

The decision-making process of an MLB batter: effects of feedback stimuli and anxiety on batting performance

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SUMMARY

Baseball's large pool of sports analytics has made it a popular subject for cognitive learning research. Prior experiments have been conducted on the performance of expert athletes by tracing their neural activity and decision-making processes. In baseball, research has been done in laboratory environments on batters' cognitive skills by simulating pitch-by-pitch scenarios using videos and capturing the batters' brain activity using an electroencephalogram (EEG) test. To test the external validity of laboratory findings, we intended to observe elite baseball players' perceptual cognitive expertise during real games using public data on Major League Baseball (MLB) games from Statcast. We hypothesized that feedback stimuli and anxiety would significantly increase batting performance in MLB games, consistent with results recorded in laboratory settings. To examine the effects of professional batters' superior perceptual and behavioral responses on competition performance, we randomly sampled 30 MLB players' batting data from the 2024 season and observed differences in their performance between 3 different "feedback stimuli and anxiety" levels: low, medium, and high. The Chi-square tests of this analysis demonstrated improvement in the pitch recognition ability of MLB batters when there is higher error-related feedback, which is the information provided to a person notifying them that a mistake has been made. Higher error-related feedback is also associated with a medium to high level of stress. The findings of this paper contribute to a better understanding of sports anxiety and the potential value of this dataset in the area of cognitive science.

INTRODUCTION

Examining performance at the collegiate level and above in sports has provided valuable insights into various domains of research, especially in the field of neuroscience. The mechanical act of batting can easily be captured through video or brain wave recordings, allowing for identification of the underlying mechanisms that enable the batter's expert performance, such as heightened motor control and pitch recognition. Due to advancements in tracking technology installed in baseball fields, more data has become available for analysis. However, the usage of this data has remained mostly limited to sports statistics or training purposes (1). Recent laboratory studies employ virtual reality to generate

computerized recordings of batting, as well as biomechanical profiling and verbal reports to capture expert performance. These computerized recordings are useful in optimizing player rosters, in-game strategy, and detecting biomechanical errors and patterns (1).

Batting is considered one of the most difficult actions in sports: the average speed for a fastball in Major League Baseball (MLB) is 94.1 mph, which leaves roughly 0.4 seconds for the batter to analyze the ball trajectory and make a decision on whether, and how, to hit the ball (2). The middle phase of the ball's trajectory (roughly 0.3 seconds) is crucial in the decision-making process of the batter, as this is when they determine the location and pitch type (fastball, curveball, etc.). Batters make predictions of the ball's trajectory based on predetermined visual cues, such as the pitcher's stance and pitching motion cues prior to the pitch (3). This 'instinct' in advanced batters with high behavioral accuracy (i.e. accuracy in both behavioral predictions and physical response) comes from their exceptional perceptual-cognitive ability, which includes superior cognitive processing speed, as well as enhanced attention and working memory. By using a computerized pitch recognition training device, researchers were able to improve collegiate athletes' perceptual ability, and thus accuracy in game performance, proving a correlation between perceptual-cognitive ability and behavioral accuracy (4).

Perceptual-cognitive ability is also characterized by high self-inhibition and higher attentional orientation to feedback. Experienced players also have high self-inhibition and shorter reaction times, which enables them to inhibit their impulse to hit the ball when they judge their initial prediction to be inaccurate (5). For example, if the batter predicts a fastball based on pitcher cues but observes mid-trajectory that it is a curveball, their initial prediction would be 'inaccurate', and the batter would need to have high self-inhibition to prevent themselves from hitting the pitch as they initially determined. In one study, electroencephalograms (EEGs) were used to show that expert players exhibit higher attentional orientation to feedback, represented in the EEG results as larger frontocentral positivity and feedback-related negativity, than novices (6). These neural differences suggest that experts process important cues more effectively and adjust more accurately after errors. In the same study, informative feedback was given to participants on the accuracy of their pitch analyses in batting simulations, a video task where participants were asked to determine if recordings of baseball pitches were balls or strikes. The participant being told that their pitch judgment was incorrect was a form of negative informative feedback, and as such, it simulated the error-related negativity associated with the brain's self-regulatory response to making an error.

Error-related negativity, which is a negative-going deflection in the EEG signals, is a representation of the neural reaction observed when batters receive negative informative feedback. Expert players had higher attentional orientation towards feedback to improve subsequent performance (6). Further research has shown that the feedback-related negativity experienced by college baseball players affects the accuracy of the player's next pitch analysis. The research results also suggested that feedback-related negativity may be related to the experienced batters' superior ability to adapt during a simulated plate appearance (7).

Sports-related anxiety is generally categorized into three types: cognitive (e.g., worrying, negative thoughts), behavioral (e.g., biting fingernails, fidgeting), and somatic (e.g., increased heart rate, sweating) (8). Research on competitive anxiety, the negative emotional state experienced specifically due to competition, in athletes generally uses the Sport Anxiety Scale 2 (SAS-2), a questionnaire to determine athletes' anxiety levels (8). Batting is usually affected by cognitive and somatic anxiety, as the time frame for a swing is too short to be affected by behavioral anxiety (8). In laboratory environments, it was seen that the negative stimuli affect batting performance positively, especially in more advanced players (9). However, the external validity of this finding is uncertain as in real games, anxiety can come from errors during play, slumps, spectators, consecutive defeats, the opposing/same-team players and coaches, and more (10). Somatic and cognitive competitive anxiety during real games might cause attentional shifting towards negativity, which impairs athletes' ability to focus on batting. In a survey study of anxiety in baseball players, errors during play were the most commonly identified cause for anxiety during baseball competitions (10). However, in previous studies, professional baseball players displayed a more flexible attentional shifting compared to rookie players (10). Contrary to the popular belief that anxiety is negatively correlated with sports performance, it was shown that competitive anxiety is positively correlated with activity in the middle temporal gyrus of the brain, resulting in improvement in decision-making accuracy of the participating baseball players.

Laboratory experiments are unable to account for several of the factors of anxiety mentioned above during real games. To further investigate expert players' perceptual cognitive performance under competitive anxiety during real games, we analyzed real MLB game data. We intended to see if the influence of anxiety and negative stimuli on batting performance is visible in big data from MLB games recorded in non-laboratory settings. Our study, like in previously referenced experiments, defined errors during play as a negative stimulus (represented by the number of strikes). As our analysis used real game data, it also inevitably included the effects of all types of on field anxiety and thus offered a more holistic evaluation of the effects of somatic and cognitive anxiety on batting.

Our analysis used four different stress levels associated with the sequence of bats in a batting appearance. The four stress levels were no to low anxiety (the first bat of a plate appearance), low anxiety (second bat at 1 strike and 0-1 outs), medium anxiety (bats at 2 strikes and 0-1 outs), and high anxiety (bats at 2 strikes, 2 outs, and with 2 runners on base). These stress levels were determined by three elements: strikes, runners on base, and outs. As strikes are caused by misjudgments or mistakes made by the batter

themselves, it serves as a negative stimulus that causes error-related negativity. Strikes are a source of stress as well: at three strikes, a "strikeout" occurs and the batter is out, which negatively affects the game and may also affect their teammates' perception of them. Runners on base are also a potential stressor and anxiety factor for batters, due to the possibility of letting down their teammates and their previous efforts. Outs are another cause of external stress. The fear of hitting the final out of an inning is especially great, due to the pressure of keeping the offensive momentum, and not letting down the batters after them.

We hypothesized that feedback stimuli and anxiety would significantly increase batting performance in MLB games, consistent with results recorded in laboratory settings. Our analysis not only confirmed the external validity of previous laboratory experiments but also demonstrated the applicability of real-game data.

RESULTS

Using the public MLB database, Statcast, we obtained data on the batting results of different plate appearances of 30 randomly selected batters with more than 1500 pitches from the 2024 season (11). We filtered the data using a preprocessor to remove all outlier data. The remaining data was organized into a frequency table with the independent variable 'anxiety and feedback stimuli' and dependent variable 'batting performance' (Table 1).

The upper 3 rows in both tables are positive results: strong-hit, weak-hit, and ball. Row 1, "strong-hit," is categorized as bats with an initial velocity above 70 mph and within a 9 to 50 (exclusive) degree launch angle. It means that the batter has correctly predicted the pitch trajectory and successfully executed the bat. Strong-hit fouls are struck by solid contact, so they are also included in this row; bunts are excluded.

	No to Low Anxiety		Low Anxiety		Medium Anxiety		High Anxiety		Total Pitches
	1. First Bat 0S/0-1O (obs./exp.)		2. Second Bat 0-1S/0-1O (obs./exp.)		3. Bat At 2S/0-1O (obs./exp.)		4. Bat At 2S/2O/RB (obs./exp.)		
Strong Hit	1497 (9%)	1844	1683 (12%)	1626	829 (14%)	687	550 (18%)	402	4559
Weak Hit	2110 (13%)	2783	2567 (18%)	2454	1335 (23%)	1037	869 (25%)	607	6881
Ball	5939 (37%)	6062	5252 (37%)	5345	2521 (43%)	2257	1275 (37%)	1323	14987
Strike Miss	1043 (7%)	1175	1197 (9%)	1037	399 (7%)	438	278 (8%)	257	2907
Strike Looking	4622 (29%)	2982	2343 (17%)	2629	262 (4%)	1111	146 (4%)	651	7373
Ball Miss (Chase)	886 (4%)	1051	975 (7%)	926	585 (10%)	391	352 (10%)	230	2598
Total Pitches	15897		14017		5921		3470		39305

Table 1: Chi-square contingency table of batters' performance in response to different anxiety levels. Observed and expected frequencies of different batting outcomes by different batting conditions, based on a subsample of 39,305 pitches of the original samples of 62,778 pitches from the 2024 MLB season. Chi-square tests of independence run using a python program. Results for chi-square test of independence between column 2 and 3: chi-square X^2 statistic 629, p-value <0.0001, df 5 (n=5). Results for chi-square test of independence between column 2 and 4: chi-square X^2 statistic 443, p-value<0.0001, and df 5 (n=5). The percentages under observed counts indicate the proportional distribution of batting outcomes at different anxiety levels. S = strike, O = out, RB = runners on base.

Row 2, “weak-hit,” also means that the batter made a correct prediction of the pitch’s trajectory; however, the bat has a lower initial velocity. Weak-hit fouls are also included in this row, while bunts are excluded. Row 3, “ball” is defined as when a batter does not swing at a pitch, and it is not called a strike. If the batter avoids swinging at a ball outside of the strike zone, it is likely they observed discrepancies in the pitch’s actual trajectory vs the predicted trajectory and effectively used self-inhibition to stop themselves from hitting the ball.

The lower three rows in the table are negative results: strike miss, strike looking, and chase. Row 4, “strike miss” is when the batter swings at a pitch but misses. A strike miss might mean that a batter successfully predicted that the pitch would be a strike but had an incorrect prediction of the exact trajectory or pitch type. It could also be a result of a correct prediction of the pitch trajectory but an unsuccessful swing. Row 5, “strike looking,” is when a batter fails to swing at a strike. Strike-lookings are likely due to an incorrect prediction of the pitch trajectory or failure during mid-trajectory to notice and correct inaccuracies in their prediction. Row 6, “chase,” is when a batter swings at a “ball” and misses. Chases could be due to incorrect prediction of the pitch’s trajectory or type. However, a batter could have also noticed discrepancies between their prediction of the pitch trajectory and the actual trajectory but had insufficient self-inhibition to stop themselves from swinging.

To assess if the independent variable (anxiety and feedback stimuli) affected the dependent variable (batting performance), we performed two Chi-square tests of independence. To prevent higher false positive results from multiple comparisons, we applied the Bonferroni correction on our test results by using an adjusted α -level of 0.025.

We ran the first Chi-square test on low anxiety versus medium anxiety, which determined there is a significant positive correlation between anxiety/stress level and batting performance ($p < 0.0001$). The second Chi-square test compared low anxiety and high anxiety and determined they are significantly different ($p < 0.0001$).

Our analysis demonstrated that the difference between different anxiety levels is statistically significant, suggesting that the observed relationship between the level of anxiety and batting performance is not due to chance. We also calculated Cramer’s V for both tests for their effect sizes to make our findings more robust, since Chi-square is very sensitive to large sample sizes and can often result in false positives. For low anxiety and medium anxiety, the Cramer’s V is 0.1765; for low anxiety and high anxiety, the Cramer’s V is 0.15783. Based on the degree of freedom ($df=5$), a Cramer’s V of less than 0.05 signifies negligible association, 0.05 to 0.13 signifies small association, 0.13 to 0.22 signifies medium association, and greater than 0.22 signifies large association. Both tests signified medium strengths of association, meaning that although there is a definite association between stress and performance, stress cannot be used as the sole factor in predicting batter performance. Therefore, there is convincing evidence that there is a correlation between anxiety/ stress and batting performance (i.e., higher anxiety corresponded with a higher percentage of strong hits and higher hit rates).

The percentage of “strong hits” (bats that equal to or exceed 70 mph) increased from 12% in low anxiety to 14% in medium anxiety and 16% in high anxiety, suggesting that batters were able to more accurately predict pitch type and

pitch location when they had higher stress (Table 1). The percentage of “balls” (a positive outcome) also increased from 37% to 43% meaning that pitch recognition improved. “Strike miss” (a negative outcome) remained at a similar percentage between different stress levels, while “strike looking” (a negative outcome) was greatly decreased, which meant that higher stress and higher error-related feedback stimuli allowed batters to identify which pitches were in the strike zone. However, “chase” increased proportional to stress and error-related feedback stimuli. This indicates the possibility that the batters’ self-inhibition of their impulse to hit the ball may be weakened by anxiety and error-related feedback stimuli (5). Additionally, in high anxiety, which includes bats at two strikes, two outs, and with two runners on base, batters are likely to feel high anxiety, as they not only have high error-related negativity (2 strikes), but also high external-stress (2 outs). Having two runners on base increases the external-stress of the batter, as it causes the bat to have a greater impact on the score (and outcome) of the game.

DISCUSSION

This study showed that MLB players’ superior cognitive perceptual skills were enhanced by negative feedback stimuli and anxiety as seen from the improved playing performance (better batting outcomes) given higher stress situations. Our analysis of real MLB game data from Statcast corroborated the findings of controlled laboratory experiments on the effects of anxiety on batting performance.

Laboratory studies have shown that elite baseball players exhibit distinctive neural patterns reflecting their exceptional perceptual abilities. This study extended that research by analyzing real game data to identify patterns of this perceptual–cognitive skill. Our analysis mostly focused on error-related feedback as a source of stress/anxiety. However, batter anxiety can result from several other factors, including the current score of the game. Especially in close game situations, the batter may feel additional anxiety. Anxiety levels may also be influenced by when the pitch occurs during the game. This analysis also ignored the effect of the pitcher and pitch types on batter performance. Pitcher fatigue can lead to changes in pitch type and velocity over the course of plate appearances or over the course of the game. As such, the game phase in which the plate appearance takes place can be a confounding variable. If there is higher pitcher fatigue during a certain plate appearance, pitches may have a lower average velocity and pitch types could be more predictable. The batter, if anticipating slower pitch velocity, may feel lower anxiety. Score differential is another possible source of anxiety for the batter, as a smaller gap between the two teams’ scores (representing a close game) may heighten performance-related anxiety. Future work should adjust measures of batting performance and anxiety to account for the effects of pitcher fatigue and score differentials (12).

As this analysis suggested the influence of error-related feedback and anxiety on the performance of baseball batters, an extended study could use a predictive model to detect more specific patterns in how players may be affected. However, the high anxiety data in our table does not exclude bats with “balls” in between the strikes of that plate appearance and the current pitch, so it is uncertain whether the most immediate stimulus (performance feedback) is positive or negative; this will need to be taken into consideration for future studies of

the effects of error-related feedback. Additionally, since the Statcast database also provides real game data in the same format for Minor League Baseball, a similar analysis could be conducted on minor league players to examine if anxiety and stress affect the performance of elite players and semi-elite players differently. We might be able to find evidence in real game data that elite players have more flexible attentional-shifting than semi-professional players, as seen in laboratory-controlled experiments (9).

It is clear from the trends seen in the MLB Statcast database discussed in this paper that professional MLB batters have exceptional cognitive perceptual skills that allow them to be resilient to the common effects of anxiety/stress. However, the underlying neural mechanisms are still relatively unknown. Although laboratory-controlled experiments using EEG tests can locate the physical part of the brain that is responsible for the batters' cognitive perceptual ability, they are unable to track the development of this ability over time. Therein lies the value of real game data from Statcast—data tracking the players' performances over the length of their career is bound to contain insight on the development of their cognitive perceptual ability that is yet to be uncovered. This study established a measurable representation of anxiety in real game data that corroborates the effects of anxiety on game performance found in laboratory experiments. Our research demonstrated the potential of big game data in cognitive research, as mining patterns from this data provided aspects of players' cognitive abilities.

MATERIALS AND METHODS

Study design

All data used in this analysis was obtained from the public domain database, Baseball Savant by the MLB Advanced Media, LP (11).

The operational definition of "anxiety" was stated as the error-related feedback from strikes in the same plate appearance and stress from the number of outs and the number of runners on base at bat. The above was considered external stress factors for baseball players. The independent variables used were the level of feedback stimuli and anxiety for the batter during a pitch. The dependent variable examined was the batting performance (outcomes) of the batter at the given feedback stimuli and anxiety level.

Data collection

Data was collected from the MLB's Statcast database, which has information on a pitch-by-pitch basis for individual players since 2014. The population for this analysis was MLB batters with at least 1500 pitches during the regular season in 2024. The pitches were randomly selected through cluster random sampling, with each batter being a "cluster". Out of the 216 MLB batters that met our inclusion criteria, 30 batters were randomly selected and their bats from the season were analyzed. There was a total of 731,960 pitches in the 216-batter population, and the 30 batters included in the study played a total of 62,778 pitches. As the total pitches analyzed in the sample (62,778 pitches) was less than 10% of the total pitches in the population (731,960 pitches), the 10% condition for sampling without replacement was satisfied and the observations in the sample were treated as independent.

The sample was obtained by downloading all 216 graphs containing player data. 30 of the raw MLB Comma-Separated

Values (CSV) files were randomly selected and processed by the Python program by extracting the needed data columns. Prior to the data analysis, the data was pre-processed to remove all outlier data (e.g., eephus pitch which are intentionally slow pitches), non-applicable data (e.g., hit-by-pitch, bad data, blank data), and strategic plays (e.g. "intentional walk", "bunt"). The columns used were "at_bat_number", "strikes", "balls", "description" "zone", "plate_x", "plate_z", "on_1b", "on_2b", "on_3b", "outs_when_up", "launch_speed", "launch_angle".

Batting performance

To measure batting performance, batting results were categorized into 6 different outcomes. From the most to the least desirable outcome, the categories used were strong hit, weak hit, ball, strike miss (a swing and a miss), strike looking (a strike without a swing), and chase (to swing at a pitch outside the strike zone). We used the "description" column from the downloaded CSV files as the primary source of information in assessing batting performance for each pitch. A secondary source used in determining which category a bat falls into was the initial velocity of a bat (determined using the columns "launch_speed" and "launch_angle"). The initial velocity of the bat was used to determine if a hit should be categorized into strong hit or weak hit. "Strong hit" was defined as a hit ball that is equal to or exceeds 70 mph (as recorded in the data column "launch speed) and between 5 to 50 degrees above ground (as recorded in the data column "launch_angle"). All other hits that fall outside of either range were categorized as a "weak hit". The "zone" column was used to examine if there was a discrepancy between the umpire's call in "description" and the actual ball location. However, due to the possible inaccuracy of this column (as it is computer recorded), we also used information from columns "plate x coordinate" and "plate z coordinate" to ascertain the accuracy of the "zone" column and to correct any possible inaccuracies.

Levels of anxiety

The three variables used to represent stress and anxiety were the number of strikes, runners on base, and outs when the player was at bat. Strikes occurred when a player either swung and missed a pitch, or if the pitch was called as a strike after the player didn't swing. In our analysis, we assumed that the more strikes the batter has, the higher the stress. The number of runners that were on base when the batter was up is also a source of external-stress, as having runners on base caused the bat to become higher-leverage (such that it was a game-changing moment). Another cause of external stress was the number of outs when the batter was up, due to expectations from their team, the crowd, and themselves.

Chi-square test tables

The columns (containing both observed and expected values) are the groups of the categorical variable (first bat, second bat, bat at 2S/0-1O, and bat at 2S/2O/RB), which are mutually exclusive (**Table 1**). Column 1, the first bat of a plate appearance (titled "first bat"), included all first bats of different plate appearances during the game. The bats in this column were not necessarily for the first pitch of the game. At the first bat, there are 0 strikes and 0-1 outs (first bats with 2 outs are excluded), so batters may feel no to low anxiety at the first bat. The exceptionally high proportion of "strike looking" (31%) showed that the batters' response to the first bat could be

influenced by confounding variables such as game strategy, thus the first bat was excluded from the tests as it was likely not determined exclusively by the batter's batting perception. Column 2, the "second bat" includes all bats under the condition of one strike and 0-1 out during the plate appearance. Column 3 includes bats at 2 strikes and 0-1 outs that directly follow a prior strike. When the player has made two strikes, they are likely to feel medium anxiety, due to the error-related feedback from prior misjudgments of pitch trajectory. Since there could be 0 or 1 outs during these pitches, there is varying external-stress for the player. Column 4 included bats at two strikes, two outs, and with two runners on base.

ACKNOWLEDGMENTS

We would like to express our gratitude to Coach Tony Liao for giving us the inspiration for this project, and for bringing his expertise in baseball to this project. He has helped us to realize the possible applications of statistical methods in baseball research.

We would also like to thank FY's father, Tzuwen Yao, for mentoring FY in the use of Python to process the data files used in this project.

Last but not least, thank you to Ms. Binh Pham-Valentukonis for reviewing this paper.

Received: June 11, 2025

Accepted: October 29, 2025

Published: May 26, 2026

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APPENDIX

https://github.com/Fifyao/MLB_Python/blob/main/read_MLB.py