Exposure To Heat and Student Cognitive Functioning

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Abstract

The number of extremely high temperature days has grown over time. Developing countries have less capacity to protect against the harm of extreme heat. It is important to understand how extreme heat affects productivity. There is a growing literature on the effects of extreme heat on productivity but very little empirical evidence in Africa. We contribute to this literature by examining the effect of extreme heat on children's test performance in Ghana. Test performance reflects skill and effort. Heat may affect test performance through changes in brain chemistry and functioning which results in decrease in attention, memory, information retention and processing. Using rich longitudinal data on children, including their attentiveness and performance on math and literacy tests, I estimate child fixed-effects models to obtain the effect of temperature on day of test on cognitive functioning. Including child fixed effects enables me to control for time-invariant characteristics of the child such as raw ability or parental attributes, enabling me to isolate the effect of temperature on the day of test. The results using data from southern Ghana suggest that exposure to high $(27-29°\mathrm{C})$ and very high temperatures (30° C or greater), relative to moderate temperatures in the $24-26°$ C range significantly reduces attentiveness while weakly reducing listening and literacy scores. We find that the test performance of children from poor households is especially sensitive to exposure to extreme heat. That children are less attentive and score less under hot testing conditions has implications for how climate change will affect learning in classrooms.

JEL: Q54, I20, I21, I24, I25
Keywords: UTCI, Temperature, Student's Functioning, Student's Attentiveness

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1 Introduction

The number of extremely high temperature days continues to grow each year. Individuals living in developing countries are the greatest risk: poorer countries are hotter, and individuals have less capacity to protect themselves against the harm of extreme heat. This has dire implications for children's development and learning, where learning outcomes are already extremely low. Indeed, the learning poverty rate [1] is estimated at 86% for Sub-Saharan African countries before the global pandemic of 2020 and 89% after the pandemic (Azevedo et al. (2022)). There many reasons for this, including socio-economic background of the children, teacher motivation and perception of efforts, school management, and children's early learning environments as determinants or drivers of low learning outcomes.

Another potential driver is extreme heat. 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 productivity in the short run in developed countries (Graff Zivin, Hsiang, and Neidell (2018)). The setting of little to no adaptation strategies to extreme heat is also studied in countries such as Brazil, China and India (Graff Zivin et al. (2020), Garg, Jagnani, and Taraz (2020), Li and Patel (2021)). However, all those studies focus the most on adults and how loss of productivity from heat could affect their long-term outcomes. Not much is known about how heat affect children productivity in a developing countries, which matters for long run learning. 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. While the latter found that heat does decrease learning, Graff Zivin et al. (2020) found no long run effects. It could be the case because of post-strategies set up to counter the effect of heat on learning (Graff Zivin, Hsiang, and Neidell 2018). Those post strategies, however are costly and are not necessarily affordable to developing countries.

This paper makes three contributions. It first provides evidence on a non-high stakes exam settings. Indeed, From studies in developing countries, we know much more about how students perform under high stakes exams. High stakes exams might require additional efforts from the students, which implies that the results might be an under-estimation of how

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

heat affects the productivity of adults. In our context there is no stake and the assessments are not fundamentally relevant for the future of the interviewed child. Yet, the assessments are time consuming and cognitively demanding. It secondly contributes to the limited evidence of study on children's productivity and add a new setting which is the Sub-Saharan African context. As stated previously, there is evidence of children functioning in a developed country. However, Africa matters because in 2050, 40% of children in the world will live on the African continent and this is a continent deeply affected by a warming planet. But we don't understand the implications for young children yet. Also, most of the work in developing countries focus mostly on young during test, on agricultural productivity Emediegwu, Wossink, and Hall (2022) and on physical (labor) productivity LoPalo (2023). While the importance of knowing about workers and agricultural productivity is not disputable, the importance of children's productivity in learning is more subtle but also as important. In fact, if children's functioning is hindered by heat, then children are not learning on hot days. This could accumulate over time and generate the overall persistent low learning trend observed in Africa. Third, this paper add additional evidence using within individual variation. This is possible because of the longitudinal nature of the data on student tests in Ghana. We thus build on the previous literature to analyze how heat affects young children's performance on a battery of cognitive and non cognitive assessments in Ghana.

We link temperature 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, QP4G has a panel with 8 survey-round over 8 years. QP4G 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 (mostly ages 4 and 5), enrolled in grades pre-primary 1 or pre-primary 2 at baseline in 2015 and were followed until 2022. Outcomes on literacy and math were regularly measured, as well as socio-emotional outcomes. 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.

Each interviewer is trained to administer those tests and had to observe the students at-

tentively to make a report at the end about their attentiveness, their dedication to the different tasks, whether they were focused or distracted and many other characteristics. We construct an overall assessment score that is a summary of the assessor reports for each child. This overall score is useful as it allows to directly quantify the behavior of the child during the test. In fact, Ahmed et al. (2022) reports that assessor reports explain meaningful variation in child academic outcomes in Ghana.

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 and a day when it is relatively hot. to compare individuals within the same location. In many studies, children are compared within the same location, within a time period. There could be concerns that unobserved time-invariant characteristics children might create a bias. These characteristics could include child's ability at birth, family background, and other individual-specific attributes that remain constant over time. Including individual fixed effects helps avoid that bias. Our specification uses 3° C temperature bins and is a non linear specification to allow for a non linear relationship between children's productivity and temperature.

Using data from all three survey-rounds jointly, we find that a deviation from the reference temperature bin (24°C and 26°C) decreases the attentiveness of children. Specifically, attentiveness decreases by respectively 0.14 and 0.1 standard deviation as it gets hotter (i.e. 27°C and 329°C; 30°C and 32°C). On the other side, the relatively cold bin (i.e. 21°C and 24°C) decreases score, but the estimate is not precise. It is argued that climate related change are exacerbating the inequality between children from relatively wealthy families and children of relatively poor families. We additionally conduct an heterogeneity analysis by socio-economic background. We find that wealthy and poor children perform worse under high temperature. More importantly, we find that, compare to the reference temperature bin, for the first hot bin, poor children perform significantly worse than their wealthy counterpart. Furthermore, for the last hot bin, the difference between wealthy and poor children disappears, suggesting that at hotter temperature the adaptation capacities that wealthy children benefit from when it starts getting hotter vanished at really high temperature.

The rest of this paper is organized as follows. Section 2 describes data and construction of key measures. Section 3 presents summary statistics. Section 4 describes the estimation strategy. Section 5 presents and interprets the main results. Section 6 concludes.

2 Data

To estimate the effects of exposure to heat on children functioning, we take advantage of a longitudinal data spanning eight (08) years in Ghana following a study called "Quality for Pre-school for Ghana" (hence, QP4G). 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 particularly use the Universal Thermal Climate Index (hence, UTCI) to represent temperature.

2.1 QP4G Data

The data on children's outcomes and characteristics is from the QP4G intervention by Wolf et al. (2019). The intervention aims at improving classroom quality and develop Ghanaian children's school readiness. The intervention was done in the Greater Accra region, in the southern part of Ghana, in 6 districts, namely Adentan, Ga Central, Ga East, Ga South, La-Nkwantanang-Madina, and Ledzokuku-Krowor. The intervention is school-based and included children aged 2 to 10 years old in the first year. The children were followed for 8 years, from 2015 to 2022. Figure B.1 shows the dispersion of different schools in our sample. The geographic dispersion is not large. At baseline, 3435 children were included in the study. There is attrition overtime of about 9% from the first survey year.

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

To assess or measure children readiness, the International Development and Early Learning Assessment (IDELA) was used for the first three survey rounds. IDELA is a set of items, where each item test a different skill which could be cognitive or non cognitive. For example, the children reading comprehension and vocabulary skills were tested, as well as their ability

to add, subtract, multiply and divide. Non cognitive tests include personal awareness. One specificity about the dataset is that there are surveyors' assessments of the student attentiveness related to some items or exercises (e.g,: listening comprehension exercise), as well as an overall assessment related to the whole test.

2.2 Merging UTCI Data and QP4G Data

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

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

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

3 Sample and Summary Statistics

3.1 Sample

We use the first three survey rounds of QP4G spanning the years 2015 to 2017. There are 3435 students in 2015, 3500 in 2016 and 3126 students recorded in 2017. From 2015 to 2016, 367 students leave the study and were replaced by 432 students on the initial wait list of selected students. From 2015 to 2017, there was an attrition rate of about 9%. Table 2 shows that the average child age is 5.8 years for all 3 survey-rounds, but 5.2 years old for the first survey-round. The distribution of age is quite large, but concentrated around 3-6 years of age at the first survey-round. In fact, 87% of the children are aged 3-6 years old. Figure B.4 shows the proportion of children in each district. Specifically, Ga South and Ledzokuku-Krowor have about 45%. Other disticts have from 13 to 17% of children.

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

3.2 UTCI Measure

In Section 2.2, we highlighted that the the UTCI combines air temperature, humidity, wind speed, and radiant heat and is a measure of the perceived temperature. The human body experience heat stress starting from a UTCI of 26°C. There could be acclimatization for individuals living in a tropical area, meaning that, the human body could adapt and function relatively well, even under hotter temperatures. The human body in these areas could tolerate up to 3.5°C more than their counterpart in colder countries. The link between acclimatization and heat stress is not documented to the best of my knowledge, but believed threshold of heat stress could be different in the tropical countries such as Ghana.

In our analysis, we define 3°C temperature bins. The 3°C temperature bins guarantee enough observations in each temperature bins. The commonly use bin size in the literature is 2°C. Using temperature bins allows for a non-linear relationship between UTCI and performance measures. Table 1 shows that while most children are exposed to a daily temperatures between 24°C and 29°C during the first and second survey-round, children are exposed to

daily temperatures greater than 27°C during the third survey-round.

Indeed, the second survey-round happened during colder days in average compared to the first and third survey rounds [2]. In the first survey-round, children were interviewed in September, October and November[3]. The third survey-round took place in February and March. Figure 1 the variation of temperature by survey-round. The figure gives an idea of the distribution of temperature within the same survey-round.

Few children are exposed to average daily temperatures below 23°C. Average daily temperature below 23°C are a deviation from the usual cold weather in Accra, Ghana [4]. Given that the human body experiences heat stress at 26°C and above, we define the "comfortable" temperature bin to be between 24°C and 26°C (included) and the effects of temperature will be relative to that temperature bin.

Figure 2 had six panels and each panel represent a district. Overall the figure shows the temperature distribution by survey-round for each one of the district. At first glance the distribution of temperature is quite large across all districts and within each survey-round. Ga Central, Ga South and Ledzokuku-Krowor experience the coldest UTCI.The figure confirms that the survey-round 3 is the hottest, and it is the case in all district.

3.3 Outcomes

To assess student functioning, we use test scores. Firstly, we use the listening comprehension score, the number-sense (one-to-one correspondence) test score, and the surveyor's assessment of the student attentiveness associated with them. Secondly, we construct a math and literacy test score based on all questions related to math and literacy. Lastly, we construct the surveyor's assessment of child attentiveness based on overall assessment questions.

Listening Comprehension & Surveyor Assessment. The listening comprehension test assess the student's listening skills. A listening test requires to be focused and attentive and therefore is a good proxy to understanding children's functioning at the moment of the test. We measure the listening comprehension score as the percentage of correct answers provided by each individual. Graff Zivin, Hsiang, and Neidell (2018) uses reading comprehension and reading

2. Two thirds of the second survey-round happened during the coldest months of the year in Accra (June and July). The other third happened during the month of May which is hotter than June and July.

3. Only one child was interviewed in November

4. This link shows historical temperature variation (both air temperature and perceived temperature) in Accra, Ghana, from 2010 to 2020. Daily temperature variation is found by zooming into the graph and shows that temperatures below 24°C are colder than usual, even for the coldest months.

cognition tests as a measure of children's functioning. The reading comprehension exercise is a similar exercise to the listening comprehension exercise in our setting. For this first measure, missing answers were accounted for as non correct answers. Table 2 shows that the overall average listening score is 56%. The average is higher for the first survey-round and monotonically increases from the first survey-round to the last one.

Attentiveness to Listening. The surveyors were asked about the students attentiveness towards the listening test. The measure "Attentiveness to Listening" is obtained by computing the average of three dummy variables. Specifically, the surveyors were asked whether the child was motivated, concentrated and diligent towards the task. Table 2 shows that overall 88% of the children were reported to be attentive during the listening test. Similarly to the listening comprehension score, there is a monotonic increase in attentiveness to the listening exercise from the first survey round to the last one.

Literacy. The literacy score is the proportion of correct answers to all the literacy questions asked to the children. Table 2 shows that the average literacy score among children is 53% and is lower for children in the first survey-round and higher in the last survey-round. Indeed, the average literacy score in the first survey-round is 40% while it is 64% in the last one.

Number Sense (One-to-one Correspondence) & Surveyor Assessment. Number Sense (One-to-one Correspondence) Score. The Number sense test is a basis to all later math concepts. The number sense score is computed as the proportion of correct answers. The average number sense score is 94% according to Table 2. The score is increasing monotonically from a survey-round to the other.

Attentiveness to Number Sense. Similarly to the measure of attentiveness to listening, the attentiveness to number sense is also the average over three variables measuring whether children were attentive. Table 2 shows that overall 94% of the children were reported attentive to the number sense exercise. The average increases monotonically from the first survey-round to the last.

Math. The math score is the proportion of correct answers to all the math questions asked to the children. Table 2 shows that the average math score among all children from all survey-round is 50%. The score is higher for later waves.

Surveyor's Overall Assessment of the Child Attentiveness. According to Ahmed et al. (2022), executive functions behaviors are complementary to executive function skills which allow a

child to regulate himself. Executive function behaviors include staying engaged, switching easily from a task to the other by staying concentrated. Ahmed et al. (2022) provide evidence that executive function skills and behaviors are informative on how children perform in cognitive tasks. IDELA measures executive function behavior by having assessors observe and rate the children on a set of seven questions. The rating is on the scale of 1-4 where 1 represents a bad performance while 4 represents the best performance. We construct the overall Surveyors' assessment of child attentiveness (1-4) by taking the average over those seven questions. Table 2 shows that children were attentive or behaving during the survey. There is little to no difference across waves.

Overall Surveyors' assessment of Attentiveness (0-1). Following the first overall measure of attentiveness, we construct a dummy version of the same outcome. To do so, we transform the original questions from a scale of 1-4 to a scale of 0-1 and we compute the average of those new dummy variables. Table 2 shows that children were attentive during the whole survey or test.

3.4 Other variables

Poverty Measure. We construct a dummy for poor using the house construction materials of the family of each child. While there is a lot of ways to construct a variable for poverty or wealth such as mother's education, income or a combination of assets, the construction materials allows for a clear cut where families who build their house with mud bricks are separated from families who build their house with cement. Table 2 shows that about 18% of the children have a poor socio-economic background.

4 Estimation Strategy

To estimate the effects of heat stress shock on child functioning on the day of the test, we mainly exploit two types of variations. The first one is a within survey-round variation in temperature. Indeed, in each survey-round individuals are assigned a daily average temperature. Also, children are usually interviewed over a course of 2 months and some days. This implies that within a survey-round children are likely exposed to different temperature. The second variation that we exploit is an across time variation (or a within child variation). Because of the longitudinal nature of our data, we observe the same individual multiple times, and while

some individual might always be exposed to the same temperature bin throughout the three survey-rounds, some individuals will switch from a hotter temperature to a colder temperature or vice versa. Intuitively, the within child variation (or across time variation will compare the same individual taking the test at different point in time, one when the individual is exposed to hotter temperature and one when the individual is not. This methodology is used in Graff Zivin, Hsiang, and Neidell (2018) and Park et al. (2020) only to the best of my knowledge. Other papers including Garg, Jagnani, and Taraz (2020), Graff Zivin et al. (2020), Li and Patel (2021), Park (2022) use a different identification where they compare the individuals within the same location. We discussed why this might be an issue and how being able to observe the same individual at multiple periods helps resolve those iissues.

Following the subsection 3.2 we define the omitted temperature bin as $24-26°C$. The specification used is:

$$y_{i,r(t)} = \sum_{c=1}^{4} \beta_c \mathbf{1}_{T_{L(i),t} \in [l_c, u_c]} + \delta_i + \delta_{r(t)} + \delta_a + \epsilon_{i,r(t)}, \tag{4.1}$$

where $[l_{\{c=1\}}, u_{\{c=1\}}] = [21°C, 23°C]$ is the first temperature bin. The omitted temperature bin in our analysis is $[l_{\{c=2\}}, u_{\{c=2\}}] = [24°C, 26°C]$. i represents a child, t represents a year and $r(t)$ stands for survey-round which embed the concept of time as a year and the concept of seasonality.Indeed, each survey round denotes a different seasons of the year. L represents location which is a cell of $2.5° \times 2.5°$. $y_{i,r(t)}$ is the outcome of child i interviewed in survey round $r(t)$. The error term $\epsilon_{i,r(t)}$ is clustered at the individual level.

The child FE, δ_i , in our specification solves omitted variable bias problems. It specifically allows to control for individual background characteristics such as innate skills or intrinsic ability, tolerance to stress, family wealth and parental support. We control for other yearly invariant characteristics, $\delta_{r(t)}$, such as seasonal variations, education policies, or the timing of the academic year [5]. We control for age, δ_a, because in our dataset, children are aged 2-11 years old, which is a wide range of age and each age implies different cognitive maturity as well as different adaptation to heat stress for example. There could be a correlation between age and heat if children take the test during a hot period when they are old and during a cold period when they are young and vice versa. We do not need to control for humidity because

5. 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.

as discussed previously, the UTCI measures embeds humidity. The third source of variation is the spatial variation. Temperature is assigned at the cell level and individual are distributed across 6 cells in our dataset.

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

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

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

5 Temperature and Children Functioning

In this section we discuss the results from our estimation equation on the various outcomes we have defined early. We explore different temperature measure. Particularly, following the literature, we construct the daily average temperature by calculating the average between the minimum and the maximum. Also, we explore the maximum temperature, and the daytime average temperature. All those different temperature measures are relative to different identification. Suzuki (2024) explains the different implications when it comes to using different temperature measures. Results are similar across all the different temperature measures. Here in this section, we will discuss the results related to the daily average temperature over the 24 hours.

5.1 Temperature and Literacy Skills

The first three columns of Table 3 show the results from a regression of the three literacy variables over temperature without child FE, using the whole sample, including the singletons. The next three columns, that is columns 4, 5, and 6 show the results of the previous regression, with the sample that contains children interviewed at least two times during the three survey-rounds. The last three columns, that is, columns 7, 8 and 9 show the results from the estimation of Eq. (4.2). The three outcome variables are the listening comprehension score, the attentiveness to listening exercise, and the literacy score.

We notice that any deviation from the reference temperature bin 24°C - 26°C worsen the listening score of children but the estimates are not precise. This is consistent with the result

in Graff Zivin, Hsiang, and Neidell (2018). Similarly to the listening score, a deviation from the comfortable bin worsen the attentiveness of children. Specifically, taking the test when the temperature is between 27°C - 30°C decreases the score by 0.08 standard deviation. Here the cold bin decreases the score of children by also about 0.08 standard deviation. The effect of temperature on the listening score has an inverted U-shape but the effect of temperature on children attentiveness as well as on the literacy score follows an increasing linear pattern whereas the coldest bin affects children the most and the hottest bin affects children the least.

5.2 Temperature and Math Skills

The first three columns of Table 4 show the results from a regression of the three math variables over temperature without child FE, using the whole sample, including the singletons. The next three columns, that is columns 4, 5, and 6 show the results of the previous regression, with the sample that contains children interviewed at least two times during the three survey-rounds. The last three columns, that is, columns 7, 8 and 9 show the results from the estimation of Eq. (4.2). The three outcome variables are the number sense score, the attentiveness to number sense exercise, and the math score.

The effects of temperature on the number sense score follows an inverted U-shape with the coldest bin decreasing significantly the number sense score by 0.11 standard deviation. Similarly to the number sense score, the coldest bin decreases children attentiveness related to the number sense exercise by about 0.16 standard deviation. The colder bin Here the cold bin decreases the score of children by also about 0.08 standard deviation. The effect of temperature on the number score also has an inverted U-shape but the effect of temperature on children attentiveness as well as on the math score follows an increasing pattern.

5.3 Temperature and Children's Attentiveness

The first two columns of Table 5 show the results from a regression of the two surveyor's measure of the child attentiveness variables over temperature without child FE, using the whole sample, including the singletons. The next two columns, that is columns 3 and 4 show the results of the previous regression, with the sample that contains children interviewed at least two times during the three survey-rounds. The last two columns, that is, columns 5 and 6 show the results from the estimation of Eq. (4.2). The two outcome variables are the two versions of the overall attentiveness of the children, where the first one is scaled from 1-4, while the

second one is scaled 0-1.

Overall, a deviation from the comfortable bin decreases the attentiveness of children. When considering the attentiveness score on a scale of 1-4, the effects is U-shaped and shows that attention decreases by respectively 0.14 and 0.1 standard deviation as it gets hotter. On the other side, the cold bin decrease score, but the estimate is not precise. When considering the dummy version of children's attentiveness, we notice that the point estimate is the same for all temperature bin and represent a significant decrease of 0.13 standard deviation of attentiveness.

5.4 Heterogeneous Temperature Effects on Children's Attentiveness Across SES Background

The first two columns of Table 6 show the heterogeneity analysis results by socio-economic status background of children using the two surveyor's measure of the child attentiveness variables over temperature without child FE, using the whole sample, including the singletons. The next two columns, that is columns 3 and 4 show the results of the previous regression, with the sample that contains children interviewed at least two times during the three survey-rounds. The last two columns, that is, columns 5 and 6 show the results from the estimation of Eq. (4.2). The two outcome variables are the two versions of the overall attentiveness of the children, where the first one is scaled from 1-4, while the second one is scaled 0-1.

The results indicate that even though all children do not perform well when the temperature is not comfortable, poorer children perform worse. The score gap between both group disappears at really high temperature. This might implies that any adaptation capacity developed by richer kids over hotter temperature, might not work at really high temperature, here $> 30°C$

6 Conclusion

The number of extremely high temperature days has grown over time and developing countries suffer the most from it because they have less capacity to protect themselves against the harm of extreme heat. On one side, countries that are the hottest are also the poorest. On the other side, poor countries experience a learning crisis whereas by age 10, over half of the population in middle- and low-income countries cannot read or count. The literature cites socio-economic background, teacher motivation and perception of efforts, school management, and also children's non readiness to school as determinants or drivers of low learning outcomes.

One potential driver is heat. Hot temperatures is proven to decrease children's productivity in the short run in developed countries. The setting of little to no adaptation strategies to extreme heat is also studied in countries such as China and India.

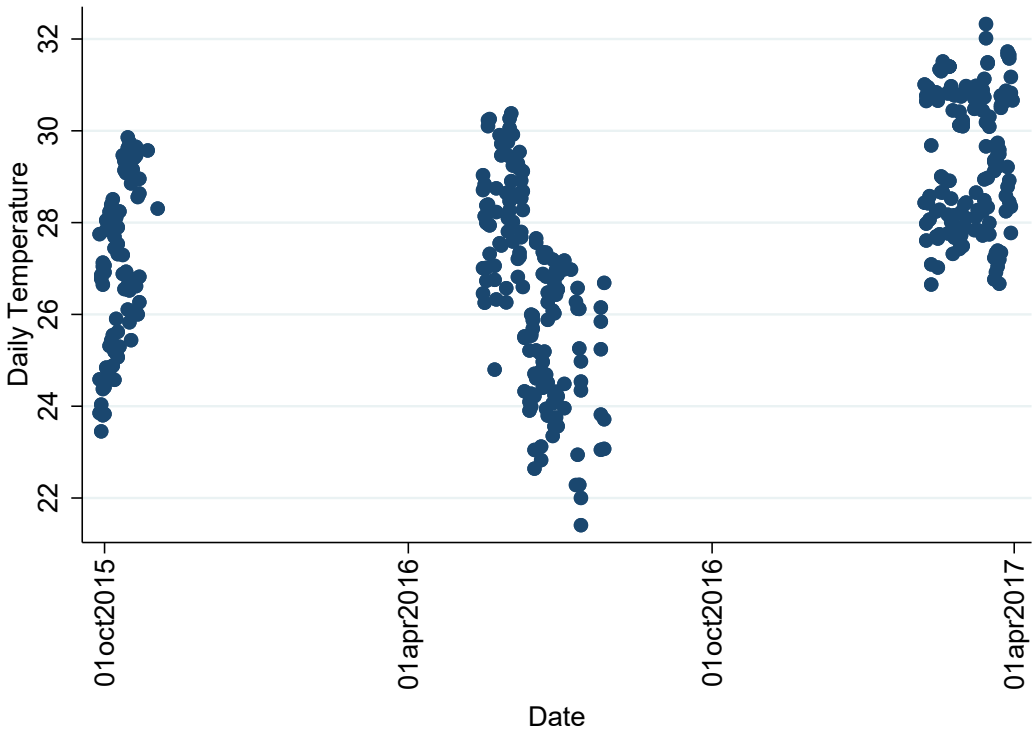
However, all those studies focus the most on adults and how loss of productivity from heat could affect their long-term outcomes in the context of high stakes exams. Not much is known about how heat affect children productivity in a developing countries. In this paper, we examine productivity in a cognitive activity using children's test performance and surveyor's assessment of students attentiveness in Ghana. The dataset is a longitudinal data on children. We link temperature 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, QP4G has a panel with 8 waves over 8 years. QP4G is a school based intervention aiming at improving children's school readiness in the Greater Accra region in Ghana. Children were 3-6 (in reality 2-10 years old), enrolled in pre-kindergarten at baseline in 2015 and were followed until 2022. Outcomes on literacy and math were regularly measured, as well as socio-emotional outcomes. 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). Each interviewer is trained to administer those tests and had to observe the students attentively in order to make a report at the end about their attentiveness, their dedication to the different tasks, whether they were focused or distracted and many other characteristics.

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.

Using data from all three survey-rounds jointly, on one side, preliminary findings show that, relative to the the estimates of literacy and math score, though negative, are not precise estimates. On the other side, attentiveness to the listening exercise is affected by hot temperature. Children's attentiveness to math exercise is affected by the cold bin relatively to the "comfortable" temperature bin (24°C and 26°C). When considering the attentiveness score on a scale of 1-4, the effects is U-shaped and shows that attention decreases by respectively 0.14 and 0.1 standard deviation as it gets hotter.

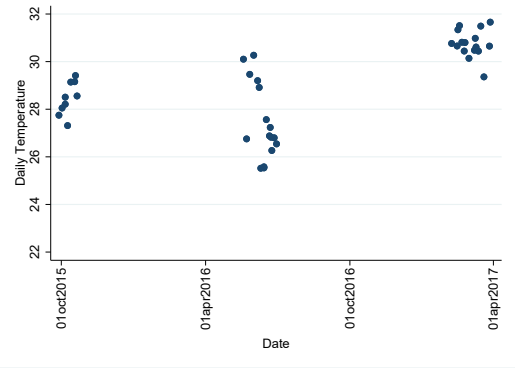
Tables and Figures

Fig. 1. Temperature Variation by Wave

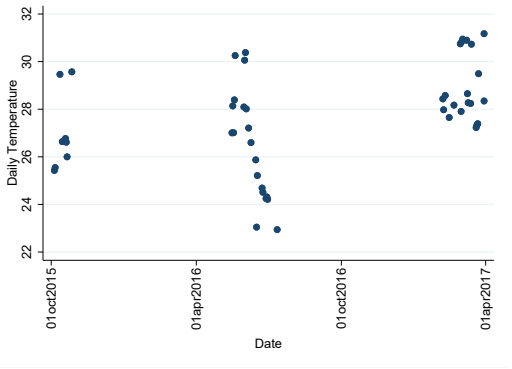


Note: The figure illustrates the temperature variation for each survey-round. The figure shows that the third survey-round is in average hotter than the first two survey-rounds. Temperature here stands for UTCI which is a proxy of the perceived temperature by the body.

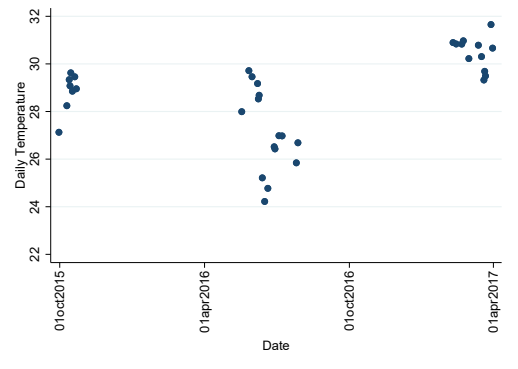
Fig. 2. Temperature Distribution by Districts



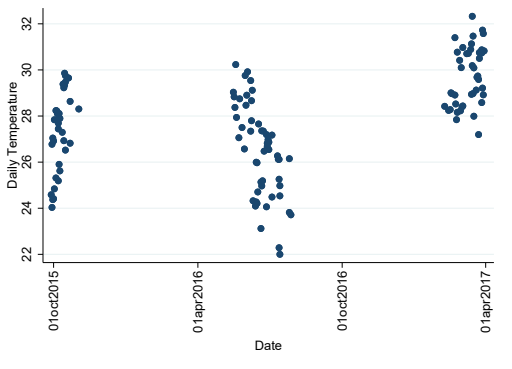
(a) Average temperature in the district Adentan by survey-round.



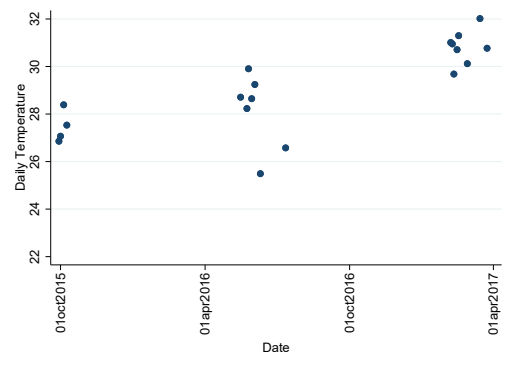
(b) Average temperature in the district Ga Central by survey-round.



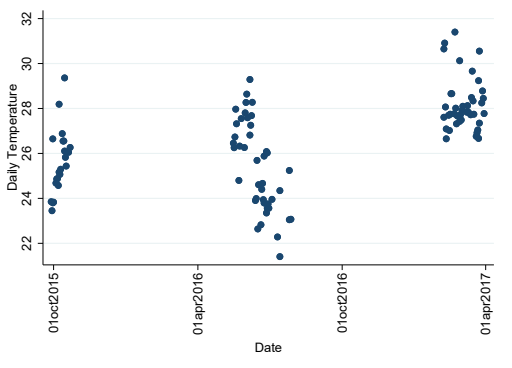
(c) Average temperature in the district Ga East by survey-round.



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



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



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

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

Table 1: Summary Statistics: Temperature

	Proportion	SD	N
Wave 1			
Temperature $< 24°C$	0.04	0.20	3,188
$24°C \leqslant$ Temp $< 27°C$	0.41	0.49	3,188
$27°C \leqslant$ Temp $< 30°C$	0.55	0.50	3,188
Temperature $\geqslant 30°C$	0.00	0.00	3,188
Wave 2			
Temperature $< 24°C$	0.09	0.29	3,312
$24°C \leqslant$ Temp $< 27°C$	0.43	0.50	3,312
$27°C \leqslant$ Temp $< 30°C$	0.42	0.49	3,312
Temperature $\geqslant 30°C$	0.06	0.24	3,312
Wave 3			
Temperature $< 24°C$	0.00	0.00	3,012
$24°C \leqslant$ Temp $< 27°C$	0.03	0.16	3,012
$27°C \leqslant$ Temp $< 30°C$	0.45	0.50	3,012
Temperature $\geqslant 30°C$	0.52	0.50	3,012
Total			
Temperature $< 24°C$	0.05	0.21	9,512
$24°C \leqslant$ Temp $< 27°C$	0.30	0.46	9,512
$27°C \leqslant$ Temp $< 30°C$	0.47	0.50	9,512
Temperature $\geqslant 30°C$	0.19	0.39	9,512

Note: Summary statistics of the average daily temperature variable by wave/year. The mean column is showing the share of children exposed to the corresponding temperature bin. Calculations are made by authors using UTCI data.

Table 2: QP4G Overview and Key Statistics

	Mean	SD	Min	Max	N
Listening Score (0-1)	0.56	0.33	0.00	1.00	9512
Attentiveness to Listening (0-1)	0.88	0.27	0.00	1.00	9512
Literacy Score (0-1)	0.53	0.24	0.00	1.00	9512
Number Sense (One-to-one Correspondence) Score (0-1)	0.71	0.37	0.00	1.00	9512
Attentiveness to Number Sense (0-1)	0.94	0.19	0.00	1.00	9512
Math Score (0-1)	0.50	0.22	0.00	0.99	9512
Overall Surveyor's Assessment Score (1-4)	3.20	0.70	1.00	4.00	9473
Overall Surveyor Assessment Score (Dummy)	0.78	0.32	0.00	1.00	9473
Poor (Dummy)	0.18	0.38	0.00	1.00	7693

Note: This table shows summary statistics of the combined survey rounds sample on key outcomes variables. Calculations are made by authors using the three first waves of QP4G data.

Table 3: Literacy and Temperature

	(1)	(2)	(3)
Omitted bin: 24-26.999	Listening Score	Attentiveness to Listening	Literacy Score
Temperature $< 24°C$	-0.0227	-0.0315	-0.0170*
	(0.0213)	(0.0193)	(0.00926)
$27°C \leqslant$ Temp $< 30°C$	-0.000503	-0.0207**	0.00392
	(0.00898)	(0.00933)	(0.00434)
Temperature $\geqslant 30°C$	-0.0160	-0.0149	-2.93e-05
	(0.0154)	(0.0144)	(0.00722)
Observations	7,940	7,940	7,940
Child FE	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes
Age FE	Yes	Yes	Yes

Robust standard errors clustered at individual level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes: Table shows regression results corresponding to equation 4.2. Specifically, the table is displaying three (03) outcomes, the listening comprehension score, how attentive the child was to the listening comprehension exercise, and the overall literacy score that pulls together all literacy related questions. Attentiveness to listening is constructed using the persistence and engagement rubric that comes right after the oral comprehension exercise. The surveyor or the interviewer is asked as a yes or no question on whether the child is concentrated, whether the child is diligent and whether the child is motivated. The variable Attentiveness to listening is the average of the three questions. All calculations are made by authors using the combined UTCI and QP4G data.

Table 4: Numeracy and Temperature.

Omitted bin: 24-26.999	(1) Number Sense (One-to-one Correspondence) Score	(2) Attentiveness to Number Sense	(3) Math Score
Temperature $< 24°C$	-0.0408**	-0.0253*	-0.0107
	(0.0188)	(0.0141)	(0.00710)
$27°C \leqslant$ Temp $< 30°C$	0.00166	-0.000972	-0.00197
	(0.00885)	(0.00665)	(0.00301)
Temperature $\geqslant 30°C$	-0.00791	0.00140	9.26e-05
	(0.0146)	(0.0104)	(0.00502)
Observations	7,940	7,940	7,940
Child FE	Yes	Yes	Yes
Survey Round FE	Yes	Yes	Yes
Age FE	Yes	Yes	Yes

Robust standard errors clustered at individual level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: Table shows regression results corresponding to equation 4.2. Specifically, the table is displaying three (03) outcomes, the number sense (one-to-one correspondence) score, how attentive the child was to the number sense exercise, and the overall math score that pulls together all math related questions. Attentiveness to the number sense (one-to-one correspondence) is constructed using the persistence and engagement rubric that comes right after the the number sense (one-to-one correspondence) exercise. The surveyor or the interviewer is asked as a yes or no question on whether the child is concentrated, whether the child is diligent and whether the child is motivated. The variable Attentiveness to listening is the average of the three questions. All calculations are made by authors using the combined UTCI and QP4G data.

Table 5: Overall Surveyor's Assessment of Child Attentiveness and Temperature

Omitted bin: 24-26.999	(1) Overall Surveyor's Assessment Score (1-4)	(2) Overall Surveyor Assessment Score (Dummy)
Temperature $< 24°C$	-0.0176	-0.0418*
	(0.0417)	(0.0213)
$27°C \leqslant$ Temp $< 30°C$	-0.0968***	-0.0390***
	(0.0217)	(0.0104)
Temperature $\geqslant 30°C$	-0.0716**	-0.0370**
	(0.0351)	(0.0168)
Observations	7,900	7,900
Child FE	Yes	Yes
Survey Round FE	Yes	Yes
Age FE	Yes	Yes

Robust standard errors clustered at individual level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes: Table shows regression results corresponding to equation 4.2. Specifically, the table is displaying two (02) outcomes, the overall surveyor's assessment score on two different scale: a scale of 1-4 and a scale of 0-1. At the end of each interview, the surveyor is asked seven (07) questions to assess how attentive the child was during the whole interview. Thus the surveyor is asked: (1) Did the child pay attention to the instructions and demonstrations throughout the assessment? (2) Did child show confidence when completing activities; did not show hesitation? (3) Did the child stay concentrated and on task during the activities and was not easily distracted? (4) Was child careful and diligent on tasks? Was child interested in accuracy? (5) Did child show pleasure in accomplishing specific tasks? (6) Was child motivated to complete tasks? Did not give up quickly and did not want to stop the task? (7) Was the child interested and curious about the tasks throughout the assessment? Those assessments questions are originally 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 score which also have the same scale takes the average of all the seven (07) questions. The dummy version of the overall score is constructed by taking the average of the dummy version of each one of the seven questions. The dummy version of each one of the seven questions takes the value 1 and 2 (of the original question) as 0 and the 3 and 4 (of the original question) as 1. All calculations are made by authors using the combined UTCI and QP4G data.

Table 6: Heterogeneity of Children's Attentiveness by Socio-Economic Background.

Omitted bin: 24-26.999	(1) Overall Surveyor's Attentiveness Assessment (1-4)	(2) Overall Surveyor's Attentiveness Assessment (0-1)
Temperature $< 24°C$	-0.0167	-0.0418*
	(0.0467)	(0.0237)
$27°C \leqslant$ Temp $< 30°C$	-0.0857***	-0.0346***
	(0.0242)	(0.0114)
Temperature $\geqslant 30°C$	-0.0869**	-0.0473***
	(0.0381)	(0.0182)
Temperature $< 24°C \times$ Poor	0.000873	-0.0171
	(0.132)	(0.0717)
$27°C \leqslant$ Temp $< 30°C \times$ Poor	-0.0904*	-0.0398
	(0.0525)	(0.0267)
Temperature $\geqslant 30°C \times$ Poor	0.0157	0.0117
	(0.0603)	(0.0283)
Observations	7,139	7,139
Child FE	Yes	Yes
Survey Round FE	Yes	Yes
Age FE	Yes	Yes

Robust standard errors clustered at individual level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes: Table shows heterogeneity analysis by interaction the temperature bins with a dummy variable for poor household. The "Poor" variable is constructed using a question about the construction material of the house where the child and his parents live. The variable has two options: 1- Mud bricks/earth, wood, bamboo, metal sheet/slate/asbestos, palm leaves/thatch (grass/raffia etc.); 2- Cement/concrete blocks, landcrete, stone, or burnt bricks

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APPENDIX

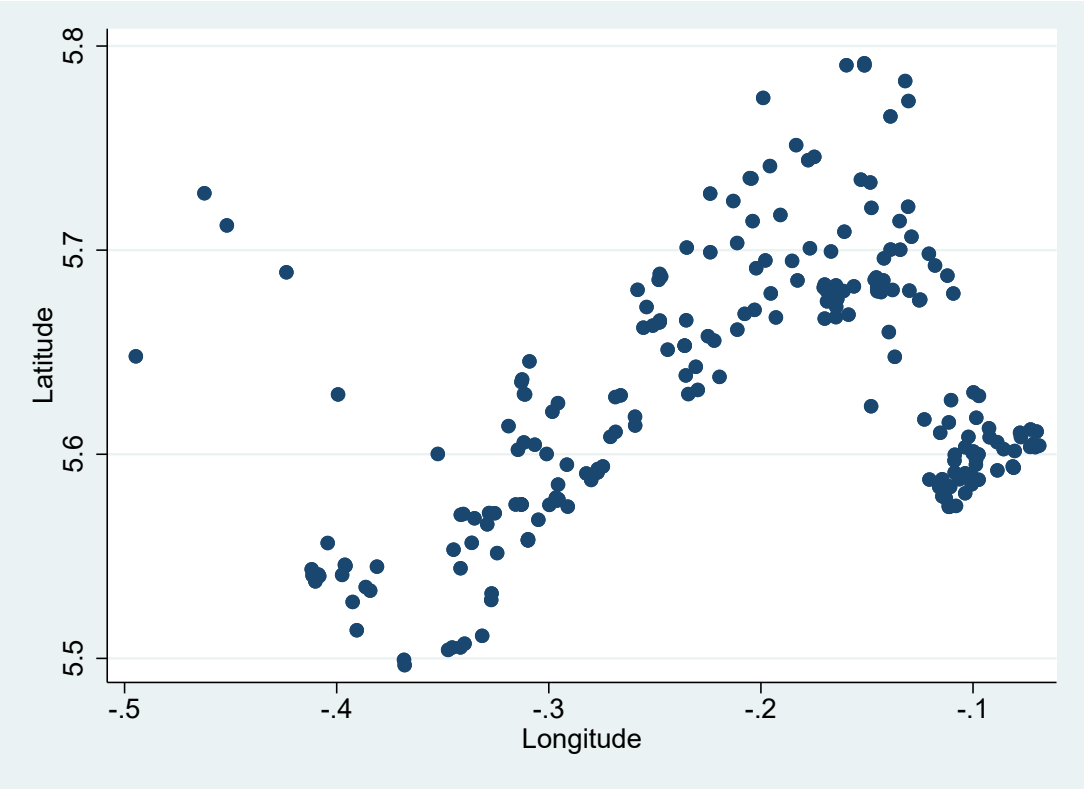
Exposure To Heat and Student Cognitive Functioning

Yabo Gwladys Vidogbena and Sharon Wolf

A Additional Estimation Results

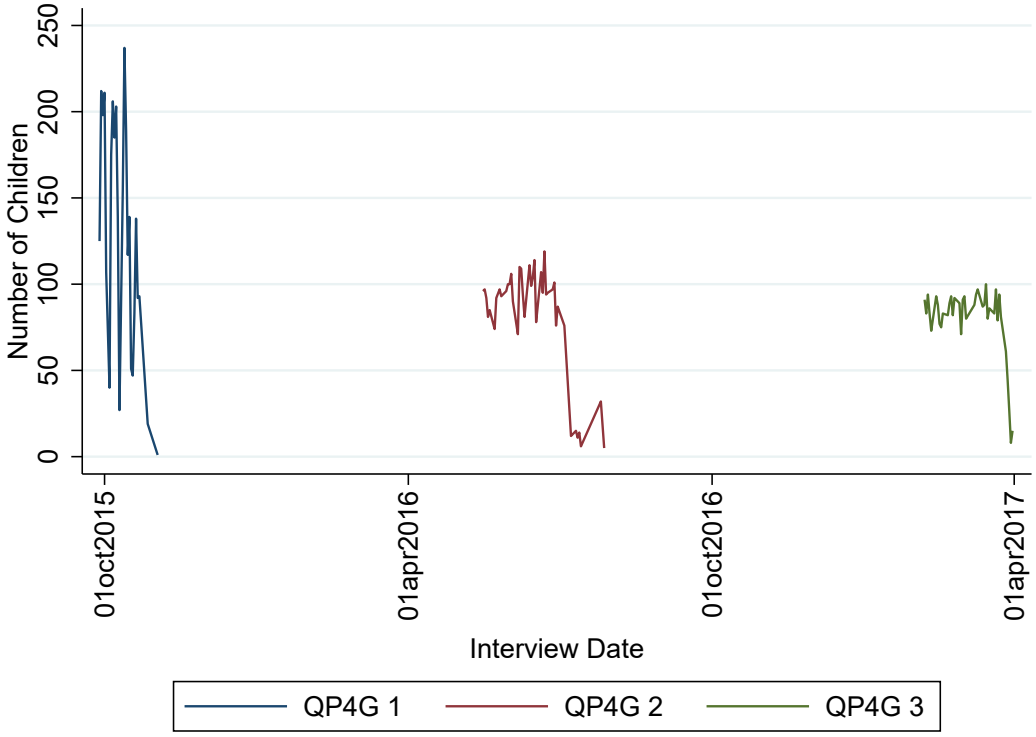
B Appendix Figures and Table

Fig. B.1. Number of Students Interviewed per Day



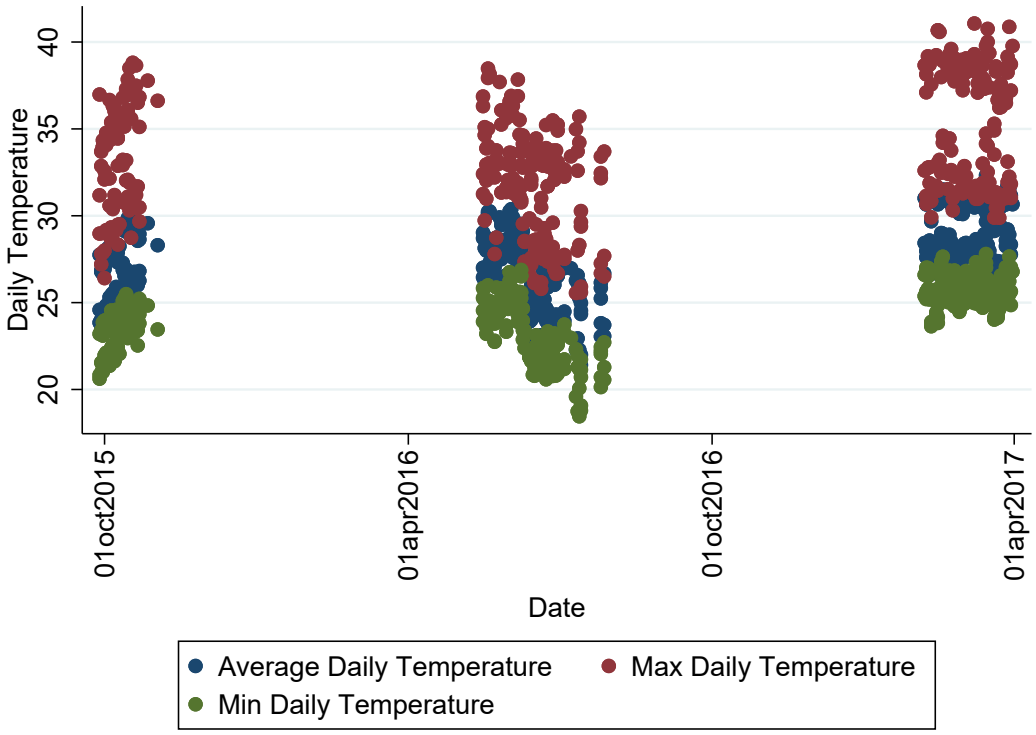
Note: The figure illustrates the dispersion of the schools using their longitude and latitude information.

Fig. B.2. Number of Students Interviewed per Day



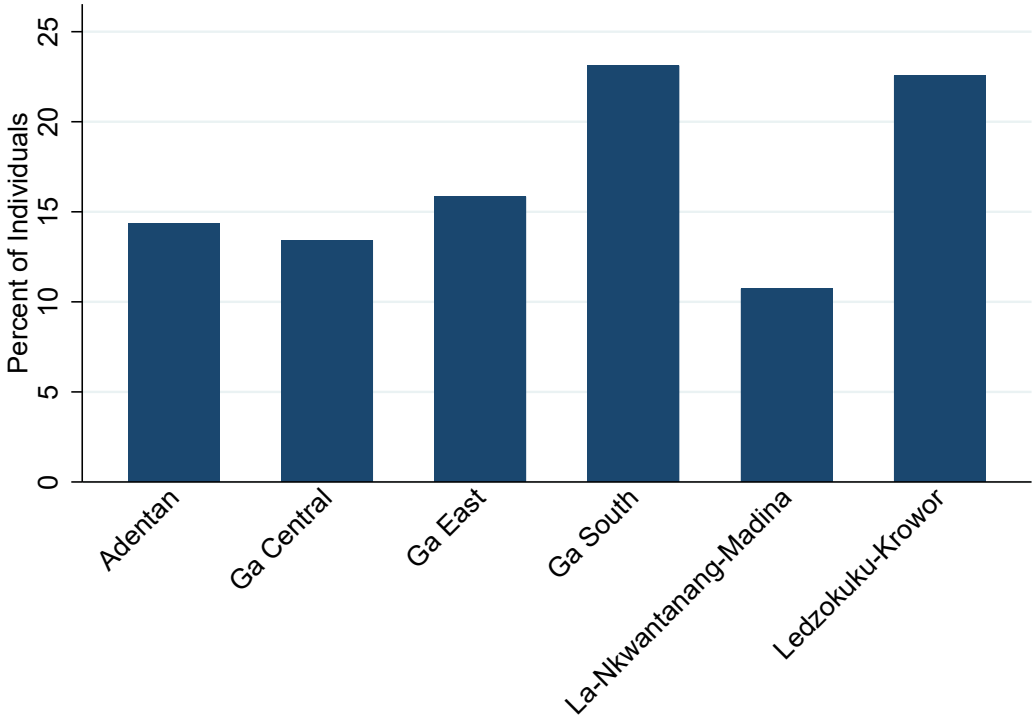
Note: The figure illustrates the daily variation in the number of interviews conducted during the three first survey-rounds.

Fig. B.3. Temperature Variation by Wave



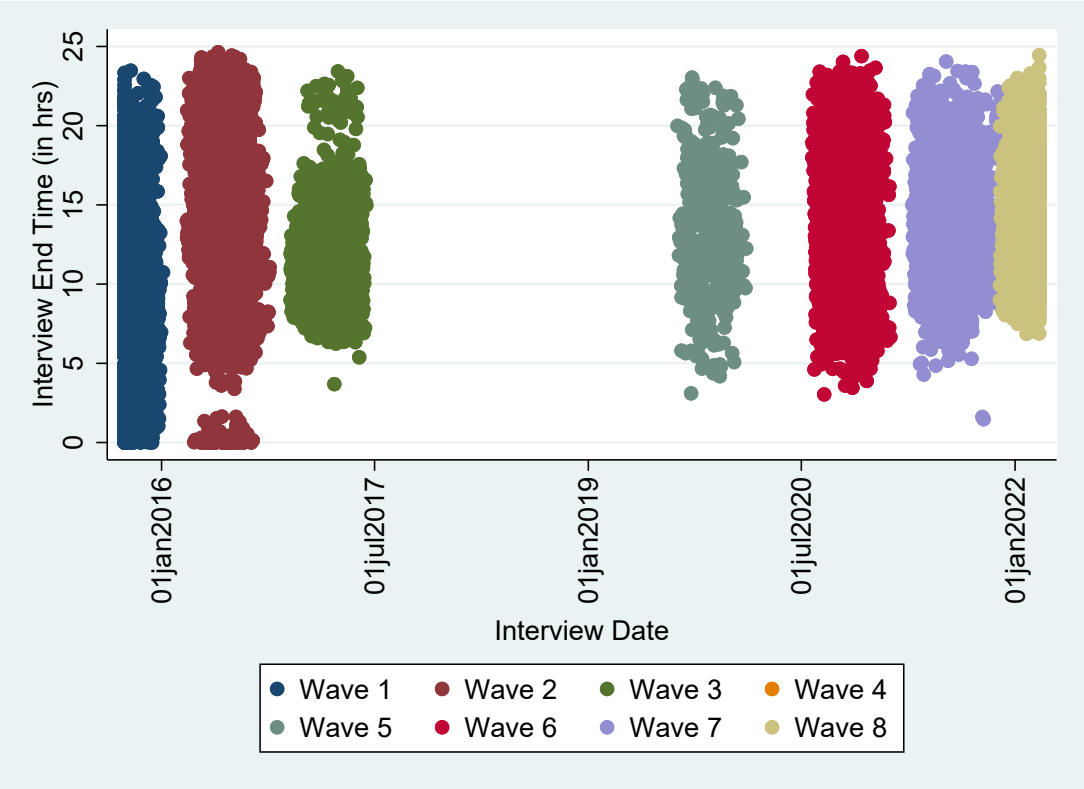
Note: The figure illustrates the temperature variation for each survey-round. The figure shows that the third survey-round is in average hotter than the first two survey-rounds. Temperature here stands for UTCI which is a proxy of the perceived temperature by the body.

Fig. B.4. 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. B.5. Number of Students Interviewed per Day



Note: The figure illustrates the hourly variation of interviews for all survey-rounds.