Temperature and Schooling: How Heat Shapes Primary Learning in West and Central Africa

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Abstract

While existing evidence suggests that heat negatively affects learning across diverse global settings, its impact in Africa is under-studied—largely due to the limited availability of nationally representative, comparable micro-data on learning. This paper addresses this gap by combining georeferenced temperature data with standardized reading and math scores from eight West and Central African countries in the Programme on the Analysis of Education Systems. The researchers find that exposure to high temperatures significantly reduces learning outcomes for students at the beginning and end of primary school, with effect sizes that are large relative to findings from other world regions. Additional analyses suggest that heat may indirectly affect learning by shifting students' time away from schooling and toward labor. While they observe little variation in the overall effect of heat by socioeconomic status (SES) or gender, the researchers find that extreme heat (above 33° C) has a disproportionately negative impact on higher-SES students. They interpret this as evidence of an erosion of compensatory advantage—wherein wealthier students who are typically buffered against adversity may be more impacted to learning disruptions under extreme heat.

1 Introduction

In the last three decades, the educational landscape in Sub-Saharan Africa (SSA) has been characterized by major policy changes—most notably removal of primary-school fees. Initiated by country-governments with support and funding of international efforts such as the UN's Education for All Initiative (1990), Millennium Development Goals (2000-2015), Global Education First Initiative (2012), and Sustainable Development Goals (2015-present), these policy changes led to dramatic expansion and equalization of primary-school access among diverse strata of society and significantly reduced gender, wealth, and rural-urban gaps in primary-school attendance (Lewin and Sabates 2011). However, the expansion in access to primary schooling corresponded with learning challenges. There are an estimated 52 million children in primary school in Sub-Saharan Africa who lack basic skills (UNESCO 2014) and there are vast socioeconomic inequalities in learning outcomes (Gruijters and Behrman 2020).

Changes in the educational landscape of SSA have occurred in the context of increasing severity and frequency of extreme weather events (Collier, Conway, and Venables 2008). Specifically, there has been an increase in extreme heat events. For example, between late March and early April 2024 the Sahel region of West Africa experienced a record-breaking five-day heat wave characterized by temperatures reaching 45° C (119° F) (Barnes et al. 2024). Today it is expected that events of this severity would occur about once every 200 years, and under future warming scenarios it could become a once-in-20-year event (ibid). Given that high temperatures have been shown to negatively impact learning in other parts of the world (Park et al. 2020; Park 2022; Park, Behrer, and Goodman 2021; Prentice et al. 2024), there is reason to suggest that temperature extremes may have important implications for Sub-Saharan learning outcomes, as suggested in a recent study on Ethiopia (Srivastava, Hirfrfot, and Behrer 2024). If anything, the high levels of reliance on agriculture for basic livelihoods, the weaker educational infrastructure, and the low levels of climate adaptation mean that many Sub-Saharan countries will be particularly vulnerable to climatic shocks (Emediegwu, Wossink, and Hall 2022).

So far, it has been challenging to empirically explore the effects of heat on learning in SSA due to a lack of high-quality learning data. This paper addresses this gap by combining georeferenced temperature data with standardized student learning data from the Programme on the Analysis of Education Systems (PASEC) in 8 West and Central African countries. The

first aim of our study is to estimate the effect of heat on learning in eight West and Central African countries. In doing so, we not only provide an important comparison to other parts of the world where there has been a documented link between heat and learning (Park, Behrer, and Goodman 2021), but also, and most importantly, we focus our analysis on countries that have experienced both an increase in the severity and frequency of extreme heat (Barnes et al. 2024; World Bank 2018) and a widespread crisis in primary-school learning (UNESCO 2014). We also investigate two mechanisms through which heat may affect learning. Guided by economic models of household behavior, we examine whether heat increases student labor participation, potentially diverting time and energy away from school. We also explore whether heat contributes to in-school hunger, which may directly impair learning by exacerbating cognitive overload, as suggested by cognitive load theory. Finally, drawing on compensatory advantage theory, we explore whether the effects of heat on learning vary by socioeconomic background or gender—probing whether more privileged students are buffered from the effects of heat, or whether extreme heat erodes this advantage.

2   Background

2.1   Heat and Learning: Existing Evidence

There is an increasingly robust evidence base on whether heat affects learning around the world; yet, to date, there has been insufficient consideration of the effects of heat on learning in Sub-Saharan Africa. At present, the most globally comprehensive study on heat and learning uses standardized learning data from 58 countries throughout Asia, Europe, the Americas, the Middle East and Australia, drawing on the Programme for International Student Assessment (PISA) between 2000 and 2015 (Park, Behrer, and Goodman 2021). Park and colleagues show that the negative effects of heat on learning are significantly larger in low-income countries compared to high-income countries, presumably due to differences in heat preparation, such as air conditioning. Several other studies focused on high- and middle-income countries in Asia, Europe, and the Americas also document the negative effects of heat on learning (Cho 2017; Garg, Jagnani, and Taraz 2020; Graff Zivin, Hsiang, and Neidell 2018; Park et al. 2020; Prentice et al. 2024; Graff Zivin et al. 2020; Porras-Salazar et al. 2018; Roach and Whitney 2022; Wang et al. 2018; Wargocki, Porras-Salazar, and Contreras-Espinoza 2019). An exception is found in Brazil, where temperature has negligible impacts on college entrance exams (Li and

Patel 2021).

To the best of our knowledge, there is only one study focused on Sub-Saharan Africa and, more precisely, on Ethiopia (Srivastava, Hirfrfot, and Behrer 2024). This study reveals that exposure to hot days corresponds to a decrease in performance on university entrance exams in Ethiopia. These effects are particularly strong in the cooler parts of the country, likely due to the lower adaptation to heat in these areas. This study makes an important contribution to the scholarship on temperature and learning by extending the focus to an African setting. However, by focusing on a university population, this study examines a selected group of people who have already overcome significant educational barriers to reach the end of high school. Existing work suggests that climatic shocks experienced at earlier ages have particularly deleterious impacts on later learning (Nubler et al. 2021; Park, Behrer, and Goodman 2021). Younger primary school-aged children may therefore be more susceptible to environmental stressors experienced during critical stages of cognitive and educational development than their older counterparts.

The limited exploration of the effects of heat on learning in Africa is partly due to the absence of learning measures collected in commonly used data sources. Historically, very few African countries have participated in the PISA, which is widely used for international learning assessments. Many of the main sources of data in SSA, such as the Demographic and Health Surveys and the Living Standards Measurement Study, collect information on school attendance but lack measures of student learning. Existing studies on temperature and schooling in SSA therefore mostly focus on school attendance (Pule et al. 2021; Randell and Gray 2016, 2019). These studies have found heterogeneous results. For example, pooled data from West and Central Africa show no significant link between higher than average temperatures in early childhood and schooling attainment (Randell and Gray 2019), but mild temperatures are associated with increased educational completion in Ethiopia (Randell and Gray 2016). Related work on other types of climatic shocks documents the negative effects of other types of rainfall shocks and droughts on various measures of learning in South and Southeastern Africa (Björkman-Nyqvist 2013; Nordstrom and Cotton 2020; Nubler et al. 2021), albeit with heterogeneity by gender (Björkman-Nyqvist 2013) and the age at which the shock was experienced (Nubler et al. 2021).

2.2 Heat and Learning: Theories and Mechanisms

Educational outcomes have long been understood as the product of both individual cognitive capacities and the broader social and economic environments in which children live. Classical sociological and educational theories emphasize that academic performance is shaped by an interplay of cognitive processes, household resources, and social norms (Coleman et al. 1966; Bourdieu and Passeron 1990; Downey and Condron 2016). More recently, scholars have expanded this focus by examining how external environmental stressors—such as fluctuations in ambient temperature—might disrupt learning (Park, Behrer, and Goodman 2021). Two broad explanations have emerged. The first explanation emphasizes direct effects: extreme heat disrupts students' physical ability to concentrate, retain information, and perform on assessments. The second explanation focuses on indirect effects: heat may alter household routines, leading to increased student absenteeism or shifts in labor responsibility (Conte Keivabu 2024). In what follows we expand on these two explanations by providing further details on the theoretical frameworks that support them.

The primary theoretical perspective behind the hypothesis that heat has a direct effect on learning is cognitive load theory (CLT). CLT posits that cognitive performance is constrained by the limited capacity of working memory and attention (Sweller 1994). CLT distinguishes between intrinsic cognitive load (task complexity), germane cognitive load (effort devoted to learning), and extraneous cognitive load, which arises from external stressors that interfere with cognition. Environmental conditions, including temperature, may contribute to extraneous cognitive load by increasing physiological strain (Ioannou et al. 2021). High ambient temperatures trigger discomfort, dehydration, and fatigue, all of which reduce cognitive resources available for learning and decision-making (Hancock and Vasmatzidis 2003; Wittbrodt and Millard-Stafford 2018). In the contexts we study in West and Central Africa the direct effects of heat on learning may be particularly exacerbated due to inadequate cooling infrastructure: about half the population of West and Central Africa does not have access to electricity (World Bank 2024) and many school facilities lack basic climate controls that require electricity. Furthermore, temperature shocks that lead to crop failure and corresponding hunger and lack of dietary diversity might exacerbate heat-related cognitive overload (Taras 2005).

Scholars have adopted several strategies to test whether cognitive load theory plays a

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role in explaining the negative effects of heat on learning. One approach has been to explore whether high temperatures impact learning on school – as opposed to vacation – days. For example, Park and colleagues find that high temperatures experienced during school days, but not vacation days, have a negative effect on student learning in 58 OECD countries (Park, Behrer, and Goodman 2021). A similar finding was observed in the U.S. where hotter school days – but not vacation or weekend days – impacted standardized test scores (Park et al. 2020). These findings suggest that the negative effects of temperature on learning are driven by school-based experiences such as cognitive overload, and not broader changes in environment that might have occurred during non-school days. Another approach used in the literature to help understand whether cognitive load theory plays a role in explaining the negative effects of heat on learning has been to exploit variation in access to cooling systems within schools. For example, an experiment in Costa Rica that randomly varied classroom temperature over a two-week period showed that students performed better on language and logical thinking tasks when classroom temperatures are maintained at neutral levels compared to when they are warm (Porras-Salazar et al. 2018).

In contrast to the focus on direct effects, another body of scholarship highlights the indirect effects that temperature can have on learning. This perspective typically takes economic models of household behavior as its orienting framework. Economic models of household behavior argue that families adjust the allocation of time and labor in response to changing economic and environmental circumstances (Becker 1965). Under normal conditions, households may prioritize educational activities; however, when faced with external stressors that increase the opportunity cost of schooling, families may reassign children's time and energy toward tasks that ensure immediate survival or economic stability (Skoufias and Parker 2002). When extreme heat disrupts daily routines, households may be forced to reallocate children's time to non-academic responsibilities. These responsibilities can include domestic chores or participation in economic activities that can lead to absenteeism among students—absenteeism that has long-term detrimental effects on learning (Cattan et al. 2023). Especially when heat shocks threaten agricultural incomes, families may cope by pulling children out of school and increasing child labor to diversify their sources of livelihood (Björkman-Nyqvist 2013; Garg, Jagnani, and Taraz 2020). Students may also avoid schools during critically hot days if they have long commutes. While commuting data is hard to come by for the countries in our study, available evidence from Ghana in West Africa shows that 90 percent of primary school children

commute on foot with average commutes of about 20 minutes daily (Afoakwah and Koomson 2021).

2.3 Socioeconomic and Gender Variation in the Impact of Heat on Learning

Given the significant disparity in learning outcomes across different socioeconomic groups in West and Central Africa (Gruijters and Behrman 2020), it is highly likely that the effects of heat on learning will vary depending on socioeconomic background. For example, Park and colleagues show that the negative effects of heat on learning observed in 58 OECD countries are significantly larger for lower-income populations (Park, Behrer, and Goodman 2021). Compensatory advantage theory helps explain why heat may differentially affect learning across SES. This theory posits that individuals with greater socioeconomic resources typically have access to buffers (e.g. better learning environments, tutoring, or technological aids) that protect them from adverse shocks (Bernardi 2014). Research in educational sociology shows that higher SES families can 'compensate' for exposure to adverse shocks by providing additional academic support or moving their children to different schools (Bernardi 2014; Torche 2018). In doing so, these high SES families effectively mitigate the adverse impacts of shocks on their children's schooling. Climate research from the US supports this view, indicating that the adverse effects of heat on learning are more pronounced among students in lower-income school districts where compensatory resources are limited (Park, Behrer, and Goodman 2021).

Research on socioeconomic variation in the impact of high temperatures on school attendance in West and Central Africa, however, challenges the expectations of compensatory advantage theory. Randell and Gray (2019) find that higher than average temperatures in early childhood lead to larger reductions in years of schooling among children from higher-SES households compared to lower-SES households. This counterintuitive finding may be explained by a phenomenon that we refer to as the erosion of compensatory advantage. This perspective suggests that higher-SES children experience a greater relative learning loss during periods of extreme heat because they normally benefit from better educational environments that facilitate higher academic performance under stable conditions. When heat shocks disrupt learning, higher-SES pupils may have more to lose compared to their lower-SES peers, whose baseline educational attainment is already constrained by chronic disadvantages such as poor school infrastructure, lower-quality instruction, and limited access to academic resources (Gruijters and Behrman 2020). In addition, extreme heat may impose new labor de-

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mands on high-SES households which can erode learning opportunities. In times of economic stress, students from high-SES backgrounds who would otherwise be focused on school activities may be required to contribute to household economic activities—whether through formal employment, managing family businesses, or assisting with domestic labor. This reallocation of time away from schooling toward labor is particularly relevant in agricultural economies, where wealthier families may own larger farms or businesses that demand additional labor during periods of climate stress. In contrast, lower-SES students who are often already engaged in labor-intensive activities may see less change in their schooling patterns.

The effect of heat on learning might also differ by gender due to gender differences in the reallocation of time and energy toward non-academic responsibilities during periods of heat. In sub-Saharan African countries, gender norms dictate differential household roles for boys and girls (Webbink, Smits, and Jong 2012). Girls are often expected to take on additional domestic responsibilities, such as caregiving, cooking, and water collection, which may reduce their time for studying or attending school. Heat can exacerbate these patterns, as water shortages and food insecurity—both of which are common consequences of prolonged heat waves—may increase household demands for female labor. When economic or environmental shocks occur, families may favor boys' (over girls') primary educational attainment and achievements. For example, rainfall shocks disproportionately decrease girls' (relative to boys) schooling outcomes in Kenya and Uganda (Björkman-Nyqvist 2013; Nubler et al. 2021). On the other hand, boys may be pulled away from school to engage in income-generating activities to support their families. For example, a study from Ethiopia shows that the negative impact of heat on university entrance exam performance was larger for boys compared to girls (Srivastava, Hirfrfot, and Behrer 2024). Experimental evidence has also shown that heat has differential effects on cognitive performance by gender: at higher temperatures, women perform better on math and verbal tasks, while men experience a decline in performance (Chang and Kajackaite 2019).

3   Data and Variables

We combine data from two sources: (1) micro-data on schooling and learning from PASEC 2014 and 2019; and (2) gridded publicly available temperature data from the ERA5 archive. In what follows we describe each of these data sources in more detail.

3.1 Data Sources and Sample

First, the micro-data on schooling and learning, PASEC, are standardized learning assessments collected by the Conference of Ministers of Education of Francophone Countries (CONFE-MEN) and are nationally representative of students in primary schools. In each country that participates in PASEC, approximately 150-250 schools are randomly chosen from an official database of all registered public, private, and community schools. Within each selected school, students from one second-grade class and one sixth-grade class are randomly selected. These students complete a standardized reading and math test and provide basic information about themselves and their families; the test occurs in April at the end of the academic year. We focus on eight West and Central African countries that participated in both rounds of PASEC data collection in 2014 and 2019: Benin, Burkina Faso, Burundi, Congo, Niger, Senegal, Tchad, and Togo. Our final sample includes 80,267 students (Table 1).

The ERA5 gridded temperature data are retrieved from the European Centre for Medium-Term Weather Forecasting (Hersbach et al. 2023). These data contain hourly data on temperature for the whole globe on a grid of parallels and meridians at a 0.25×0.25-degree resolution (approximately 31 km at the equator). Using data on temperature for every hour of all days between 1 September 2013 and 31 March 2014 and 1 September 2018 and 31 March 2019, we calculate a daily average temperature for each stratum (i.e. the smallest geographic unit in PASEC, see Figure 1 for details on stratum size) in our sample by averaging the hourly temperature data for each day within each stratum.

To create our final dataset, we match each student in the PASEC dataset with temperature data for the current academic year based on their stratum of residence. Since the PASEC exam is administered in April, we define the academic year as starting on September 1st of 2013 or 2018 (depending on the survey wave) and ending on March 31st of 2014 or 2019 (depending on the survey wave).

3.1.1 Outcome Measures

The main outcomes of interest are test scores in math and reading. In addition, we include two variables—labor and hunger—to explore mechanisms identified in the literature through which high temperatures may impact test scores.

Learning. PASEC collects math and reading test scores across countries (similar to the PISA). These test scores, which are standardized to have a mean of 500 and a standard deviation of 100 across all pupils, are our main measure of learning. We analyze math and reading scores separately as prior research has found that temperature tends to have a greater impact on math performance than on reading (Park et al. 2020).

Labor. We measure labor with a binary indicator for whether the student reports that they frequently engage in non domestic work outside of school (farming, commerce, or physical labor). This variable is only available for students in grade 6.

Hunger. We measure hunger with a binary variable for whether the student reports being frequently hungry in school. This variable is only available for students in grade 6.

3.1.2 Measures of Heat Exposure and Control Variables

Heat. We construct a stratum-level measure of temperature which counts the number of days in a given academic year that fall into six temperature bins: less than 21°C, 21°–24°C, 24°–27°C, 27°–30°C, 30°–33°C, greater than 33°C. This approach to measuring temperature, which allows us to account for non-linearity in the relationship between temperature and learning, is substantively similar to that reported in Park et al.'s international comparative study of the effects of temperature on learning in 58 OECD countries (Park, Behrer, and Goodman 2021). However, it differs from Park et al. in three respects. Firstly, Park et al. focus on temperature over a longer time-frame (i.e three years prior to the exam) whereas we focus on a more narrow time-frame (i.e. the 9 months prior to the exam). This change allows us to more precisely estimate how temperature experienced during the current academic year impacts end-of-year test scores. Secondly, Park et al. use different temperature bins that are cooler than our categories (less than 15°, 16-20°, 21-26°, 27° and greater). While their analysis covers a broad range of countries with varying climatic conditions (including hot and cold climates), our analysis focuses on a smaller set of countries characterized by warmer climates. We therefore adjusted the temperature bins to better reflect the specific environmental conditions of our setting. Thirdly, Park et al. utilize maximum daily temperature whereas we rely on mean daily temperature calculated by averaging all hourly recordings which offers a more accurate measure of daily temperature exposure.

Precipitation and humidity. To account for other climatic conditions, we control for continuous measures of average precipitation and humidity in the stratum of residence during the current academic year. These variables, calculated in the same way as the temperature variables, come from the ERA5 archive.

Student demographic characteristics. We control for a binary measure of student gender and a continuous measure of student age. Student's age varies from 4 to 27 years old, with grade 2 students being younger (mean of 8) than grade 6 students (mean of 13).

Socioeconomic status. We measure socioeconomic status in two ways. We first construct a composite measure of household wealth using principal component analysis on household assets reported by the students (Gruijters and Behrman 2020)[1] . Since information on household assets is only collected for students in grade six, for students in grade two, we create a measure of whether the respondent never speaks French at home, which we use as a proxy of low socioeconomic status (the reference category is speaking French at home sometimes, often or always). Supplementary analyses of students in grade 6 suggest that never speaking French at home is strongly negatively correlated with the composite measure of household wealth, thus giving us confidence that this is an adequate proxy.

4 Empirical Strategy

We estimate the effect of heat on learning using a two-way fixed effects approach that includes fixed effects for stratum and year. Temperature is measured in the seven-month period from September 1 to March 31 for a given stratum-year. We thus exploit variation in temperature within the same stratum over two periods of time (i.e. 2014 and 2019) to identify the effect of temperature on learning. Intuitively, our empirical strategy compares the learning outcomes of two cohorts of students from the same stratum, where one cohort was exposed to higher temperatures due to plausibly exogenous variation in weather across years. Specifically, we estimate the following equation:

$$y_{isy} = \sum_{k=1}^{K} \beta_k \, \text{Temperature}_{k,sy} + \sigma \, X_{isy} + \alpha_s + \theta_y + u_{isy}, \tag{4.1}$$

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1. The list of assets used to construct the household assets is as follows: TV, computer, radio, DVD player, hi-fi system, cellphone, fridge, fan, AC, stove, table, sewing machine, electric iron, car or truck, tractor, bicycle, latrines, materials of walls of the house, and electricity

where y is the reading or math test score of student i living in stratum s and surveyed in year y, and Temperature$_{k,sy}$ is the number of days in each of the six temperature bins during the seven months leading up to the April exam in stratum s and year y[2]. The coefficients of interest, β_k, measure the effect of one additional day of exposure to temperature bin k on test scores. All models control for a vector of variables X, including precipitation, humidity, student demographic characteristics, and socioeconomic status. We also include stratum α and year θ fixed effects. We use country weights to ensure that our results are representative of the students living in the eight countries[3]. Also, we cluster standard errors at the stratum level in line with previous work (Park, Behrer, and Goodman 2021). Because prior research suggests that the effects of temperature on learning vary by age (Nubler et al. 2021; Park, Behrer, and Goodman 2021), we conduct the analyses separately for students in grades 2 and 6.

In additional analyses, we investigate potential mechanisms through which heat affects learning. First, we examine the effects of heat on labor using the same empirical strategy as above. This analysis investigates the potential indirect effects of heat on learning outcomes, informed by economic models of household behavior which suggest that families may reallocate students' time toward labor in response to environmental shocks. We also examine the effects of heat on self-reported hunger in school as an additional channel through which heat may impair learning. This is relevant in light of cognitive load theory which suggests that physiological stressors such as hunger and dehydration can exacerbate extraneous cognitive load, thereby impairing cognitive functioning. In contexts where heat shocks lead to crop failure and food insecurity, these effects may be particularly pronounced. While these analyses offer insight into both indirect and direct pathways, our data do not permit a more comprehensive examination of additional mechanisms, such as absenteeism or in-school behavior. Prior research shows that heat experienced on school days negatively affects learning, whereas heat on vacation days does not (Park, Behrer, and Goodman 2021), suggesting that school-based experiences mediate these effects. However, were unable to conduct a similar schools-versus-vacation analysis due to substantial measurement error in reported vacation days across the countries in our study.

Last, we explore whether the effects of heat on learning are heterogeneous by socioeco-

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2. The total number of days adds up to 212 days.

3. The country weights are calculated as the ratio of the number of students in each country for a given year and grade to the number of students in our sample for the same year and grade. The number of pupils in each country enrolled in primary education and in the final grade of primary education for 2013 and 2018 was taken from the World Bank Data Bank on Education Statistics - All Indicators, sourced from the UNESCO Institute for Statistics.

nomic background or gender. To this end, we interact our treatment measures of temperature with variables for socioeconomic status and gender, as described in Equation 2. These analyses examine whether high SES buffers the effects of heat on learning (i.e., a compensatory advantage) or has the opposite impact (i.e., erosion of compensatory advantage). They also investigate whether heat exacerbates gender-based disparities in learning.

$$y_{isy} = \sum_{k=1}^{K} \Big(\beta_k + \gamma_k \, SES_i\Big) \, Temperature_{k,sy} + \sigma \, X_{isy} + \alpha_s + \theta_y + u_{isy}. \qquad (4.2)$$

5   Results

5.1   Descriptive Overview of Climatic Conditions in Our Study

Figure 1 shows the average temperature for all the available strata in the eight West and Central African countries during the timeframe of our study. Most strata in our dataset have high average temperatures ranging between 25°C and 28°C. Table 1 shows that students in our sample experience extreme temperatures (for summary statistics by grade see Table A.1). On average, students in our sample experience 4 days above 33°C, 24 days between 30°C and 33°C, 80 days between 27°C and 30°C, and 60 days between 24°C and 27°C in the academic school years that we study (Table 1). There is, nonetheless, important variation by country (Table A.2). For example, Burkina Faso, Niger, and Tchad all have an average of 4 to 9 days in the academic year above 33°C, whereas Burundi and Congo have no days in this range. Burundi has an equatorial climate with high mean yearly temperatures, but low climatic variations (Figure 1), with an average of 134 days during the school year below 21°C, 77 days between 21°C and 24°C and no days above 27°C (Table A.2). There is also considerable country-level variation in relative humidity and precipitation as well: Benin, Burundi, and Congo have particularly high humidity, whereas Burkina Faso, Niger, Senegal, and Tchad, have particularly low precipitation (Table A.2).

5.2   The Effect of Heat on Learning

We explore the effect of academic-year temperature on primary school students' test scores at the end of the school year. Figures 2 visualizes the effects of temperature on reading and math scores for students in grade 2 (top panel) and grade 6 (bottom panel), respectively, including

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95% confidence intervals (see Table 2 for estimates and standard errors). The patterns observed in these data closely mirror what is observed in previous research (Park, Behrer, and Goodman 2021): cooler temperatures (that is, less than 21°C) lead to higher reading and math scores, and hotter temperatures (that is, greater than 24°C) lead to lower reading and math scores. This general pattern holds for both students in grades 2 and 6, albeit with some differences in statistical significance. On one hand, the magnitude of the temperature coefficients are larger in most cases for students in Grade 2 compared to Grade 6 at high temperatures (i.e. over 24°C). On the other hand, there are age-based differences in the effects of cooler weather on test scores in our data. Among 6 Graders, each additional day during the academic year below 21°C (compared to 21°–24°C) is associated with more than a one-point higher math and reading scores. The magnitudes of the same coefficients are about half the size for Grade 2 students and are not statistically significant.

The findings also show a clear temperature-learning gradient. Specifically, high temperatures have large negative effects on learning. For example, each additional day during the academic year between 30° and 33°C (compared to the reference of 21°–24°C) is associated with more than three-point lower reading and math scores among grade 2 students and 1.5-1.8 point lower reading and math scores among grade 6 students. These are remarkably large coefficients if we take into account the high numbers of hot days experienced by students in our sample throughout the academic year (Table 1), e.g. the average student in our sample experiences 24 days between 30°C and 33°C throughout the school year. Furthermore, our results reflect one additional day in a given temperature range but do not account for the cumulative impacts of several hot days in a specific bin (i.e. experiencing multiple days between 30° and 33°C in a row might lead to greater impact). Since test scores are standardized to have a mean of 500 and a standard deviation of 100, the cumulative effects of additional hot days we observe in our study are substantial. To provide perspective, days with temperatures above 33°C lead to a decline of about 2 points in math test scores. Given a gender gap in grade 6 math test scores of approximately 8 points, a decline of about 2 points in math test scores means that the impact of one day above 33°C is roughly 25% of the gender gap. The magnitude of our results is particularly striking when we compare them with other research from elsewhere in the world: Park, Behrer, and Goodman (2021) find that each additional day above 26.7°C in the 3 years before the exam lowers the PISA test scores by 0.18 percent of a standard deviation.

We find mixed evidence that the other climatic variables in our analyses impact learning

(Table 2). Relative humidity has a negative effect on math and reading scores for students in grade 2 and math scores for students in grade 6, and there is no effect of precipitation on test scores for students in either grade. There is strong evidence of variation in test score performance by SES and gender. Among students in Grade 6, the household asset index is positively correlated with both math and reading test scores, which suggests wealthier students do better on average in math and reading. Among both students in Grades 2 and 6, never speaking French at home (a proxy for low-SES) is associated with performing significantly worse in both math and reading. The magnitude of these coefficients is fairly sizable: for example, never speaking French at home is associated with 50-60 point lower math and reading scores respectively in Grade 2. Females also perform worse in math and reading across both grades with one exception: in Grade 2 reading, females score only about 1.6 points lower than males on average—a difference that is not statistically significant.

5.3 Exploration of Mechanisms

As a next step, we provide insight into the mechanisms through which heat affects learning. To this end, we explore the effects of temperature on students' labor participation among Grade 6 students (data on labor participation is not available for Grade 2 students). A positive effect of heat on labor participation would support the perspective that heat has an indirect effect on learning by reallocating time away from schooling and toward labor. Table 3 shows that the probability of engaging in labor rises significantly for temperatures above 24°C, with the largest effects occurring in the 30°–33°C range ($\beta = 0.008$, $p < 0.01$). At temperatures above 33°C, labor participation remains elevated as well ($\beta = 0.004$, $p < 0.05$). While the coefficients might appear small (i.e. each additional day between 24°-27°C (compared to 21°–24°C) is associated with half a percentage point higher probability of labor participation) they become sizable once we take into account their cumulative effects. Interestingly, we find a negative effect of temperatures below 21°C and labor participation ($\beta = -0.003$, $p < 0.01$), suggesting that cooler-than-average conditions may slightly reduce the likelihood of students engaging in non-domestic work.

Although our data does not permit us to accurately isolate the direct effects of heat on learning, we are able to explore how heat impacts hunger—a factor that may exacerbate cognitive overload and thereby impair learning outcomes. We observe that compared to the reference category (21°–24°C), temperatures between 24°–27°C, and 30°–33°C are significantly

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associated with an increased probability of students reporting frequent hunger (Table 3). Once again, the magnitude of these coefficients is small, but they might have a substantial cumulative effect. For example, each additional day between 30° and 33°C increases the probability of frequent hunger by 1 percentage point, and there are, on average, 24 days in this temperature range in our sample.

5.4 Heterogeneous Effect of Heat on Learning by SES and Gender

We explore whether the effects of heat on learning are heterogeneous by SES and gender. We start by interacting the temperature categories with the household asset index (our measure of SES where a higher score on the household asset index represents greater SES) as described in Equation 2. We limit this analysis to Grade 6 students because the household asset index was only available for this subset of students. We find that in most cases the effect of temperature on learning varies little by socioeconomic background (Table A.3). There is one important exception. We find that the negative effect of very high temperatures (i.e. above 33°C) on reading and math scores is significantly larger for students with higher scores on the household asset index (i.e. higher SES) compared to lower scores on the household asset index (i.e. lower SES). This can be seen visually in Figure 3 where we show the average marginal effect of temperature above 33°C on math scores (top panel) and reading scores (bottom panel) across different levels of the asset index, with 95% confidence intervals. This finding aligns with an erosion of the compensatory advantage hypothesis, which suggests that high-SES students, who typically benefit from stable, well-supported educational environments, may experience a greater relative learning loss when these advantages are disrupted by extreme temperatures. Figure 4 provides further insight by showing the heterogeneous effects of temperature above 33°C on labor participation (top panel) and hunger (bottom panel) by SES among grade 6 students, with 95% confidence intervals (see Table A.4 for estimates and standard errors). These analyses show that the positive effect of very high temperatures (i.e. above 33°C) on labor participation is significantly larger for higher SES students compared to lower SES students; however, the positive effect of very high temperatures (i.e. above 33°C) on hunger is significantly smaller for higher SES students compared to lower SES students. We hypothesize that due to the erosion of compensatory advantage high-SES students experience significantly higher labor participation during extreme heat, which negatively impacts their learning outcomes; yet, their socioeconomic advantage continues to provide relative protection against hunger.

Next, we examine whether the impact of temperature on learning outcomes varies by gender by interacting the temperature variables with the gender of the student. Table 4 shows that in most cases the effects of temperature on learning do not significantly differ by gender. There are two main exceptions to this pattern. First, there are significant gender differences in the effect of temperatures below 21°C (compared to the 21°-24°C range) on math scores for Grades 2 and 6 students. More specifically, the positive association between the number of days below 21°C (compared to 21°-24°C) and math scores is significantly larger for females compared to males. Second, there is a significant gender difference in the effect of temperatures above 33°C (compared to the 21°-24°C range) on reading scores for Grade 6 students. Specifically, the coefficient of temperatures above 33°C on reading scores is not statistically significant for males, but for females each additional day during the academic year above 33°C (compared to 21°–24°C) significantly decreases reading test scores by about 1.5 points.

6 Discussion

Temperature variability and change may pose significant challenges to education in coming years, particularly in SSA and the Global South more broadly. Yet, existing work on heat shocks and schooling in Africa has been limited by the lack of nationally comparable and representative micro-data with information on learning. Our study contributes by exploring how heat shocks affect learning outcomes in eight West and Central African countries, where high temperatures are expected to increase in frequency and duration in the coming years (Barnes et al. 2024). In empirical analyses, we show that high temperatures have large negative effects on learning among students in grade 2 and grade 6 of primary school. Crucially, the magnitude of the effects we find in our study is particularly large compared to other regions of the world (Park, Behrer, and Goodman 2021). As our analysis is based on a school-based sample that excludes children not in school, our estimates of the effects of heat on learning may be conservative, as they do not capture students who may have dropped out due to heat. These findings are particularly important because the countries in our study face both an increase in the severity and frequency of extreme heat (Barnes et al. 2024; World Bank 2018) and a learning crisis (UNESCO 2014). Our study demonstrates the potential for temperature shocks to exacerbate already poor learning outcomes, with profound implications for the generation of young people in West and Central Africa today.

The finding that high temperatures reduce the learning outcomes of primary school

students may be explained either via direct effects, where heat disrupts concentration and performance, or indirect effects, such as reallocation of time away from schooling. In the second part of our analysis, we therefore explored the mechanisms through which heat might affect learning. We found evidence that hotter temperatures lead to increases in labor, and conversely, cooler temperatures lead to decreases in labor. It is worth noting that the labor measure does not include domestic tasks at home, and thus we may have overlooked some of the gender-differentiated ways in which heat impacts learning. Nonetheless, these findings support the perspective that temperature has an indirect effect on learning by reallocating time away from schooling and toward labor. At the same time, temperature may also directly affect learning by increasing cognitive strain; unfortunately, we were unable to directly test for this possibility using our data. Nonetheless, we found clear evidence that hot temperatures lead to increases in frequent hunger in schools. To the extent that hunger makes concentration more difficult, it is plausible that the direct effects of temperature on learning are exacerbated by hunger (Afridi, Barooah, and Somanathan 2019; Kroeger 2023).

In the final part of our analyses, we found that the effect of temperature on math and reading scores does not vary by SES for most temperature bins. Yet, there is one important exception: the negative effect of very high temperatures (i.e. above 33°C) on reading and math scores is significantly larger for higher SES students compared to lower SES students. Furthermore, the positive effect of very high temperatures on labor is significantly larger for higher SES students compared to lower SES students. This finding challenges the compensatory advantage perspective (Bernardi 2014) positing that individuals with greater socioeconomic resources tend to have access to buffers that protect them from adverse shocks. To the contrary, we find evidence of an erosion of compensatory advantage, with high-SES students experiencing significantly higher labor participation during extreme heat, which in turn might impact their learning. This finding aligns with another study showing that above-average temperatures in early childhood lead to greater reductions in years of schooling among children from higher-SES households compared to lower-SES households in West and Central Africa (Randell and Gray 2019). These findings run counter to what is observed in OECD countries in other parts of the world where the negative effects of heat on learning are significantly larger for lower-income populations (Park, Behrer, and Goodman 2021). This discrepant finding suggests that the ways in which socioeconomic status interacts with learning are heterogeneous across contexts. Another possibility is that some of the larger negative effects of extreme heat

on learning for higher (compared to lower) SES populations would be attenuated if we had data on the full population of school-aged children. For example, if students who dropped out of school due to heat shocks were more likely to be lower SES they would not be included in our current sample.

We also find that in most cases the effects of temperature on learning do not significantly differ by gender, although there is evidence of significant gender differences in the effects of heat on learning at very cool and very hot temperatures. The absence of stronger gender differences in our results is somewhat unexpected given that other studies suggest negative climatic shocks can differentially impact schooling outcomes by gender (Björkman-Nyqvist 2013; Nubler et al. 2021), often due to the different roles boys and girls have in the household (Webbink, Smits, and Jong 2012). As with socioeconomic status, if heat-related dropout varies by gender, the true effects of temperature on learning may be substantially greater than our estimates indicate.

Our analyses show that heat significantly affects learning in the West and Central African countries we study. From a policy perspective, these findings raise a number of challenges. A major strategy to deal with the adverse effects of temperature on learning is to invest in air conditioning and other electricity-dependent forms of climate control. But in this context, such solutions are largely unrealistic: about half of the population in West and Central Africa lacks access to electricity (World Bank 2024), and many school do not have the most basic climate infrastructure. These constraints highlight the need to innovate in creative ways that might provide students in West and Central Africa with better conditions that facilitate learning. Alternative approaches could include adjusting the school calendar or daily schedule to maximize attendance during cooler periods; introducing school-based feeding programs to help with temperature-related hunger; or providing agricultural support that would reduce labor needs among primary-aged students. Identifying how a scalable solution to the challenges of heat and learning is crucially important: at present, Sub-Saharan Africa has among the largest population of young people in the world; by 2030 young Africans are expected to make up 42 percent of the global youth population (PRB 2019). Continued investment in education is essential—not just for improving learning outcomes, but for improving the future well-being of the next generation.

Tables and Figures

Fig. 1. Average temperature for the countries in our study
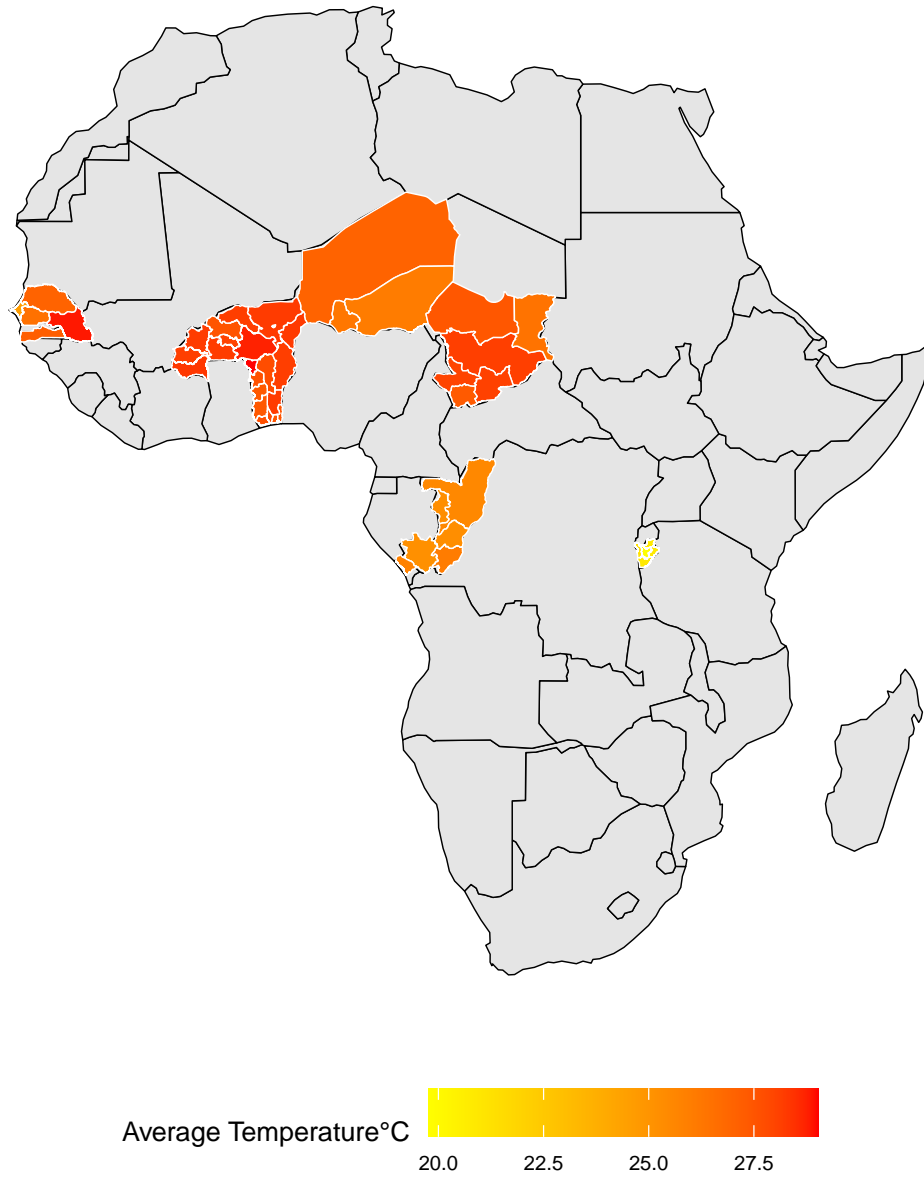
Note: Average temperature over the study time frame (2014-2019) in Benin, Burkina Faso, Burundi, Congo, Niger, Senegal, Tchad and Togo.

Fig. 2. Impact of Temperature on Learning for Students in Grades 2 (top panel) and 6 (bottomo panel).
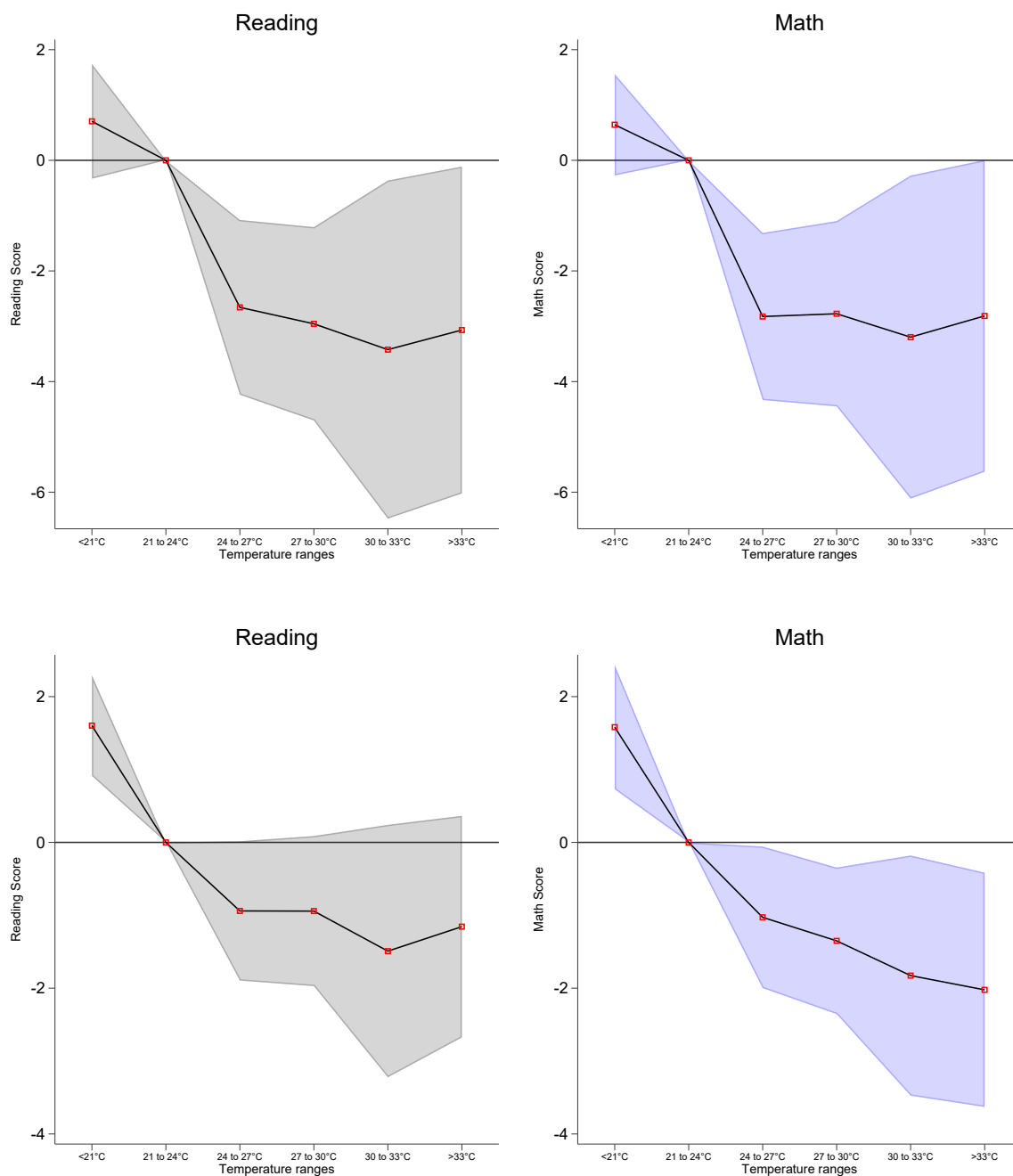
Note: This figure plots the effect of accumulated exposure to different temperature bins over the previous academic year, including vacation days, on student test scores at the end of the academic year. The observed effects are in terms of a 100th of a standard deviation. The top panel plots the estimates for grade 2 students and the bottom panel plots the estimates for grade 6 students.

Fig. 3. Heterogeneity by SES in Effect of Temperature Above 33°C on Learning
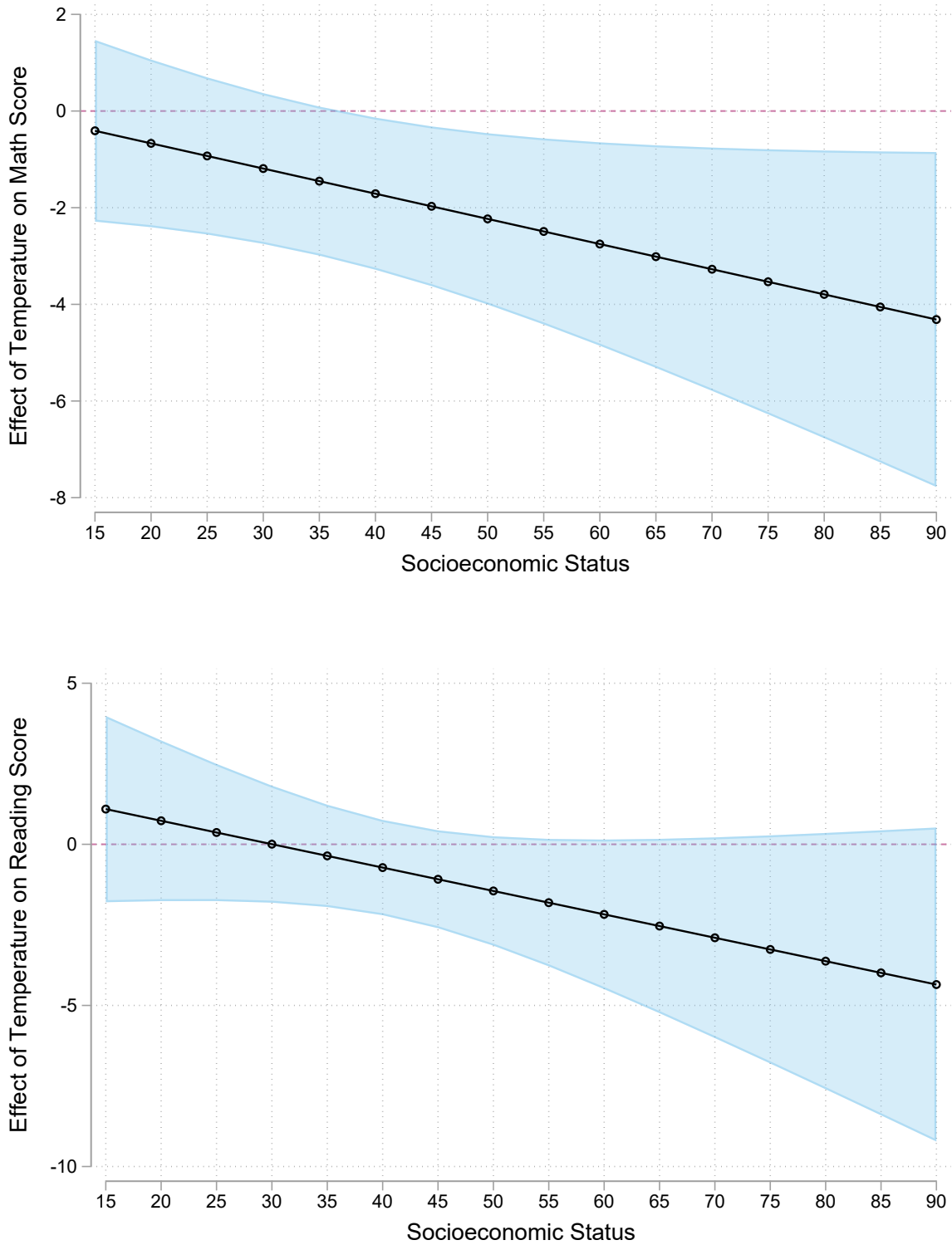
Note: Results presented as Average Marginal Effect of temperature above 33°C on learning over different levels of asset index. Generated following regression of the effect of temperature on math and reading test scores, including interactions between SES (asset index) and temperature. The top panel plots the effect by socioeconomic groups for math test score and the bottom panel for reading test score. Only grade 6 students are considered since information on assets is collected for those students only.

Fig. 4. Heterogeneity by SES in Effect of Temperature Above 33°C on Labor Participation and Hunger
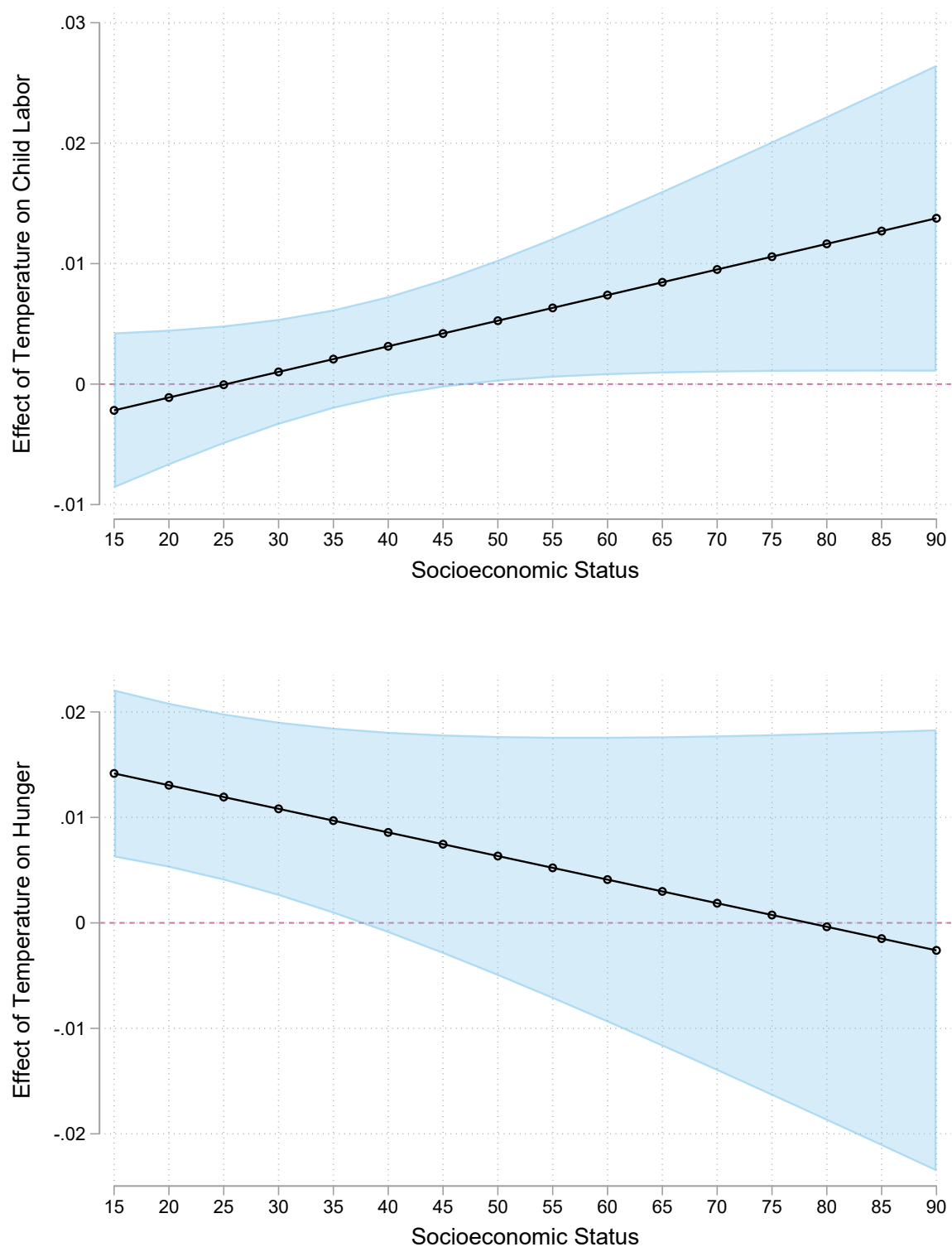
Note: Results presented as Average Marginal Effect of temperature above 33°C on learning over different levels of asset index. Generated following multi-variable regression of the effect of temperature on labor and hunger, including interactions between SES (asset index) and temperature. The top panel plots the effect by socioeconomic groups for labor and the bottom panel for hunger. Only grade 6 students are considered since the information on assets, hunger and labor participation is collected for those students only.

Table 1: Summary Statistics.

	Mean	SD	Min	Max	N
Outcome Variables					
Mean Math Score	516.924	104.167	82.326	968.807	80267
Mean Reading Score	514.321	110.238	21.323	965.824	80267
Pupil is Often Hungry	0.476	0.499	0.000	1.000	58760
Labor Participation	0.583	0.493	0.000	1.000	60373
Absolute Temperature					
# of Days Below 21° C	18.861	45.327	0.000	201.000	80267
# of Days Between 21 and 24° C	25.040	29.482	0.000	154.000	80267
# of Days Between 24 and 27° C	60.313	29.829	0.000	189.000	80267
# of Days Between 27 and 30° C	80.073	39.975	0.000	165.000	80267
# of Days Between 30 and 33° C	24.036	19.112	0.000	70.000	80267
# of Days Above 33° C	3.677	5.087	0.000	22.000	80267
Other Variables					
Relative Humidity	47.761	17.888	22.976	85.964	80267
Precipitation	15.725	21.193	1.120	92.625	80267
Student's Age	8.526	1.668	4.000	27.000	80267
Female (=1 if student is female)	0.484	0.500	0.000	1.000	80267
Never Speaks French at Home	0.577	0.494	0.000	1.000	80267
Household asset index	48.861	10.113	17.544	88.340	60499

Note: Data on students is from a program that evaluates learning in francophone countries in Africa. Data on temperature is from ERA5 archive. The analyses use two cross sectional datasets collected in 2014 and 2019. The first panel displays the outcomes of this paper. The two main outcomes are Math Score and Reading Score, and two other outcomes are hunger and labor that allow to test for potential mechanisms. The second panel shows the average number of days of a giving temperature bin for all countries in our sample between both years, accounting for vacation days. The third panel shows other variables use as control in our specification, including additional weather variables and students' background characteristics. To generate the statistics, we first generate country weights, and then multiply country weights by sampling weights and we use the latter.

Table 2: Impact of Temperature on Learning for Students in Grades 2 and 6.

	Grade 2		Grade 6	
	(1)	(2)	(3)	(4)
	Mean Math Score	Mean Reading Score	Mean Math Score	Mean Reading Score
Temperature (Ref. Cat.: # of Days Between 21 and 24° C)				
# of Days Below 21° C	0.644	0.706	1.582***	1.602***
	(0.456)	(0.515)	(0.423)	(0.342)
# of Days Between 24 and 27° C	−2.824***	−2.658***	−1.028**	−0.940*
	(0.750)	(0.785)	(0.482)	(0.475)
# of Days Between 27 and 30° C	−2.774***	−2.956***	−1.350***	−0.942*
	(0.832)	(0.868)	(0.499)	(0.511)
# of Days Between 30 and 33° C	−3.197**	−3.422**	−1.827**	−1.491*
	(1.450)	(1.518)	(0.818)	(0.860)
# of Days Above 33° C	−2.813*	−3.068**	−2.023**	−1.156
	(1.399)	(1.467)	(0.798)	(0.755)
Relative Humidity	−7.639**	−11.947***	−6.148*	−5.205
	(3.562)	(4.057)	(3.414)	(3.153)
Rain	0.810	1.294	0.781	1.445
	(2.803)	(3.230)	(1.978)	(1.717)
Student's Age	6.773***	1.833	−7.021***	−8.531***
	(1.033)	(1.245)	(0.896)	(0.950)
Sex (Ref. Cat.: Male)				
Female (=1 if student is female)	−12.289***	−1.633	−8.220***	−4.045***
	(2.299)	(1.774)	(1.075)	(1.142)
French at Home (Ref. Cat.: Speaks French at Home)				
Never Speaks French at Home	−49.642***	−59.095***	−23.948***	−24.921***
	(4.386)	(5.305)	(2.429)	(2.769)
Household asset index			0.957***	1.571***
			(0.132)	(0.164)
Observations	19768	19768	60499	60499
Year FE	Yes	Yes	Yes	Yes
Strate FE	Yes	Yes	Yes	Yes

Notes: The table reports the results from a multi-variable regression of the effect of temperature on math and reading test scores for students in Grades 2 and 6. Robust standard errors clustered at strata level in parentheses. Reported estimates describe how learning in math and reading change for pupils in grade 2 and grade 6 when one day with mean temperature 21-24° C is replaced by one day of a given other temperature category. Vacation days are included. We generate country weights and use them in our regressions. Asset information is not collected for Grade 2 students. We do find a significant correlation between the variable "Never Speaks French at Home" and the variable "Pupil Asset Index" for Grade 6. *** The variable "Never Speaks French at Home" is 1 if the student never speaks French at home, 0 if the student speaks french sometimes, often and always. The reference is "Speaks French sometimes, often and always". *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3: Impact of Temperature on Hunger and Labor Participation for Students in Grade 6.

	(1) Pupil is Often Hungry	(2) Labor Participation
Temperature (Ref. Cat.: # of Days Between 21 and 24° C)		
# of Days Below 21° C	0.001	-0.003***
	(0.001)	(0.001)
# of Days Between 24 and 27° C	0.005**	0.005***
	(0.003)	(0.001)
# of Days Between 27 and 30° C	0.006**	0.003*
	(0.003)	(0.001)
# of Days Between 30 and 33° C	0.009*	0.008***
	(0.004)	(0.002)
# of Days Above 33° C	0.007	0.004*
	(0.006)	(0.002)
Relative Humidity	0.041***	0.031***
	(0.009)	(0.008)
Rain	-0.018**	-0.001
	(0.008)	(0.005)
Student's Age	0.007**	0.020***
	(0.003)	(0.003)
Sex (Ref. Cat.: Male)		
Female (=1 if student is female)	0.003	-0.071***
	(0.005)	(0.011)
French at Home (Ref. Cat.: Always Speaks French at Home)		
Never Speaks French at Home	0.001	0.014
	(0.009)	(0.009)
Household asset index	-0.003***	-0.005***
	(0.001)	(0.001)
Observations	58760	60373
Year FE	Yes	Yes
Strate FE	Yes	Yes

Notes: The table reports the results of a multi-variable regression of the effect of temperature on hunger and labor on students in Grade 6. Robust standard errors clustered at strata level in parentheses. Reported estimates describe how hunger and labor for pupils in grade 6 change when one day with mean temperature 21-24° C is replaced by one day of a given other temperature category. Vacation days are included. We generate country weights and use them in our regressions. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4: Heterogeneity by Gender.

	Grade 2		Grade 6	
	(1) Mean Math Score	(2) Mean Reading Score	(3) Mean Math Score	(4) Mean Reading Score
Temperature (Ref. Cat.: # of Days Between 21 and 24° C)				
# of Days Below 21° C	0.560 (0.451)	0.672 (0.517)	1.474*** (0.428)	1.588*** (0.340)
Female × # of Days Below 21° C	0.131*** (0.036)	0.042 (0.043)	0.224** (0.094)	0.040 (0.051)
# of Days Between 24 and 27° C	−2.864*** (0.750)	−2.655*** (0.784)	−1.083** (0.483)	−0.957** (0.474)
Female × # of Days Between 24 and 27° C	0.061 (0.044)	−0.016 (0.043)	0.087 (0.058)	0.024 (0.041)
# of Days Between 27 and 30° C	−2.784*** (0.827)	−2.944*** (0.867)	−1.413*** (0.496)	−0.948* (0.505)
Female × # of Days Between 27 and 30° C	0.001 (0.042)	−0.033 (0.039)	0.080 (0.054)	−0.018 (0.041)
# of Days Between 30 and 33° C	−3.227** (1.448)	−3.435** (1.512)	−1.900** (0.812)	−1.494* (0.854)
Female × # of Days Between 30 and 33° C	0.041 (0.117)	0.021 (0.099)	0.118 (0.076)	−0.015 (0.063)
# of Days Above 33° C	−2.656* (1.405)	−3.030* (1.569)	−1.957** (0.798)	−0.941 (0.748)
Female × # of Days Above 33° C	−0.363 (0.563)	−0.089 (0.496)	−0.176 (0.196)	−0.532* (0.283)
Relative Humidity	−7.640** (3.561)	−11.943*** (4.058)	−6.300* (3.431)	−5.248 (3.148)
Rain	0.828 (2.810)	1.297 (3.234)	0.937 (1.997)	1.521 (1.728)
Student's Age	6.746*** (1.031)	1.821 (1.249)	−7.036*** (0.894)	−8.530*** (0.947)
Sex (Ref. Cat.: Male)				
Female (=1 if student is female)	−18.101*** (5.951)	1.033 (5.728)	−25.979** (10.577)	−2.578 (7.000)
French at Home (Ref. Cat.: Always Speaks French at Home)				
Never Speaks French at Home	−49.588*** (4.380)	−59.096*** (5.305)	−23.843*** (2.457)	−24.873*** (2.789)
Household asset index			0.960*** (0.131)	1.575*** (0.163)
Observations	19768	19768	60499	60499
Year FE	Yes	Yes	Yes	Yes
Strate FE	Yes	Yes	Yes	Yes

Notes: Table reports the results of an heterogeneity by gender of the main effect. Reported estimates describe how hunger and labor for pupils in grade 2 and grade 6 when they are exposed to different temperature bins. Vacation days are included. We generate country weights and multiply country weights by sampling weights and use the latter in our regressions. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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Temperature and Schooling: How Heat Shapes Primary Learning in West and Central Africa

A   Appendix Figures and Table

Table A.1: Summary Statistics by Grade.

	Grade 6	Grade 2
Mean Math Score	508.024	517.187
	(98.470)	(104.339)
Mean Reading Score	508.367	514.488
	(102.486)	(110.482)
# of Days Below 21° C	15.503	18.974
	(39.922)	(45.490)
# of Days Between 21 and 24° C	24.334	25.066
	(27.459)	(29.551)
# of Days Between 24 and 27° C	61.978	60.258
	(29.005)	(29.858)
# of Days Between 27 and 30° C	80.961	80.037
	(38.165)	(40.035)
# of Days Between 30 and 33° C	25.591	23.986
	(19.126)	(19.111)
# of Days Above 33° C	3.634	3.680
	(5.003)	(5.092)
Relative Humidity	46.294	47.808
	(17.677)	(17.894)
Precipitation	14.215	15.776
	(19.933)	(21.233)
Student's Age	12.989	8.380
	(1.558)	(1.458)
Female (=1 if student is female)	0.486	0.484
	(0.500)	(0.500)
Never Speaks French at Home	0.263	0.588
	(0.440)	(0.492)
Pupil is Often Hungry	0.476	
	(0.499)	
Labor Participation	0.575	
	(0.494)	
Household asset index	48.861	
	(10.113)	

Notes: Data on students is from a program that evaluates learning in francophone countries in Africa. Data on temperature is from ERA5 archive. The analyses use two cross sectional datasets collected in 2014 and 2019. We show the same variables as in Table 1 by country for our sample. To generate the statistics, we first generate country weights, and then multiply country weights by sampling weights and we use the latter.

Table A.2: Summary Statistics by Country.

	BENIN	BURKINA FASO	BURUNDI	CONGO	NIGER	SENEGAL	TCHAD	TOGO
Mean Math Score	480.833	503.921	608.407	562.022	492.014	545.707	503.175	467.576
	(97.071)	(95.200)	(55.448)	(91.409)	(117.611)	(98.245)	(94.459)	(86.559)
Mean Reading Score	483.666	505.447	624.347	550.122	485.570	533.956	491.420	459.383
	(87.109)	(108.233)	(92.730)	(99.650)	(107.348)	(115.410)	(78.446)	(88.150)
# of Days Below 21° C	0.000	0.119	134.276	0.000	13.771	3.348	1.634	0.000
	(0.000)	(0.381)	(44.631)	(0.000)	(14.371)	(6.867)	(3.313)	(0.000)
# of Days Between 21 and 24° C	0.556	12.240	76.740	19.869	31.317	34.594	12.175	3.150
	(1.425)	(9.779)	(43.935)	(9.137)	(11.103)	(24.725)	(9.692)	(2.772)
# of Days Between 24 and 27° C	72.544	62.405	0.984	172.442	50.632	77.292	67.871	81.524
	(16.649)	(9.313)	(1.333)	(9.622)	(10.113)	(14.087)	(13.107)	(22.964)
# of Days Between 27 and 30° C	128.676	100.722	0.000	19.689	62.135	79.025	93.994	107.883
	(20.757)	(15.896)	(0.000)	(16.436)	(18.214)	(20.913)	(12.873)	(20.543)
# of Days Between 30 and 33° C	9.924	30.179	0.000	0.000	49.641	17.521	26.891	16.034
	(13.285)	(7.836)	(0.000)	(0.000)	(11.880)	(17.041)	(7.460)	(15.141)
# of Days Above 33° C	0.299	6.335	0.000	0.000	4.504	0.220	9.434	3.409
	(1.415)	(4.350)	(0.000)	(0.000)	(4.334)	(0.876)	(5.707)	(7.366)
Pupil is Often Hungry	0.375	0.519	0.530	0.363	0.561	0.385	0.463	0.417
	(0.484)	(0.500)	(0.499)	(0.481)	(0.496)	(0.487)	(0.499)	(0.493)
Labor Participation	0.508	0.648	0.634	0.396	0.663	0.380	0.662	0.606
	(0.500)	(0.478)	(0.482)	(0.489)	(0.473)	(0.485)	(0.473)	(0.489)
Relative Humidity	71.343	37.526	72.534	81.744	28.081	47.985	38.845	60.504
	(13.580)	(3.261)	(3.129)	(2.602)	(2.866)	(8.728)	(6.079)	(10.808)
Precipitation	21.733	6.240	65.600	43.183	1.996	6.971	6.983	18.723
	(5.646)	(1.899)	(21.832)	(8.885)	(0.625)	(3.654)	(2.100)	(5.853)
Student's Age	7.209	8.834	9.585	8.002	8.360	8.429	8.962	7.847
	(1.570)	(1.762)	(1.715)	(1.506)	(1.111)	(1.310)	(1.728)	(1.438)
Female (=1 if student is female)	0.478	0.491	0.512	0.500	0.449	0.517	0.463	0.468
	(0.500)	(0.500)	(0.500)	(0.500)	(0.497)	(0.500)	(0.499)	(0.499)
Never Speaks French at Home	0.563	0.593	0.017	0.456	0.781	0.721	0.559	0.728
	(0.496)	(0.491)	(0.128)	(0.498)	(0.413)	(0.449)	(0.496)	(0.445)
Household asset index	52.419	49.661	42.754	53.800	44.625	55.617	45.513	47.592
	(9.082)	(7.781)	(7.319)	(9.604)	(11.280)	(8.335)	(10.278)	(8.726)

Notes: Data on students is from a program that evaluates learning in francophone countries in Africa. Data on temperature is from ERA5 archive. The analyses use two cross sectional datasets collected in 2014 and 2019. We show the same variables as in Table 1 by country for our sample. To generate the statistics, we first generate country weights, and then multiply country weights by sampling weights and we use the latter.

Table A.3: Heterogeneity by SES for Grade 6 in Math and Reading

	(1) Mean math score	(2) Mean reading score
Temperature (Ref. Cat.: # of Days Between 21 and 24° C)		
# of Days Below 21° C	1.716***	1.824***
	(0.534)	(0.414)
# of Days Below 21° C × Household Asset Index	-0.003	-0.005
	(0.008)	(0.008)
# of Days Between 24 and 27° C	-1.113*	-1.088*
	(0.559)	(0.548)
# of Days Between 24 and 27° C × Household Asset Index	0.001	0.002
	(0.005)	(0.006)
# of Days Between 27 and 30° C	-1.543**	-1.148**
	(0.579)	(0.547)
# of Days Between 27 and 30° C × Household Asset Index	0.003	0.003
	(0.005)	(0.006)
# of Days Between 30 and 33° C	-1.794*	-1.484
	(1.012)	(1.065)
# of Days Between 30 and 33° C × Household Asset Index	-0.002	-0.002
	(0.007)	(0.008)
# of Days Above 33° C	0.372	2.183
	(1.253)	(2.134)
# of Days Above 33° C × Household Asset Index	-0.052*	-0.073
	(0.028)	(0.049)
Relative Humidity	-6.235*	-5.286
	(3.420)	(3.168)
Rain	0.965	1.707
	(1.974)	(1.743)
Student's Age	-6.999***	-8.510***
	(0.904)	(0.949)
Sex (Ref. Cat.: Male)		
Female (=1 if student is female)	-8.218***	-4.043***
	(1.071)	(1.127)
Never Speaks French at Home	-23.987***	-24.970***
	(2.437)	(2.785)
French at Home (Ref. Cat.: Always Speaks French at Home)		
Household Asset Index	0.991	1.658*
	(0.809)	(0.915)
Observations	60499	60499
Year FE	Yes	Yes
Strate FE	Yes	Yes

Notes: Table reports the results of an heterogeneity analysis by socioeconomic status of the main effect. Reported estimates describe how Math and Reading for pupils in grade 6 change by socioeconomic groups when they are exposed to different temperature percentiles. Vacation days are included. We generate country weights and multiply country weights by sampling weights and use the latter in our regressions. *** p<0.01, ** p<0.05, * p<0.1.

Table A.4: Heterogeneity by SES in Hunger and Labor Participation.

	(1) Pupil is Often Hungry	(2) Labor Participation
Temperature (Ref. Cat.: # of Days Between 21 and 24° C)		
# of Days Below 21° C	-0.00152	-0.00312
	(-0.78)	(-1.59)
# of Days Below 21° C × Household Asset Index	0.0000593	0.0000139
	(1.55)	(0.34)
# of Days Between 24 and 27° C	0.00110	0.00234
	(0.42)	(1.05)
# of Days Between 24 and 27° C × Household Asset Index	0.0000808***	0.0000527
	(3.32)	(1.32)
# of Days Between 27 and 30° C	0.00416	0.00125
	(1.46)	(0.62)
# of Days Between 27 and 30° C × Household Asset Index	0.0000384	0.0000297
	(1.54)	(0.93)
# of Days Between 30 and 33° C	0.00306	0.00628*
	(0.79)	(1.83)
# of Days Between 30 and 33° C × Household Asset Index	0.000104**	0.0000360
	(2.42)	(0.70)
# of Days Above 33° C	0.0175***	-0.00537
	(3.55)	(-1.12)
# of Days Above 33° C × Household Asset Index	-0.000224	0.000213*
	(-1.57)	(1.83)
Relative Humidity	0.0405***	0.0308***
	(4.71)	(4.16)
Rain	-0.0169**	-0.0000527
	(-2.29)	(-0.01)
Student's Age	0.00702**	0.0199***
	(2.32)	(7.42)
Sex (Ref. Cat.: Male)		
Female (=1 if student is female)	0.00325	-0.0717***
	(0.68)	(-6.78)
French at Home (Ref. Cat.: Always Speaks French at Home)		
Never Speaks French at Home	0.000350	0.0128
	(0.04)	(1.38)
Household Asset Index	-0.0137***	-0.0130*
	(-3.30)	(-1.89)
Observations	58760	60373
Year FE	Yes	Yes
Strate FE	Yes	Yes

Notes: Table reports the results of an heterogeneity analysis by socioeconomic status of the main effect. Reported estimates describe how hunger and labor participation for pupils in grade 2 and grade 6 change by different socioeconomic groups when they are exposed to different temperature percentiles. Vacation days are included. We generate country weights and multiply country weights by sampling weights and use the latter in our regressions. *** p<0.01, ** p<0.05, * p<0.1.