begins to experience heat stress starting at a UTCI temperature of 26°C. Specifically, 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 take into account acclimatization. Individuals living in tropical areas may adapt and function relatively well even under higher temperatures. For example, the human body in these regions may tolerate up to 3.5°C more than their counterparts in colder climates. To the best of our knowledge, the link between acclimatization and heat stress remains undocumented, and the thresholds for heat stress may differ in tropical

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

countries such as Ghana.

Ghana, as a tropical country, has a relatively high average temperature. According to its Climate Risk Country profile by the World Bank, the annual mean temperature is 27.3°C. Given this high annual mean, one might hypothesize that individuals in Ghana and similar countries are acclimatized to hot temperatures. If such acclimatization exists, it should be reflected in the results of the current study. Specifically, if individuals are indeed acclimatized to heat, we should expect to observe very small or no effects of heat on children's outcomes.

For the analysis, We define UTCI temperature bins of 3°C. While the commonly used bin size in the literature is the 2°C, defining 3°C temperature bins ensures that there are enough observations in each temperature bin. Table 1 shows the different UTCI temperature bins defined for the analysis. Using UTCI temperature bins allows for capturing a non-linear relationship between UTCI and children's outcomes. We define the average daytime UTCI temperature as the average of all hourly UTCI temperature from 8 a.m. to 5 p.m., considering that children are not in school outside these hours.

4.3 Merging UTCI Data Into QP4G Data

The UTCI is linked to three survey-rounds of QP4G using location information on one side and date of survey information on the other. Students were interviewed in schools. We first aggregate the school's longitude and latitude information to the nearest $0.25° \times 0.25°$. Then we 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 tablets. 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

For the analysis, the sample is restricted to children with at least two survey rounds of data and non-missing information on age. This yields a total of 2920 unique children and 8173 observations used in the various analyses. Figure D.1 shows the proportion of children in each district. About 45% of the observations come from children were interviewed in Ga South and Ledzokuku-Krowor schools. In each other district, approximately 15% of students were interviewed.

The date of birth of children, as well as the age at the last birthday, were collected throughout the survey rounds and from multiple sources within the same round. The primary source is the caregiver. These two information allow us to construct a reasonable and decent age variable. It is worth noting, however, that some inconsistencies exist in the reported date of birth across different survey rounds.

Figure D.6 and Table 1 show both within- and between-survey round variation in UTCI temperature. One important observation is that the surveys were not conducted during the same months each year. The third survey round is notably hotter than the first two, as the interviews took place during the dry and hot harmattan season. Second, within a single survey round, individuals are exposed to different UTCI temperature bins. Third, across rounds, we observe that children are exposed to different (or the same) temperature bins. These movements show that there is within individual variation in exposure, as some children move from one temperature bin to another across rounds. This variation is crucial for identifying the effect of heat on child outcomes.

Figure 3 shows the within-survey round variation of UTCI temperature by district. Each panel represents a district. At first glance, there is both 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 seems to be hotter than the other.

5 Empirical Strategy

To estimate the effects of heat stress on child functioning on the day of test, we exploit within child variation in temperature across rounds of the survey. 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 the data, we 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).

We use the following specification to estimate the effect of heat exposure on child outcomes:

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

where $\mathrm{UTCI}^{27-30^\circ}_{l(i),t}$ is a dummy for UTCI temperature between 27°C and 30°C (excluded), $\mathrm{UTCI}^{30-33^\circ}_{l(i),t}$ is a dummy for UTCI temperature between 30°C and 33°C (excluded), $\mathrm{UTCI}^{33-36^\circ}_{l(i),t}$ is a dummy for UTCI temperature between 30°C and 33°C (excluded), and $\mathrm{UTCI}^{>36^\circ}_{l(i),t}$ is a dummy for UTCI temperature greater than 36°C. The omitted UTCI temperature bin in the 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 $l(i)$ $\times$ day-of-test t 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 day-of-test and $r(t)$ stands for survey round which embeds the concept of time as a day and the concept of seasonality. Each survey round denotes a different season of the year. $y_{i,t}$ is the outcome of child i interviewed on day t. The error term $\epsilon_{i,t}$ is clustered at the individual level.

The child FE, α_i , in the 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 for any selection related to location choice by children's parents. For example, there could be situations where low socioeconomic households sort into hotter or less hot places compared to high socioeconomic households or vice versa. It could also be that temperature is correlated with household characteristics, for example, hotter places might be poor and colder places might be richer.

We control for other yearly invariant characteristics, $\delta_{r(t)}$, such as seasonal variations, education policies, or the timing of the academic year.[2] We control for age, σ_a, because in the dataset, children are aged 2-11 years old, which is a wide range of age and each age might

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.

imply different cognitive maturity as well as different adaptation to heat stress for example. Age fixed effects allow us us to control for learning happening between two testing periods.

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

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

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.

We 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, we estimate:

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

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

6 Estimation Results

In this section, we discuss the results from the estimations on the various outcomes we constructed earlier.

6.1 Temperature and Child Executive Function Behavior Rating

Table 3 presents the results from estimating Equation 5.1. The first seven outcome variables in the table correspond to the seven questions from the assessor report completed at the end of each test. Figure D.2 lists these seven questions. The final outcome is the overall child executive behavior rating, which is calculated as the average of the seven individual ratings. The omitted UTCI temperature bin, which serves as the reference category, corresponds to the least hot temperature range, 24 to 27 °C. All coefficients should be interpreted relative to this reference bin.

Overall, the results show that for each question on the report, and for the average of all questions on the report, exposure to relatively higher temperature reduces child executive function behavior rating. In other words, children are less able to stay focused on cognitive tasks when it gets hotter. The results also indicate that even moderate heat stress (27 °C to 32 °C in our sample) is detrimental to children. Furthermore, the negative effect becomes more pronounced as children are exposed to strong (32 °C to 38 °C), and very strong (38 °C to 46 °C) heat stress 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 rating by 0.05 points on a 1-to-4 scale. This represents approximately a 2% decline relative to the omitted group average of 3.11. In particular, children become significantly less careful (see β_1 in column 4) and less motivated (see β_1 in column 6). The next coefficient, β_2, indicates a decrease of 0.1 points on a 1-to-4 scale, which corresponds to roughly a 4% decrease from the omitted group average. At this level, 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 points on a 1-to-4 scale, which corresponds to about a 6% decrease from the omitted group average. β_4 shows a decrease of 0.1 points as well which corresponds to a decrease of 4% from the omitted group average. The smaller magnitude of β_4 relative to β_3 may suggest limited statistical power to detect an effect at the highest temperature bin.

To better understand how large or small the previous estimates are, and to pinpoint where on the scale children are most affected, we examine the margins of the overall outcome. Table 4 presents the results for these different margins. Column 1 shows results for a dummy equal to one if the child's overall executive function rating is either 2, or 3 or 4. Column 2 shows the results for a dummy equal one if the child's overall rating is either 3 or 4. The final column shows the results for a dummy equal one if the child's overall rating is 4.

The estimates in the first column of Table 4 indicate an increased likelihood of moving from higher ratings (4, 3, or 2) to the lowest rating of 1. In other words, exposure to hotter temperatures raises the probability that a child is rated as "almost never attentive" rather than "sometimes", "often" or "almost always" attentive. The term "attentive" here refers broadly to the seven aspects of executive function on which the assessor evaluates the child. Quantitatively, heat exposure increases the likelihood of receiving the lowest rating by up to 1.6

percentage points. This suggests that as global temperature rises, an increasing number of children may struggle with attentiveness in classroom settings.

The estimates in the second column of Table 4 indicate an increased likelihood of moving from higher ratings of 4 or 3, to lower ratings of 2 or 1. In other words, exposure to hotter temperatures raises the probability that a child is rated as "almost never" or "sometimes " attentive, rather than "often" or "almost always" attentive under hotter temperatures. Quantitatively, this represents an increase of up to 6 percentage points in the likelihood of a child becoming "less attentive" due to heat exposure.

The results in column 3 of Table 4 show a decline in the likelihood of being rated as "almost always" attentive (rating of 4). Specifically, children become more likely to receive a rating of 3, 2, or 1, indicating they are "often," "sometimes," or "almost never" attentive instead. This shift corresponds to a decrease of up to 10 percentage points in the probability of being "almost always" attentive. These findings suggest that heat affects the most attentive children, and as global temperatures continue to rise, a growing number of students may learn less in classrooms.

6.1.1 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 examine intermediate ratings by assessor of student's executive function. An example of such report is found on Figure D.3. This intermediate report includes fewer questions, compared to the overall report. Moreover, each question is recorded as a binary indicator, rather than on a 1-4 scale. Analyzing these intermediates ratings enables us to better understand children's behavior throughout the course of the test, rather than only at the end.

Table 5 presents the results of this analysis. Columns 1 to 4 show the effect of heat on children's executive function behavior during the 6^{th} item of the test. Item 6 corresponds to the number sense exercise which is a mathematics task administered near the beginning of the test. Column 1, 2 and 3 report the results for each question individual question related to this section. Column 4 displays the results for the average of the three questions. Columns 5 to 8 show the effect of heat on the executive function behavior of children during 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, while negative, are not statistically significantly different from zero. This suggests that all children, regardless of temperature exposure, begin the test with comparable levels of executive function. In other words, children exposed to hotter temperatures appear to have sufficient cognitive resources to overcome any initial heat-related discomfort, and therefore do not behave differently from those in the reference temperature category at the start of the test. However, column 8 indicates a decrease of up to 6 percentage points in children's executive function behavior during the oral comprehension exercise under hotter conditions. This finding implies that although children start the test unaffected by temperature differences, prolonged exposure to heat throughout the testing period impairs attentiveness.

6.1.2 Heterogeneous Effects of temperature on Child Executive Function Behavior Rating

Socioconomic Background. The effect of heat on children's executive function may vary by socioeconomic status. Children from high socioeconomic status (SES) households are likely to be exposed to more cognitively stimulating activities. In addition, wealth provides better health, which may mitigate the effects of heat. These factors could lead to differences in behavior under hot conditions. Column 1 of Table 7 presents the results of the heterogeneity analysis by children's socioeconomic background. Columns 2, 3, and 4 report the results for the different margins. The estimated equation corresponds to Eq. 5.2. The upper panel shows the results for children from low socioeconomic backgrounds, while the lower panel displays the differential effects for children from high socioeconomic backgrounds.

The first column of the upper panel indicates that the executive function behavior of children from low socioeconomic backgrounds decreases when they are exposed to higher UTCI temperatures (relative to the 24–27°C range). The corresponding column in the lower panel shows that children from high socioeconomic backgrounds perform better. However, even among children with high socioeconomic status, heat reduces executive function behavior. The third column indicates that children from wealthier backgrounds are significantly less likely to drop from a rating of 3 or 4 to a rating of 1 or 2. The direct implication is that rising UTCI temperatures may exacerbate the learning gap between socioeconomic groups in everyday classroom settings, with potentially long-term consequences.

Age Group. The effect of heat on children's executive function may vary by age groups. Younger children are at an early developmental stage, including the development of their brain. Table 8 presents the heterogeneity analysis results by age group, using both the overall child executive function behavior and the three dummies for each of its margins. The estimated equation is Eq. 5.3. The upper panel shows the results for the youngest children (under 6 years old), while the lower panel presents the differential effects for older children.

The first column of the upper panel indicates that the executive function behavior of younger children decreases when they are exposed to hotter UTCI temperatures (relative to the 24–26°C range). The corresponding column in the lower panel indicates that older children do not show significant changes in behavior. These results suggest that there is no evidence of acclimatization over time.

6.1.3 The Role of Assessor Behavior

LoPalo (2023) finds that heat impacts interviewer productivity, raising the question of whether the estimated results reflect the impact of heat on the interviewer's perception of child executive function. However, it is unlikely that our findings are primarily driven by interviewer behavior.

First, interviewers in our context are professionals who were trained by psychologists to administer the tests. While the nuances between each question might not be obvious to an untrained person, interviewers are well-versed in these distinctions and rated children accordingly. Furthermore, the questionnaires included intermediate ratings that helped interviewers stay attentive to the child's behavior throughout the entire interview.

Second, we conduct an analysis at the interviewer-date level, examining interviewer productivity following the approach in LoPalo (2023). In our case, the main outcome is the number of interviews conducted per day—a relevant measure since interviews take place in schools, where children are available only for a limited period each day. We find no significant effect of heat on the interviewer's daily productivity. This suggests that the results on children's executive function behavior are mostly driven by the children themselves rather than by the interviewers' perceptions during the test. That said, the number of daily interviews may be constrained by other factors such as school-specific student quotas and the distance between schools, which can limit the interviewers' ability to move freely between locations.

Third, our heterogeneity analysis across socioeconomic groups shows that executive function behavior is higher among children from low socioeconomic backgrounds. If the effect were entirely driven by interviewers, this heterogeneity would imply that interviewers systematically alter their perceptions only for children from low socioeconomic backgrounds—an unlikely scenario.

Nonetheless, even if interviewer bias were the sole driver of the results, it would still suggest a loss of productivity on hot days, with meaningful implications for learning in classroom settings on hot days.

6.2 Temperature and Test Scores

So far, the results show that children's cognitive functioning declines as temperature rises. A critical question now is whether children perform differently on cognitive tasks under hotter conditions. One possibility is that children might exert extra effort to counterbalance the adverse effects of heat, potentially leading to longer task completion times. This adjustment is more likely when the exam or test is not timed, as in our case, where there are no skipping patterns in the math and literacy sections.

Table 6 presents the results for test scores. The first column displays the results for the math score, while the second column shows the results for the literacy score. Although the estimates are negative, suggesting potential adverse effects, we find no statistically significant impact of heat on test scores. We propose three possible hypotheses to explain this. First, as temperatures rise, both children and assessors may take longer than usual (relative to the omitted bin of 24-27°C) to complete tasks, resulting in a longer test duration. This hypothesis could be further explored by analyzing the duration of interviews.

Second, it is possible that the true effect is so small that the current study lacks the statistical power to detect it. This is consistent with the observations in Park et al. (2020), which suggests that the effect on test score is minimal, and that their ability to detect this effect is due to the large sample size they used.

Third, it is possible that the test may be either too difficult or too easy, making it hard to observe any differences between students. However, this is unlikely, as this assessment has been successfully used in various contexts to measure cognitive performance.

7 Conclusion

In the context of global warming and persistently low learning levels in developing countries, this paper examines the effect of heat on cognitive functioning. Heat affects learning and performance through changes in brain chemistry and functioning, leading to declines in attention, memory, information retention, and processing. This paper contributes to the literature by providing the first evidence on the effect of heat on children's executive function—or "attentiveness"—using individual fixed effects in the context of a West African country.

Using linked UTCI temperature data and children's outcome data, we find that deviations from the reference UTCI temperature bin (24°C–26°C) reduce children's attentiveness. Specifically, attentiveness decreases by 0.05, 0.11, 0.18, and 0.13 points as temperatures rise to 27°C–29°C, 30°C–32°C, 33°C–35°C, and 35°C–41°C, respectively. We observe up to a 1.6 percentage point increase in the likelihood of a child becoming inattentive, and a 10 percentage point decrease in the likelihood of being "almost always" attentive under high temperatures.

We also find that the decline in attentiveness is more pronounced at the end of the test. In contrast, estimates at the beginning of the test are negative but not statistically significant. This supports the idea that children start fresh and can initially cope with the heat, but as the test progresses and exposure to heat continues, their attentiveness diminishes.

We do not find a significant effect of heat on test scores. This may suggest that children and assessors exert additional effort to offset the adverse effects of heat. Since the assessments are not timed and administered individually, it is possible that interviews take longer on hotter days.

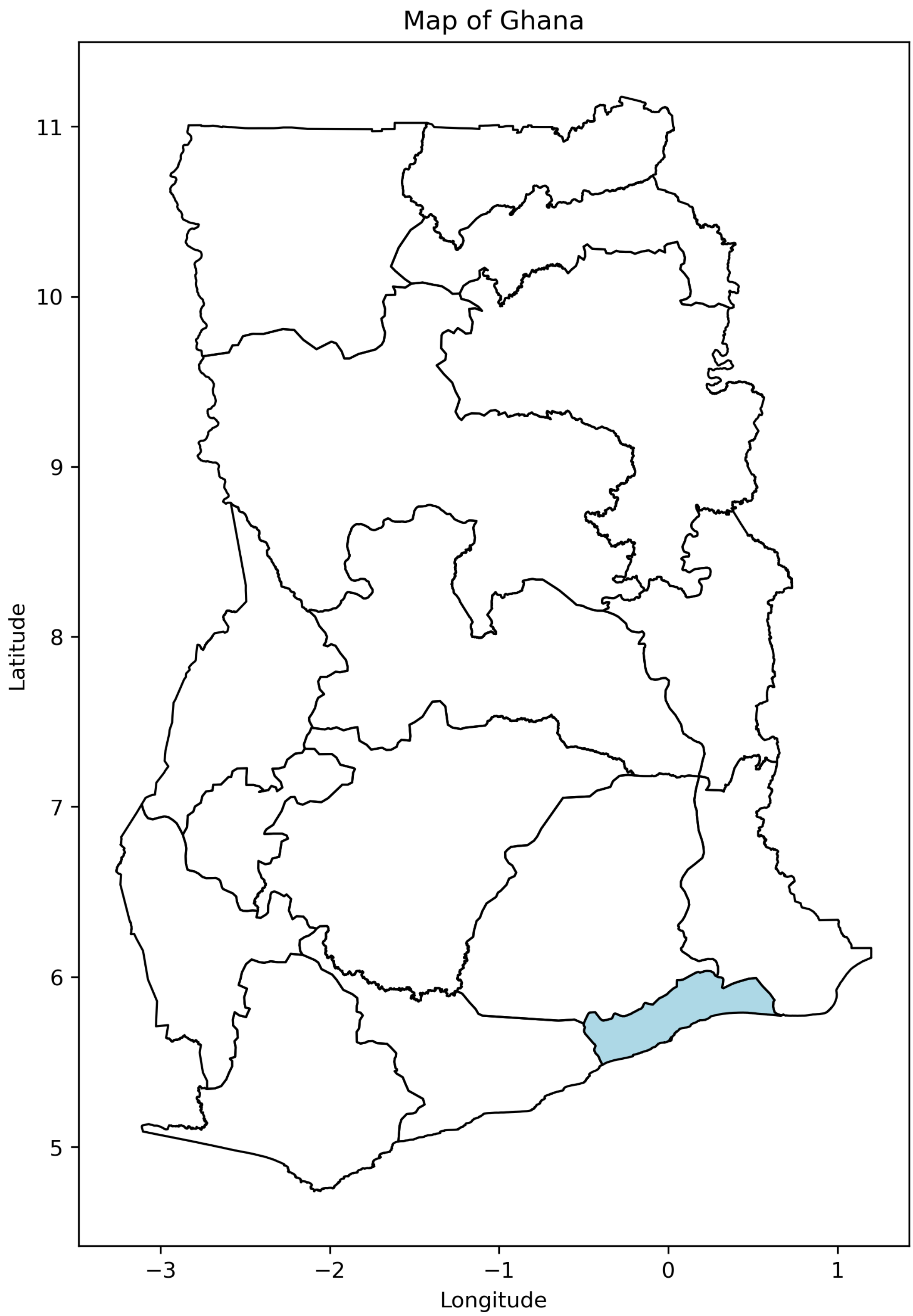
The paper also examines whether the effects of heat differ by socioeconomic status. Results show that children from low socioeconomic backgrounds are less attentive under heat compared to their wealthier peers, potentially widening learning gaps as temperatures rise and the frequency of hot days increases.

Finally, we explore whether the effect of heat varies by age group. We find no evidence of differential effects by age. This may suggest that there is no acclimatization when it comes to cognitive activities.

Overall, the findings in this paper have important implications for classroom learning. As global temperatures continue to rise, the number of less attentive students is likely to increase. Moreover, the learning gap between socioeconomic groups may widen, as children from low-income backgrounds are more adversely affected by heat. Developing countries are particularly vulnerable, as they have fewer resources to mitigate the impacts of rising temperatures.

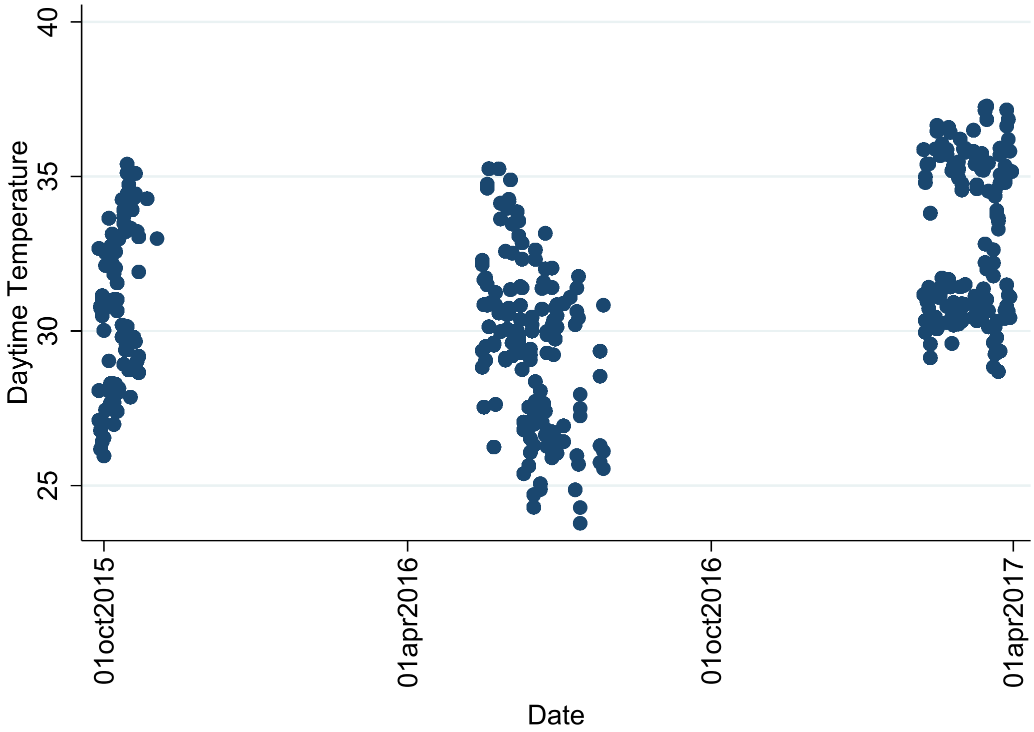
Tables and Figures

Fig. 1. Map of Ghana



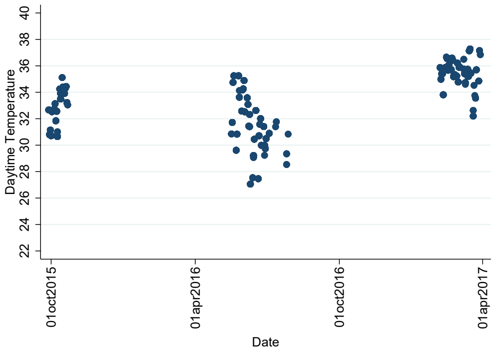
Note: The figure illustrates the map of Ghana. The blue area depicts the Greater Accra region where the data used in this paper was collected.

Fig. 2. Temperature Variation by Wave

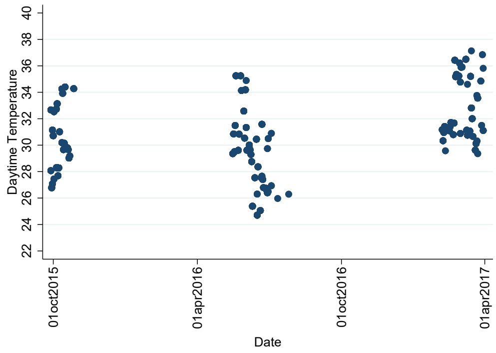


Note: The figure illustrates the temperature variation for each survey-round. The figure shows that the third survey-round is in average hotter than the first two survey-rounds. Temperature here stands for UTCI which is a proxy of the perceived temperature by the body.

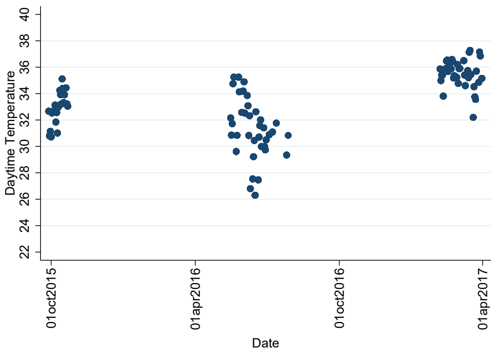
Fig. 3. UTCI Temperature Distribution by Districts



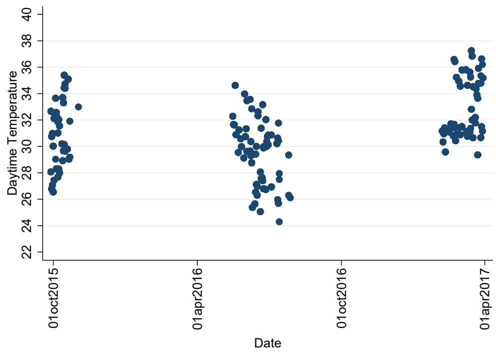
(a) District of Adentan.



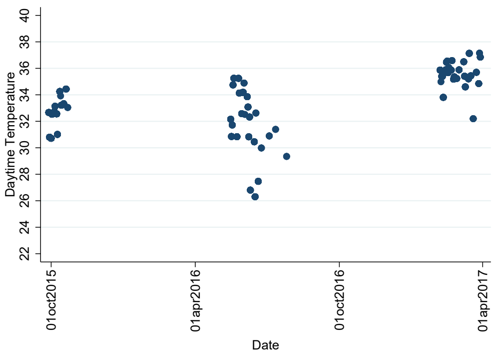
(b) District of Ga Central.



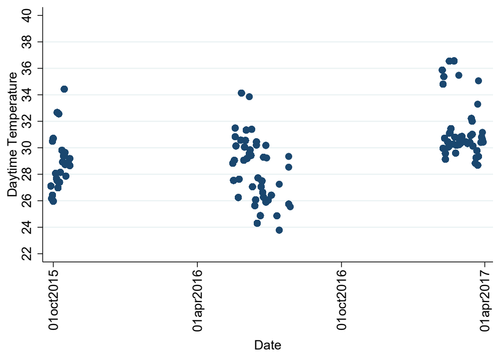
(c) District of Ga East.



(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			
Omitted Bin: $< 27°C$	(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
$27°C \leqslant$ 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. 5.2 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. 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 9: Executive Function Skills

Omitted Bin: $< 27°C$	(1) Short Term Memory	(2) Inhibitory Control	(3) Overall EF Skills	(4) Overall EF Skills (IC$\geqslant$1)	(5) Overall EF Skills (IC$\geqslant$2)
$27°C \leqslant$ Temp $< 30°C$	0.009	0.076***	0.056***	0.010	0.011
	(0.011)	(0.029)	(0.017)	(0.009)	(0.009)
$30°C \leqslant$ Temp $< 33°C$	-0.017	0.028	0.012	-0.011	-0.011
	(0.011)	(0.031)	(0.018)	(0.010)	(0.010)
$33°C \leqslant$ Temp $< 36°C$	-0.004	0.067*	0.039*	0.004	0.005
	(0.014)	(0.040)	(0.023)	(0.013)	(0.013)
Temperature $\geqslant 36°C$	0.027	0.093*	0.073**	0.033*	0.033*
	(0.019)	(0.050)	(0.030)	(0.017)	(0.017)
Child FE	Yes	Yes	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes	Yes	Yes
Age FE	Yes	Yes	Yes	Yes	Yes
Observations	6778	6778	6778	6778	6778

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.

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 System (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

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

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:

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

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

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

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

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

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

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

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

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

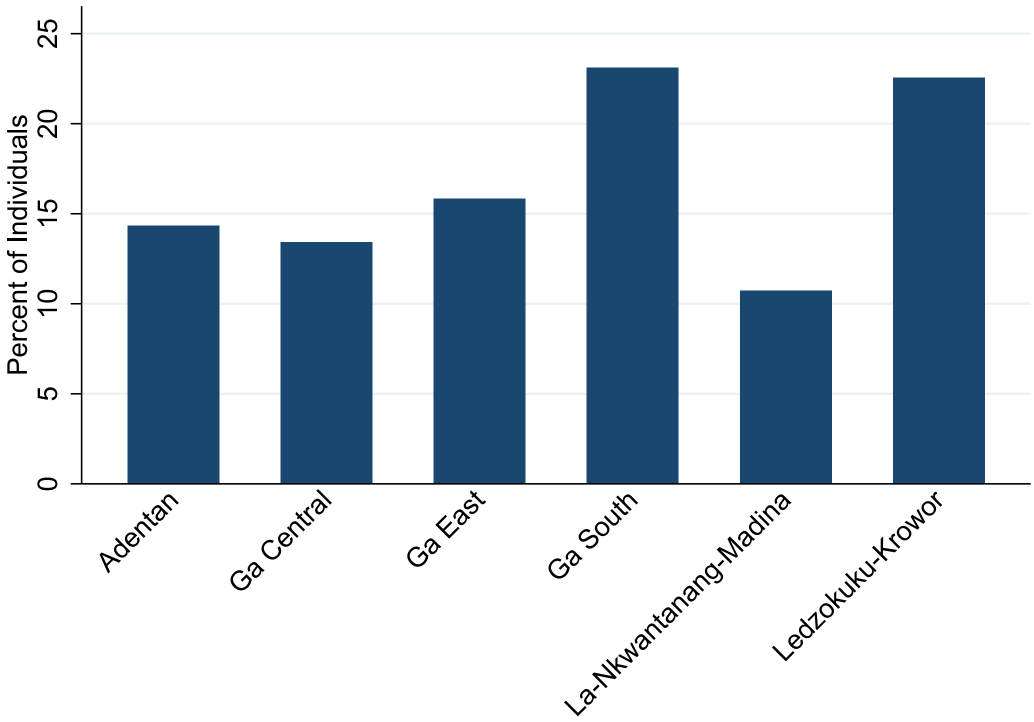
such that we compute both the daytime average temperature and the daily average temperature.

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 Tables

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.

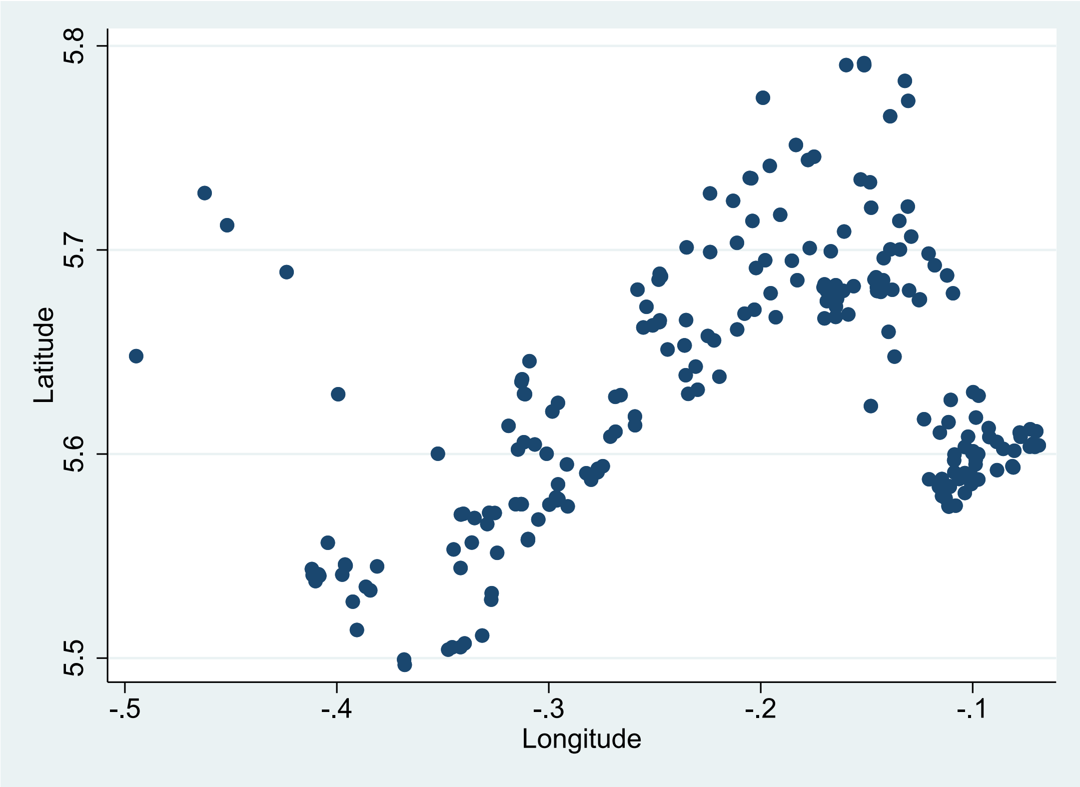
Fig. D.2. Overall Report Questions

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

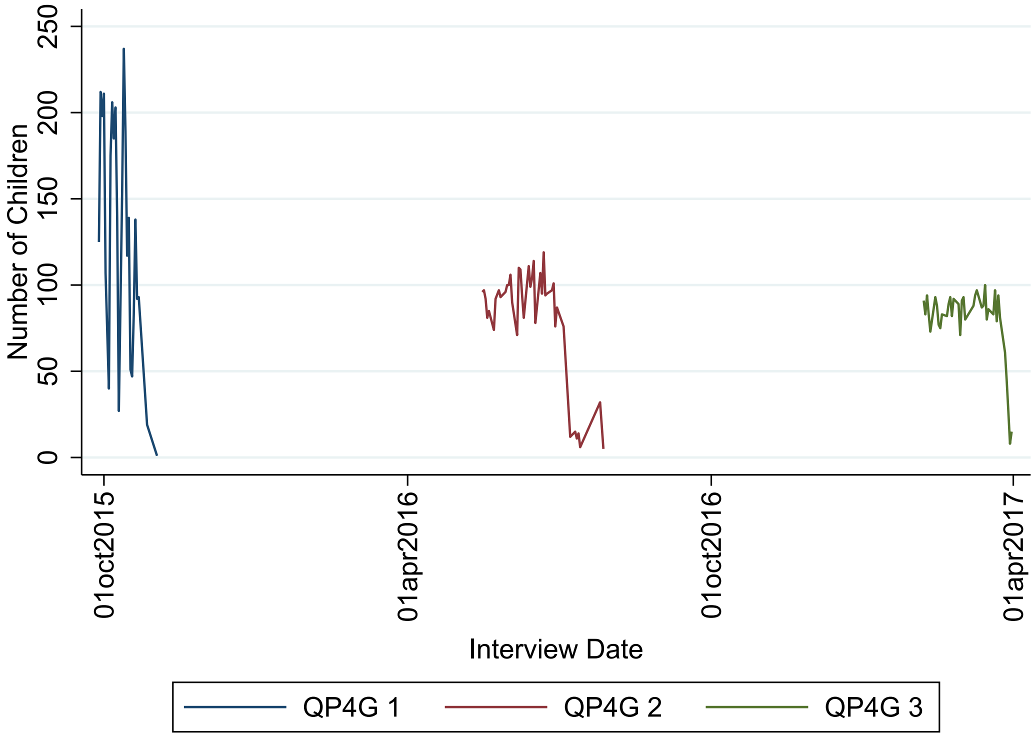
SCORING					
	Scoring categories	*Scoring options*			
Item No.	**Comprehension**	Correct (1)	Incorrect (0)	No response (-99)	Doesn't know (-88)
2401.	**"Who stole the cat's hat?"** (the mouse)	[ ]	[ ]	[ ]	[ ]
2402.	**"What is the color of the hat?"** (red)	[ ]	[ ]	[ ]	[ ]
2403.	**"Why did the cat chase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



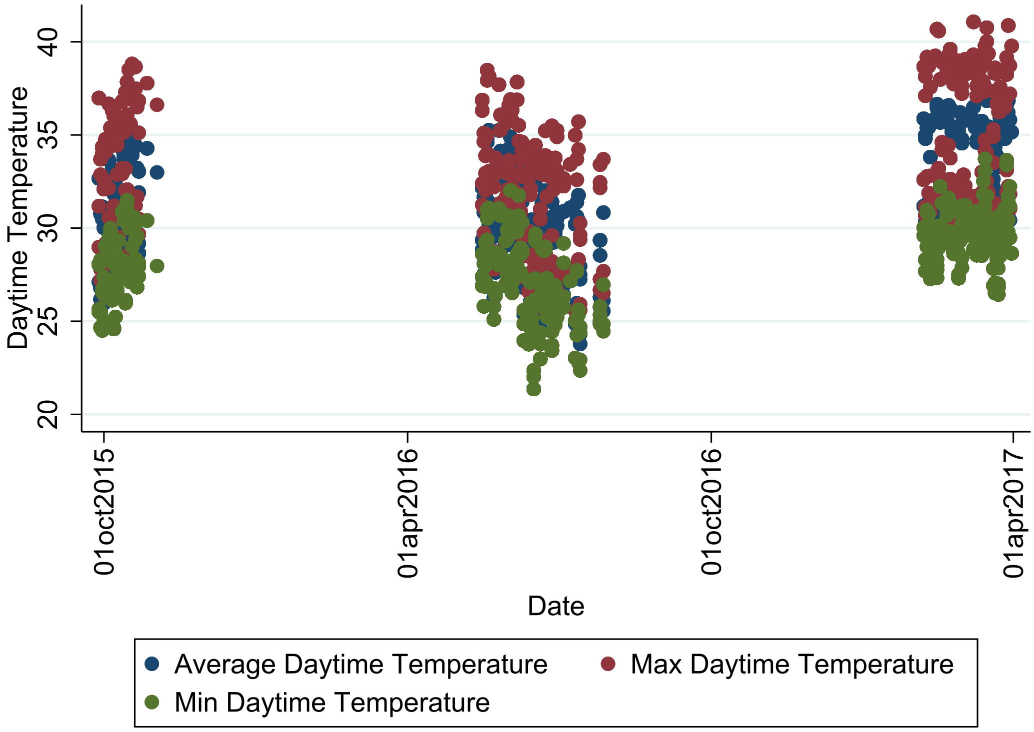
Note: The figure illustrates the dispersion of the schools using their longitude and latitude information.

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.