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Heating Up at the Plate: Relationships between Temperature, Climate Type in Place of Birth, and MLB Batting Performance

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ABSTRACT

This study seeks to determine whether long-term heat acclimatization affects batting performance of Major League Baseball players based upon the climate in which a player was born. Each player with at least one at-bat from 1980–2018 was linked to a climate class and subdivision based on the Köppen-Geiger climate classification of their place of birth, and the ambient temperature at game time was determined for each game that took place. Games played in temperatures at least one standard deviation below and above the mean were categorized as cold- and hot-weather games, respectively. Common baseball metrics such as batting average, slugging percentage, and isolated power were calculated and aggregated based on climate class, climate subdivision, and temperature category. Differences in batting performance were assessed using the ANOVA and Tukey-Kramer tests. It was found that players from cold-winter climates hit for significantly less power in hotter temperatures than players from some other climates.

Keywords: acclimatization, baseball, sports globalization, weather, climate

INTRODUCTION

One aspect of being a sports fan that many find enjoyable is speculating on their team of choice, be it player acquisitions and trades, game performance, or strategy. In sports that are played primarily outdoors—such as baseball, football, and soccer—fans and media often discuss the perceived advantages or disadvantages that teams or individual players may have by playing in conditions to which they are not accustomed. For example, fans of the Green Bay Packers football team believe their team holds an advantage over opponents when playing at home in their open-air stadium in northeast Wisconsin when frigid temperatures are in the forecast (Lee 2022). Even teams themselves consider this by attempting to acclimatize to uncharacteristic conditions ahead of games, such as the New England Patriots football team practicing outdoors in preparation for cold-weather games (Cerullo 2017). Football is not unique in regard to weather's effect on the game; conventional wisdom in baseball is that batters dislike playing in cold weather, and offensive production increases with the warming of temperatures (Branom 2020). This is supported through various studies, such as Huang, Chiu, and Chang (2021).

The effects of atmospheric conditions do not stop at temperature or other elements of weather; significantly lower pressure (by way of game locations at higher altitudes) is also thought to give the home team an advantage. Take, for example, sports teams located in Denver, Colorado: the Broncos (football), Rockies (baseball), Nuggets (basketball), and Avalanche (ice hockey). It is believed that each of these teams has an advantage playing at home because their athletes are better acclimatized to the altitude as compared to their opponents (Gruenauer 2020). While the effect of weather on the players in sports is often at the forefront of the minds of fans, media, players, and team personnel, what is not often considered is whether some players have an advantage because the climate of the place where they were born and raised acclimatized them to certain conditions. In this study we take advantage of the vast and detailed dataset associated with Major League Baseball (MLB) to investigate whether differences in batting performance exist between players from different climates when it is either colder or hotter than normal during games.

The concept of sports acclimatization (Mee, et al. 2015, Sawka, Periard, and Racinais 2015) and, specifically, acclimatization in baseball (Florida HSAA 2013, Illinois HSA 2019) is well-researched in athletic preparedness and performance literature as well as a variety of state-sponsored manuals. Accordingly, it provides that acclimatization (or acclimation) confers biological adaptations that mitigate physiological strain, improves exercise capacity, and reduces the risks of environmentally-induced health hazards. Athletes are encour-

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aged to conduct repeated exercise in ambient conditions that simulate expected conditions in advance of the competitive environment. These training protocols vary in duration and intensity and must be adapted to specific environmental conditions. Generally, these individuals must *gradually* increase their exposure to these conditions to maximize acclimation. As a result, adaptations include integrated thermoregulatory, cardiovascular, respiratory, metabolic, and molecular responses that alter the physiology of athletes over time.

The temporal aspect of conditioning (and better yet, residency) is critical. Studies indicate that longer acclimatization times in advance of competition lead to better adaptations. For example, Muza, Beidleman, and Fulco (2010) found that continuous residence and/or daily exposures at high altitude induce ventilatory acclimatization and result in a reduction in acute mountain sickness better than shorter durations and/or lack of residency. However, high-altitude training is beneficial to athletes who compete in low-elevation environments as well. Numerous elite track-and-field athletes train in Park City, Utah [~2,100 meters (about 1.3 miles) above sea level] to boost red blood cell counts (that carry oxygen throughout the body) even if competition events are held in locations of considerably lower elevation.

Similar hypoxic training is deemed critical to the success of Kenyan and Ethiopian long-distance runners. However, adding to the benefits of high-altitude training itself is a composite of long-term exposure and genetic attributes which include development of a high maximal oxygen uptake as a result of extensive walking and running at an early age, development of highly economic metabolism based on somatotype (body shape) and lower limb characteristics, and favorable skeletal-muscle-fiber composition and oxidative enzyme profile (Wilber and Pitsiladis 2012). Along the same lines, Niu, et al. (1995) found that lowland athletes, despite long-term training and residency in high altitude (even exceeding two years), were unable to attain the same gross mechanical efficiency as local highland Tibetans.

Specific to baseball, Koch and Panorska (2013) found that almost all batting statistics significantly improved in warm weather games as compared to games played in 'cold' and 'average' temperatures. The reason for this is that temperature is considered the most important meteorological variable in affecting fly ball distances, since warm air is less dense than cold air (Kraft and Skeeter 1995). A baseball's coefficient of restitution, which is the ratio of speeds after and before an impact, is also lower with a cold baseball (Drane and Sherwood 2004). In addition, Koch and Panorska (2013) observed a logarithmic decrease in distance traveled by a batted ball with temperatures below 40˚F (4.4°C), suggesting that extremely cold games are more likely to experience even greater offensive futility than expected. Moreover, Rammsayer, Bahner, and Netter (1995) found that a decrease in a person's core temperature resulted in significantly slower reaction and movement times, which affect the rate of force for batted balls. Accounting for the effects both on baseballs and players themselves, it is rather evident that warmer temperatures lead to greater offensive productivity. Thus, from the outset, in this study it is expected that all subsets of MLB players experienced improved offensive performance with higher temperatures. However, there is particular interest in whether various subsets of players experienced differential rates of improvement as temperature increases.

Evidence suggests that warmer-winter climates have produced a disproportionate share of MLB players, and that those players have outperformed cohorts originating from severe-winter climates in measures related to batting. For example, Schwartz (2014) examined the statistic of Wins Above Replacement[1] (WAR) for MLB players born in the U.S. between 1940–89 at the county, state, and regional scales. He discovered that not only is there an increasing share of players coming from areas with warmer winters through time, but that those players are outperforming their peers. However, he argued socioeconomic privilege (best examined at the county scale) was the best predictor of player success in recent decades, as these individuals were more likely to have network support (e.g., family and trainers) and better facilities and equipment to improve their skills. While Little League baseball has been declining, participation in travel baseball, which is much more expensive, has been increasing (Gregory 2017). Schwartz (2014) argued that socioeconomic privilege is one reason, among many, that the share of African American players in the MLB has steadily declined since 1981.

While this may be an explanation for divergent trends among U.S.-born players, an increasing share of MLB players in recent decades has come from abroad, particularly Latin America. The number of players from Latin America surpassed the number of African Americans in 1993, and as of 2016, these groups comprised 27.4% and 6.7% of the MLB population, respectively (Armour and Levitt 2016). Unlike the factor of socioeconomic privilege for American players, many Latinos come from impoverished backgrounds where baseball is seen as 'a way out' (Vargas 2000). This has led to numerous young players rising through the ranks in baseball academies sponsored by MLB teams, many of whom are willing to sign inexpensive contracts. This financial incentive makes these players particularly enticing to MLB teams, helping to explain why a year-round culture of baseball player development has become paramount in countries with warm winters like the Dominican Republic and Venezuela.

It is the potential beneficial aspect of long-term exposure to atmospheric conditions that was further investigated in this study. With specific regard to ambient temperature, statistical patterns of batting performance for MLB players based on the climate classification at their place of birth were examined. Accordingly, possible correlations between increases in game-time temperatures and offensive production were explored. Specifically, it was determined whether there were statistically significant correlations between game-time temperatures, offensive production for players, and the climate class and subdivision in which they were born. Put simply, the question to be answered was: "Do all subsets of players (based on climate categorization in place of birth) experience improvements in hitting performance with increasing temperatures, and do certain subsets of players experience *differential rates of improvement* as game-time temperatures are warmer?"

DATA AND METHODS

In order to assess the batting performance of MLB hitters for this study, it was necessary to acquire data about individual baseball games—including the result of every plate appearance (PA), a temperature representative of the environment in which each game was played, and the climate classification for the location where each player was born. The outcomes of the PAs were used to calculate common statistics frequently employed within the game of baseball to describe a hitter's performance. These measures were easily aggregated by climate classification and ambient temperature to analyze the possible effects they may have on successfully hitting a baseball in the major leagues.

Game Data

All data pertaining to MLB games were obtained from Retrosheet (https://www.retrosheet.org/game.htm) as event files, which include play-by-play data, game-time temperature, location the game was played, and whether it was a day or night game, among other information. Even though game-time temperature is used herein to represent the ambient temperature during each game, we recognize that temperatures usually rise slightly during day games and fall slightly during night games, but do not believe this has a significant effect on our findings. Although data from regular season games are available on Retrosheet as early as 1919, those prior to 1974 contain some number of missing games, so the dataset for this study consists of all regular season games played 1980–2018 (88,090 games). Play-by-play data were parsed by game such that each player's events from any specific game were easily queried, which allowed for the calculation of four statistics: batting average (AVG), slugging percentage (SLG), isolated power (ISO), and batting average on balls-in-play (BABIP). Only statistics for hitting were taken into account in this study, although pitching statistics may warrant examination in future work.

The four statistics chosen for this study each describe different aspects of a batter's performance. AVG is the ratio of the number of hits per official at-bats[2] (ABs), providing a general measure for how successful a batter is at hitting the ball. Since AVG does not account for the type of hit [i.e., single (S), double (D), triple (T), or home run (HR)], SLG uses the same formula, but weights each type of hit accordingly:

$$SLG = \frac{S+2D+3T+4HR}{AB} \tag{1}$$

This measure not only includes the number of hits a player had, but also describes the quality of those hits, where two players with identical AVGs would have different SLG statistics if one only hit singles and the other hit a combination of singles and doubles. It is also useful to isolate the "power" component of a player's SLG by subtracting AVG from it, resulting in ISO. This describes how many extra bases (beyond a single) a player averages per at bat. Finally, as a way of assessing whether a batter has been especially lucky or unlucky, the ratio of the number of hits per balls hit into the field of play (batting average on balls in play; BABIP) is calculated as:

$$BABIP = \frac{S+D+T}{AB-K-HR+SF}. \tag{2}$$

Events that do not result in the ball entering into the field of play [i.e., home runs, strikeouts (K), walks, hit batsmen] are not included in this calculation, but at-bats are incremented by sacrifice flies (SF) since the ball is put into play, even though they are not traditionally counted as at-bats. The average league-wide value of BABIP is close to 0.300, where values much higher than that suggest a player has been lucky (more balls put into play are hits), and values lower suggest unluckiness. However, hard-hit balls are more likely to fall for a hit than softly-hit balls, which can affect BABIP for individual players. Together, these four statistical measures can allow for analysis of a hitter's or group of hitters' performances.

While most games included in this study had game-time temperatures provided in the Retrosheet event files, about 19.5% did not, most of which were from the 1980s and 1990s. For these games, the hourly temperature at the surface weather station nearest to the location of the game was retrieved from the National Centers for Environmental Information's (NCEI) Integrated Surface Database (Smith, Lott, and Vose 2011), with games identified as "day" games using the temperature at 1300 local standard time (LST), and "night" games at 1900 LST. If a stadium with a retractable roof was missing a game-time temperature, it was assigned 72°F (about 22°C). After including NCEI temperatures, there were only 490 games (0.6%) with missing game-time temperatures due to missing data from both Retrosheet and NCEI, so those games were omitted from the dataset.

Player Climate Classification Data

In addition to play-by-play data, Retrosheet also maintains a comprehensive directory of information about players (https://www.retrosheet.org/boxesetc/index.html#Players), among which is each player's city, state, and country of birth. The city in which each player was born was used to identify in which climate that player was associated for this study. Although it is acknowledged that there are likely numerous cases in which a player was born in one location and moved to one or more different locations before entering professional baseball, with 7,495 players credited with at least one PA during the period of study, it was not practical to identify where each player lived throughout their pre-adult lives to determine which climate best represents where they spent their formative years. However, with over 58% of the U.S. population born in the state of their current residence (United States Census Bureau 2019), and only 3.6% of the global population residing outside their country of birth (United Nations 2020), it is not unreasonable to suppose that birthplace is representative of many U.S.-born players, and most international players.

Using the city in which a player was born, each player was assigned a climate based on the Köppen-Geiger climate classification map created by Beck, et al. (2018), which has a 1-km resolution (Fig. 1). In this classification system, climates are differentiated based on a location's average values of temperature and precipitation. Climate classes are identified as tropical (A), arid (B), temperate (C), cold (D), and polar (E). Tropical climates were subdivided as rainforest (Af), monsoon (Am), or savannah (Aw); arid climates as desert (BW) or steppe (BS), with the additional identifier of hot (h) or cold (k) appended to each; temperate and cold climates were both subdivided as dry summer (s), dry winter (w) or without a dry season (f), with an additional classifier of hot summer (a), warm summer (b), or cold summer (c) included; and polar climates were subdivided as tundra (ET) or Ice Cap (EF).

Geographic coordinates for each player's birth city were obtained from the GeoNames gazetteer (http://www.geonames.org/), allowing for a precise climate designation to be identified for each location. With knowledge of each player's location of birth, that place's precise climate designation, the game-time temperature of each game played during the period of study, and the individual performance of each player for each of these games, analysis was done by compiling the statistics of players based on criteria such as climate classification and game-time temperature in order for comparisons to be made.

Methods

Over the period of study there were 87,600 games with game-time temperatures available, resulting in an average game-time temperature of 72.8°F (22.7°C), and a standard deviation of 10.7°F (5.9°C; Fig. 2). The noticeable peaks at 68°F, 70°F, and 72°F are most likely attributed to stadiums with either fixed or retractable roofs that are climate-controlled for at least a portion of games each season. There were 60,544 games played within one standard deviation of the average game-time temperature (63–83°F), with 13,397 played with game-time temperatures more than a standard deviation colder than the mean (less than 63°F), and 13,659 games played with temperatures at least one standard deviation warmer (more than 83°F). For the purposes of this study, these are the thresholds that are used to identify games that were played in "cold weather" and "hot weather".

A total of 7,495 players had at least one AB from 1980–2018, with every climate class except polar (E) represented (Fig. 3). Temperate climates (C), such as those found in the U.S. South and West Coast, accounted for over 40% of the birth places (3,077), with the Cfa subdivision (no dry season and hot summers) responsible for 1,988 players. The climate class where the second highest number of players was born was D (cold climates; 1,925 players), most of which coming from the Dfa subdivision. Locations classified as cold climates include the Midwest and northeast United States, and most of southeastern Canada (where most Canadian players were born). The fewest number of players (other than in E climates) were born in arid (B) climates, such as the mountainous states in the western U.S., while almost 20% of players were born in tropical (A) climates, which include southern Florida, most of the Caribbean and Central America, and a large proportion of northern South America.

When assessing the performance of individual players at various game-time temperatures, or even a range of temperatures, it is important to establish a minimum threshold of at-bats to assure an adequate sample size. According to Rule 9.22(a) in the Official Baseball Rules (Major League Baseball 2021), for a player to be eligible for an individual batting championship during a single season, that player must accumulate at least 3.1 plate appearances for each game his team plays (502 PAs for a 162-game season, which is currently the

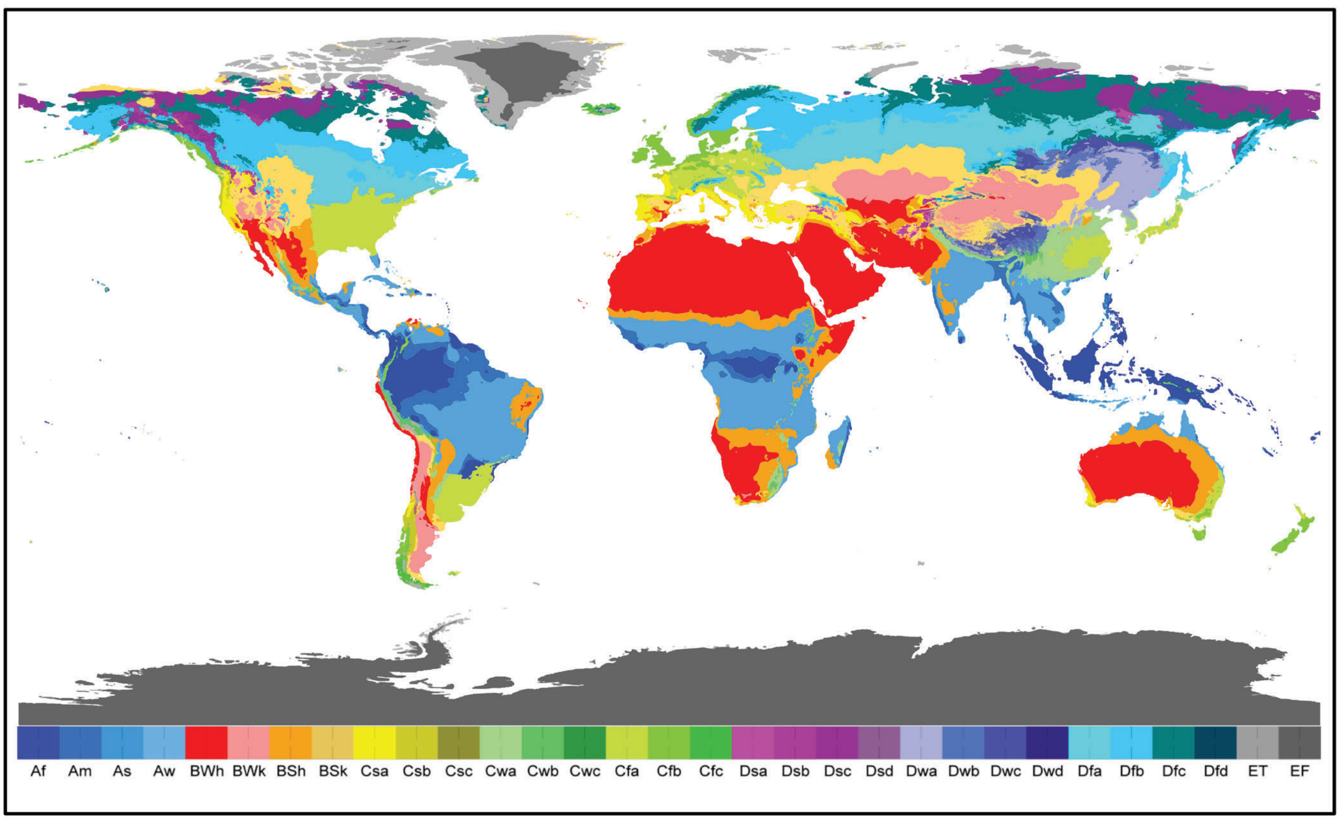

Figure 1. Climate subdivisions based on the Köppen-Geiger classification scheme (Beck, et al. 2018). These data are available under the CC BY 4.0 license (https://creativecommons.org/licenses/by-nc/4.0), and no changes were made to the data.

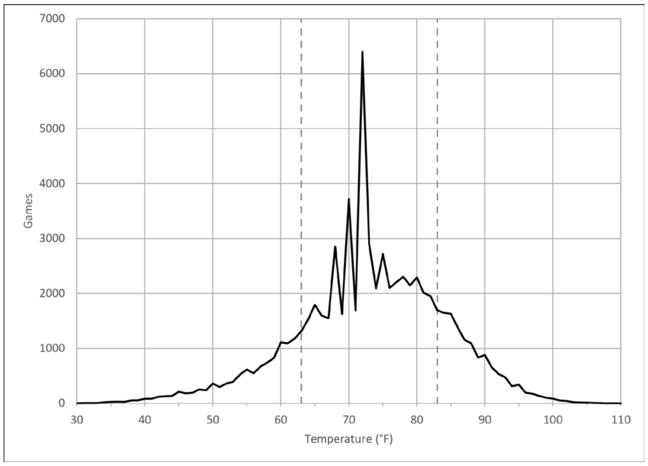

Figure 2. Number of games for each game-time temperature in the dataset. The vertical, dashed lines identify the range defined by one standard deviation below and above the mean game-time temperature.

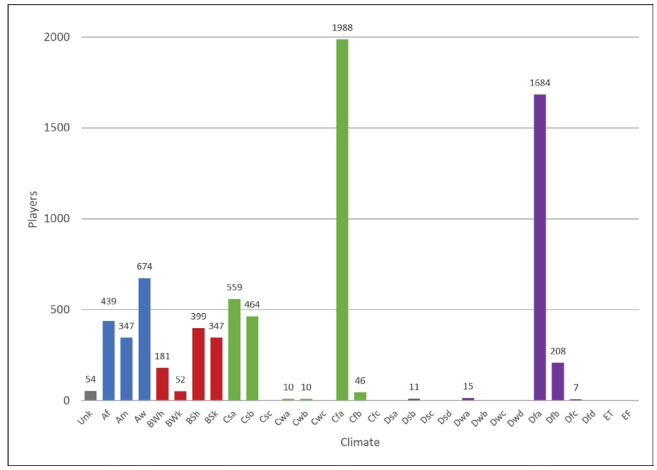

Figure 3. The number of players in the dataset born in each climate class subdivision. Subdivisions within the same climate class are shown in the same color. For areas in which a climate class and subdivision could not be calculated, the designator "Unknown" (Unk) was used.

length of a typical MLB season). For this study, we require a player have at least 50 ABs within a particular range of game-time temperatures, or approximately 10% of those required for a player to be eligible for an individual championship, to be included when evaluating individual player performance. We use AB rather than PA as a minimum threshold because statistics such as AVG and SLG do not include non-AB events (e.g., walks) in their calculation, meaning that the sample size for an individual player with 50 PAs could effectively be smaller than that. This minimum AB requirement is also used for players to contribute their performance to the bulk statistics for climate classes and subdivisions.

There are two perspectives by which performance can be evaluated: how each individual player performed at a given game-time temperature, or how all players as a group with the same birthplace climate class or subdivision performed at a given game-time temperature. For the purpose of comparing climate subdivisions to one another, only those that were the birthplace for at least 100 players were considered to assure a reasonable sample size, especially when factoring in the AB threshold for individual players. There were more players who qualified as "hot-weather" players (those with at least 50 ABs in games with temperatures above 83°F) than "cold-weather" players (those with at least 50 ABs in games with temperatures below 63°F) for each subdivision (Table 1), which is to be expected since the typical MLB regular season encompasses the entire Northern Hemispheric summer, with a team's season beginning in late March or early April and ending in late September or early October. Approximately 25–35% of players from a particular climate subdivision qualified as either a hot- or cold-weather player, while slightly fewer players met the requirements to qualify for both. Even though a player was classified as a hot- or cold-weather player (or both), only the ABs by that player that occurred during a hot- or cold-weather game were used when comparing the two game time temperature regimes.

RESULTS AND DISCUSSION

In "cold weather" games, all qualifying players taken as a whole had a batting average of 0.257 (Table 2), while for "hot weather" games the overall AVG was 0.274 (Table 3), showing that overall, Major League Baseball players hit better in warmer temperatures than colder. This improvement with temperature holds true when dividing the players by climate class and climate subdivision, as well. In fact, improvement was observed across the board for the other hitting statistics (SLG, ISO, and BABIP). This shows that in addition to getting hits more frequently in warmer temperatures, more of those hits resulted in extra bases (i.e. doubles, triples, and home runs), which is usually a sign of harder-hit balls. Even though the BABIP values for cold-weather games ranged from 0.283 to 0.293, which is lower than the 0.300 value that is considered league-average, they are not so low that one would consider the hitters in those climate subdivisions unlucky. Instead, it is likely there were fewer hard-hit balls.

The effect of temperature on AVG is further illustrated through the collective performance of all eligible players who had ABs at each specific temperature from 40°F to 100°F, where players born in each of the four climate zones showed improvement with increasing temperatures (Fig. 4). Players from temperate (C) climates had the greatest increase in AVG, while those from arid (B) climates improved the least. Although players born in tropical (A) climates did not increase their AVG as much as those from other climates, they did consistently have higher values than those from the other three climate classes. Both at lower and higher temperatures the sample sizes tend to be relatively small (nearing 1,000 ABs), so focusing on individual values at a given temperature may not be as meaningful as the overall trends.

In the same way that hitters were more successful at getting hits as the game-time temperature increased, players from all four climate classes also enjoyed an increase in SLG (total

Table 1. Number of players included in the dataset, with subsets for each climate class and subdivision. Cold-weather players are those that had a minimum number of at-bats when the game-time temperature was colder than 63°F, hot-weather players had a minimum number of at-bats when the game-time temperature was warmer than 83°F, and both cold- and hot-weather players are those that qualified for both.

Climate	Total Players	Cold-weather Players	Hot-weather Players	Both Cold- and Hot-weather Players
All	7290	2279	2378	2067
A	1460	482	511	439
B	927	283	304	257
C	3011	959	988	872
D	1892	555	575	499
Af	439	139	151	125
Am	347	117	117	106
Aw	674	226	243	208
BWh	181	54	57	48
BSh	399	134	145	125
BSk	347	95	102	84
Csa	559	185	190	168
Csb	464	155	159	136
Cfa	1988	619	639	568
Dfa	1684	503	517	450
Dfb	208	52	58	49

bases per AB) with increasing temperature (Fig. 5). Much like with AVG, players from temperate (C) and arid (B) climates had the largest and smallest increases in SLG, respectively, but players from tropical (A) climates did not consistently hit for more power than those from other climates. In fact, with respect to overall trends over increasing temperatures, players from A climates had the second highest SLG value at colder temperatures and warmer temperatures. Most notably, players from C climates had the lowest values for SLG at the coldest temperatures, but the highest at hotter temperatures. Isolating the power component of SLG (number of extra-bases per AB), players from B climates had the largest ISO values from cold temperatures to hot, but also had the smallest rate increase across temperatures (Fig. 6). Players born in C climates enjoyed the largest increase, while maintaining their position as the climate class with the second highest ISO values, moving from values closer to those from A climates in cold-weather games to nearly the same values as those from B climates in hot-weather games.

When comparing the performance of individual players based on the climate class in which they were born, the analysis

Table 2. Statistical measures for each climate class and subdivision for games played with game-time temperatures below 63°F.

Climate	AVG	SLG	ISO	BABIP
All	0.257	0.395	0.137	0.289
A	0.259	0.394	0.134	0.292
B	0.254	0.397	0.143	0.285
C	0.257	0.396	0.139	0.29
D	0.257	0.391	0.134	0.287
Af	0.261	0.401	0.14	0.293
Am	0.257	0.395	0.138	0.289
Aw	0.259	0.389	0.129	0.292
BWh	0.25	0.386	0.136	0.283
BSh	0.255	0.407	0.152	0.284
BSk	0.253	0.385	0.132	0.287
Csa	0.259	0.402	0.143	0.286
Csb	0.254	0.386	0.131	0.288
Cfa	0.257	0.397	0.139	0.291
Dfa	0.257	0.391	0.134	0.287
Dfb	0.258	0.395	0.137	0.287

Table 3. Statistical measures for each climate class and subdivision for games played with game-time temperatures above 83°F.

Climate	AVG	SLG	ISO	BABIP
All	0.274	0.436	0.162	0.303
A	0.276	0.435	0.16	0.304
B	0.271	0.436	0.165	0.3
C	0.274	0.439	0.164	0.304
D	0.272	0.429	0.157	0.299
Af	0.279	0.456	0.176	0.305
Am	0.276	0.438	0.162	0.305
Aw	0.273	0.42	0.147	0.303
BWh	0.271	0.445	0.174	0.301
BSh	0.272	0.445	0.174	0.297
BSk	0.269	0.417	0.147	0.303
Csa	0.276	0.443	0.167	0.301
Csb	0.275	0.431	0.156	0.305
Cfa	0.274	0.439	0.166	0.305
Dfa	0.272	0.428	0.156	0.299
Dfb	0.273	0.437	0.164	0.299

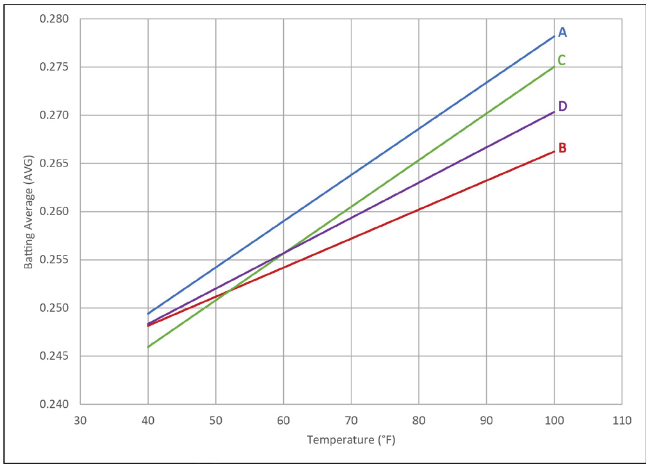

Figure 4. Trendlines of cumulative batting average values for each climate class at each game-time temperature between 40°F and 100°F. Tropical (A) climates are shown in blue, arid (B) in red, temperate (C) in green, and cold-winter (D) in purple.

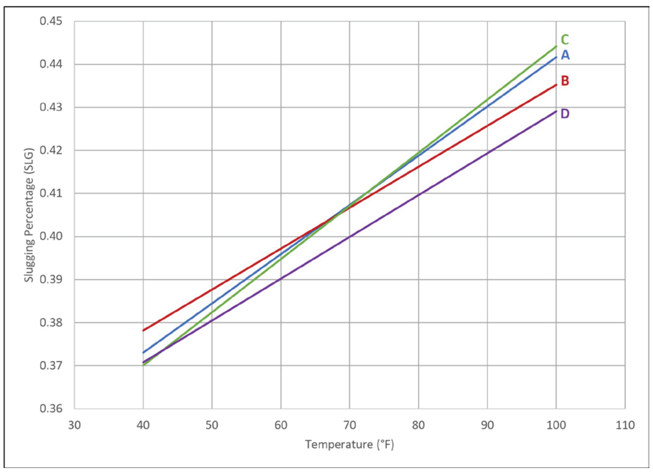

Figure 5. Same as Figure 4, but for slugging percentage values.

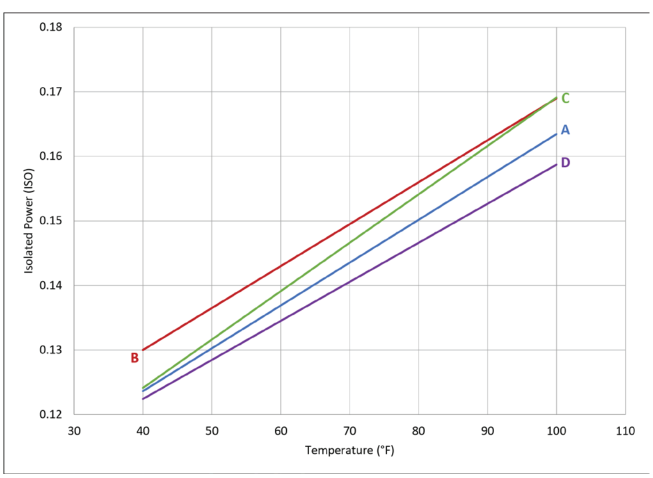

Figure 6. Same as Figure 4, but for isolated power values.

of variance (ANOVA) test was used to identify if significant differences exist between the four classes. The results of this test revealed significant differences between climate classes at the 5% significance level in SLG and ISO, but only for hot-weather games (Table 4). A Tukey-Kramer test (with an experiment-wise confidence level of 95%) was performed to further examine the differences in SLG and ISO between all combinations of pairs of classes, with the C-D pair significant at the 5% level for both statistics (Table 5); for ISO, the B-D pair was significantly different at the 10% level. Collectively, D-climate players had ISO values in hot-weather games that were lower than the other classes by as much as 0.008 (Table 3), while their SLG value trailed by as much as 0.010. The fact that players from D climates had AVG values similar to the other classes in hot-weather games suggests that while they're able to make contact at the same rate as other batters, these players are potentially not hitting the ball as hard as those from other climate classes, especially C climates.

ANOVA tests comparing the three statistical measures among players from each climate subdivision yielded similar results, with significant differences identified in hot-weather games for SLG and ISO (Table 4). However, none of the individual pairs of climate subdivisions were significantly different when a Tukey-Kramer test (with a 95% experiment-wise confidence level) was applied. Significant differences do exist between players from different subdivisions with respect to SLG and ISO, but since the Tukey-Kramer test controls the error rate to prevent pairs wrongly being identified as significant, and a greater threshold must be overcome for a pair to test as significant (especially with 55 possible pairs in this instance), it is not surprising that none of the pairs were identified as being significantly different.

Table 4. ANOVA test *p*-values from comparing individual player performance based on climate classes and climate subdivisions. Values less than 0.05 are shown in bold.

	Under 63°F			Over 83°F		
Climate	AVG	SLG	ISO	AVG	SLG	ISO
Classes	0.225	0.352	0.135	0.159	**0.041**	**0.017**
Subdivisions	0.372	0.42	0.371	0.173	**0.029**	**0.017**

Table 5. Tukey-Kramer test *p*-values from comparing individual player performance in hot-weather (over 83°F) games based on climate classes. Values less than 0.10 are italicized, and less than 0.05 are shown in bold.

Climate Classes	SLG	ISO
A vs. B	0.929	0.368
A vs. C	0.874	0.421
A vs. D	0.341	0.761
B vs. C	1	0.956
B vs. D	0.164	0.059
C vs. D	**0.032**	**0.032**

In addition to comparing individual player performance for both cold- and hot-weather games separately, players from the various climate classes and subdivisions were also compared by the differences in their individual performance by subtracting each of their cold-weather statistics from the hot-weather counterpart. ANOVA test results indicated significant differences between climate subdivisions at the 10% level for SLG and 5% level for ISO (Table 6), while none of the differences between climate classes were significant for any statistical measure. A Tukey-Kramer test (with a 95% experiment-wise confidence level) did not return significant differences between any pairs of subdivisions for SLG, but for ISO a significant difference (p = 0.026) was identified for the Af-Dfa pair (rainforest vs cold-winter climate without a dry season and hot summers). Players from Af climates improved their ISO by 0.036 on average, while those from Dfa climates only improved by 0.022.

CONCLUDING REMARKS

In this study, a preliminary attempt was made at investigating the role of long-term heat acclimatization by examining whether players hailing from different climate classes or subdivisions experienced statistically significant differences in offensive production between cold- and hot-weather games. The main results from this study include:

All players, regardless of the climate class in which they were born, performed better as the game-time temperature increased;

In cold-weather games, there were no significant differences between players from different climate classes or subdivisions in the statistical measures of AVG, SLG, or ISO;

In hot-weather games, there were no significant differences in AVG between players from different climate classes or subdivisions, but players from D climates hit for significantly less power (SLG and ISO) than players from C climates;

When considering differences in performance from cold- to hot-weather games for individual players, those from rainforest climates (Af) had a significantly greater improvement in ISO than those from cold-winter climates without a dry season and hot summers (Dfa).

These results may help to refute the notion that players who were born in warm climates (including the U.S. South, West Coast, and most of Latin America) struggle when temperatures are cold. While it is true that they do not perform as well in the cold as when it's hot, players from all climate classes and subdivisions do not hit well for average or power in these conditions. Previous work established the physical and physiological reasons why hitters do not perform as well in the cold, but this study shows that acclimatization to the cold, or lack thereof, at least through place of birth, does not provide any advantage.

However, also evident is the fact that the rates of improvement were more pronounced for players from classes A and C as temperatures increased. Accordingly, this does support the notion that players hailing from warmer climates hit better, relative to their peers, when temperatures increase. By extension, players hailing from cold-winter climates (class D, which includes most of the Midwest and southeastern Canada), demonstrated less improvement as temperatures increased. Surprisingly, and similar to class D players, those hailing from dry climates (class B, including much of the Interior West and Southwest of the U.S. as well as much of Mexico) generally demonstrated less improvement as temperatures increased as well. Although it is natural to assume that players originating from B climates would be accustomed to year-round warm 'weather', this particular climate class also includes mid-latitude desert and steppe, which are also associated with severe winters. In fact, Fig. 3 shows that 399 players were born in those two subdivisions. For both class B and D, their reduced rates of improvement perhaps suggest that ambient temperature has less of an effect on their offensive performance. In other words, it is possible that temperatures matter less to players hailing from cold-winter climates (even if arid).

It is noteworthy that all significant results from this study include players from D climates, but do not include the statistical measure AVG. Whether cold or hot, no significant differences existed between players from different climates with respect to accumulating hits, but players from D climates lagged behind some of their peers from other climates when it came to hitting for power in hot-weather games. While the data do not suggest a rationale for these significant differences, it is possible that these cold-climate players may not be as acclimatized to hot-weather conditions. So while they are able to hit safely at a rate similar to their peers, they are not able to drive the ball as well for extra-base hits.

One caveat when interpreting the results from this study centers around the use of birthplace when assigning climate characteristics to players. It would likely be better to base this connection on the location where players attended secondary school, which could perhaps provide a better idea of where they spent their formative years. However, obtaining such data is rather difficult while maintaining a robust dataset, and may or may not differ substantially from the climate classifications based upon birthplace. Also, considering that an upbringing characterized by socioeconomic privilege appears to increase the likelihood for success in the U.S. (Schwartz 2014), while being raised in poverty appears to be an important determining variable for success in Latin America (Vargas 2000), any potential multivariate analysis that factors in the importance of wealth and resources is rather complicated (at least, from an international perspective). However, this does open the door for further investigation on smaller scales. For example, do players born in Venezuela tend to come from a specific region within that country, and if so, how do climate, history, and socioeconomic development differ from elsewhere?

Additionally, using a singular temperature to represent the ambient conditions throughout a baseball game does not account for changes in temperature that occur during the

Table 6. ANOVA test p-values from comparing differences in individual player performance from cold-weather to hot-weather games. Values less than 0.10 are italicized, and less than 0.05 are shown in bold.

Climate	AVG	SLG	ISO
Classes	0.178	0.119	0.234
Subdivisions	0.282	*0.065*	**0.041**

three-hours that most MLB games last in open-air venues. It is recognized that temperature will usually rise during games that begin in the early afternoon and drop in those games that begin in the evening. While a game could start in an "average" temperature regime and either warm or cool into a "hot" or "cold" temperature regime, respectively, the pace of play in a game is not linear, making it difficult to parse out which ABs occurred before or after such a change in temperature regime occurred. Ideally, the temperature from the fifth inning of a typical MLB game would be the most representative since it's the approximate midpoint, but since Retrosheet does not provide this information, it would be difficult to determine for the same reason described above.

For future analysis, including apparent temperatures, which account for wind speed and humidity, could provide a better understanding of the effect of ambient conditions on offensive production. While this study shows relationships between changes in actual temperature and batting performance, the literature also suggests that physical adaptations to ambient conditions include more than just responses to temperature alone. For example, it would be insightful to determine if higher or lower levels of humidity have differential effects on players based on whether they originate from wet or dry climates. Further, while this study relied on the Köppen-Geiger climate classification to describe players' birthplaces, which considers both temperatures and precipitation, only the variable of temperature is germane to the research questions; it might be worthwhile to examine batting performance based upon aspects of the temperature of a player's birthplace.

Another dimension of this same line of inquiry that is of interest for future work is the effect of acclimatization on pitching performance. While there would likely be parallels between the findings based on batting performance (i.e., a decrease in pitching performance with increasing ambient temperature), there are unexplored dimensions that have to do with the climate in which a pitcher spent his formative years. Here, however, we would hypothesize that significant differences between pitchers may arise in cold-weather games, which is especially important since the MLB playoffs typically take place in October and early November.

FOOTNOTES

1. Wins Above Replacement is a statistical measure that considers a player's value to their team in terms of the number of wins they contribute as compared to that of a hypothetical replacement-level player.
2. At-bats are defined as "when a batter reaches base via a fielder's choice, hit or an error … or when a batter is put out on a non-sacrifice" (https://www.mlb.com/glossary/standard-stats/at-bat). Plate appearances that result in a walk, hit by pitch, catcher's interference, or a sacrifice do not count as at-bats.

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