

Predicting In-Game Actions from Interviews of NBA Players

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Sports competitions are widely researched in computer and social science, with the goal of understanding how players act under uncertainty. Although there is an abundance of computational work on player metrics prediction based on past performance, very few attempts to incorporate out-of-game signals have been made. Specifically, it was previously unclear whether linguistic signals gathered from players' interviews can add information that does not appear in performance metrics. To bridge that gap, we define text classification tasks of predicting deviations from mean in NBA players' in-game actions, which are associated with strategic choices, player behavior, and risk, using their choice of language prior to the game. We collected a data set of transcripts from key NBA players' pre-game interviews and their in-game performance metrics, totalling 5,226 interview-metric pairs. We design neural models for players' action prediction based on increasingly more complex aspects of the language signals in their open-ended interviews. Our models can make their predictions based on the textual signal alone, or on a combination of that signal with signals from past-performance metrics. Our text-based models outperform strong baselines trained on performance metrics only, demonstrating the importance of language usage for action prediction. Moreover, the models that utilize both textual input and past-performance metrics produced the best results. Finally, as neural networks are notoriously difficult to interpret, we propose a method for gaining further insight into what our models have learned. Particularly, we present a latent Dirichlet allocation-based analysis, where we interpret

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*model predictions in terms of correlated topics. We find that our best performing textual model is most associated with topics that are intuitively related to each prediction task and that better models yield higher correlation with more informative topics.*¹

1. Introduction

Decision theory is a well-studied field, with a variety of contributions in economics, statistics, biology, psychology, and computer science (Einhorn and Hogarth 1981; Berger 1985). Although substantial progress has been made in analyzing the choices that agents make, prediction in decision-making is not as commonly researched, partly due to its challenging nature (Gilboa 2009). Particularly, defining and assessing the set of choices in a real-world scenario is difficult, as the full set of options that an agent faces is usually unobserved, and her decisions are only inferred from their outcomes.

One domain where the study of human action is well defined and observable is sports, in our case, basketball. Professional athletes are experts in decision-making under uncertainty, and their actions, along with their outcomes, are well-documented and extensively studied. While there are many attempts to predict game outcomes in basketball, including win probability, players' marginal effects, and the strengths of specific lineups (Coate 2012; Ganguly and Frank 2018), they are less focused on the decisions of individual players.

Individual player actions are difficult to predict as they are not made in lab conditions and are also a function of "soft" factors such as their subjective feelings regarding their opponents, teammates, and themselves. Moreover, such actions are often made in response to the decisions that their opponents and teammates make. Currently, sports analysts and statisticians who try to predict such actions do so mostly through past performances, and their models do not account for factors such as those mentioned above (Kaya 2014).

However, there is an additional signal, ingrained in fans' demand for understanding the players' current state: pre-game interviews. In widely successful sports such as baseball, football, and basketball, top players and coaches are regularly interviewed before and after games. These interviews are usually conducted to get a glimpse of how players and coaches are currently feeling and allow them to share their thoughts, given the specifics of the upcoming game and the baggage they are carrying from previous games. Following the sports psychology literature, we wish to use these interviews to gain insight about the players' emotional state and its relation to actions (Uphill, Groom, and Jones 2014).²

In the sports psychology literature, there is a long-standing attempt to map the relationship between what this literature defines as "emotional state" and performance. The most popular account of such a relationship is the model of Individual Zones of Optimal Functioning (IZOF) (Hanin 1997). IZOF proposes that there are individual differences in the way athletes react to their emotional state, with each having an optimal level of intensity for each emotion for achieving top performance. IZOF suggests viewing emotions from a utilitarian perspective, looking at their helpfulness in achieving individual and team goals, and aims to calibrate the optimal emotional state for each player to perform at her best.

1 Code is available at: <https://github.com/nadavo/mood>.

2 Building on this literature, we use this concept of "emotional state" freely here and note that although some similarities exist, it is not directly mapped to the psychological literature.

In this paper we build on that literature and aim to predict actions in basketball, using the added signal provided in the interviews. We explore a multimodal learning scheme, exploiting player interviews alongside performance metrics or without them. We build models that use as input the text alone, the metrics, and both modalities combined. As we wish to test for the predictive power of language, alone or in combination with past performance metrics, we look at all three settings, and discuss the learned representation of the text modality with respect to the “emotional state” that could be captured through the model.

We treat the player’s deviation from his mean performance measure in recent games as an indication to the actions made in the current game. By learning a mapping from players’ answers to underlying performance changes, we hope to integrate a signal about their thoughts into the action prediction process. Our choice to focus on deviations from the mean performance, and not on absolute performance values, is also useful from a machine learning perspective: It allows us to generalize across players, despite the differences in their absolute performance. We leave a more in-depth discussion of the formulation of our prediction task for later in the article (Section 4).

Being interested in the added behavioral signal hidden in the text, we focus on the task (Section 4) of predicting metrics that are associated in the literature with in-game behavior and are endogenous to the player’s strategic choices and mental state: shot success share on the offensive side, and fouls on the defensive side (Goldman and Rao 2011). We further add our own related metrics: the player’s mean shot location, his assists to turnovers ratio, and his share of 2-point to 3-point shot attempts. We choose to add those metrics as they are measurable on a play-by-play basis, and are interesting measures of relative risk. We believe our proposed measures can isolate to some extent the risk associated with specific types of decisions, such as when to pass, when to shoot, and where to do it.

Almost no single play result is a function of only one player’s action; yet, our positive results from models that exploit signals from individual players only (Section 7) indicate that meaningful predictions can be made even without direct modeling of inter-player interactions. As this is a first report on the topic, we leave for future work an exploration of how player interactions can be learned, noting that such an attempt will surely entail a more complex model.³ Also, we believe that if the interviews provide a strong signal regarding players’ in-game decisions, it should be observed even when interactions are not explored. Hopefully, our work will encourage future research that considers interactions as well.

We collected (Section 3) a data set of 1,337 interviews with 36 major NBA players during a total of 14 seasons. Each interview is augmented with performance measures of the player in each period (quarter) of the corresponding game. To facilitate learnability, we focus on NBA all-stars as they are consistently interviewed before games, and have played key roles throughout their career. Also, the fact that many players in our data set are still active and are expected to remain so in the following years, gives us an opportunity to measure our model’s performance and improve it in the future.

We start by looking at a regression model as a baseline for both the text-only and the metrics-only schemes. Then, we experiment with structure-aware neural networks for their feature learning capabilities and propose (Section 5) models based on long short-

³ There are novel attempts to estimate players’ partial effect on the game (Gramacy, Taddy, and Tian 2017), which constitute estimating the difference they make on final game outcomes. However, in this research we decided to focus on metrics that can be attributed to specific types of decisions and not to overall game outcomes.

term memory (LSTM) (Hochreiter and Schmidhuber 1997) and convolutional neural network (CNN) (LeCun et al. 1998). Finally, to better model the interview structure and to take advantage of recent advancements in contextual embeddings, we also use a BERT-based architecture (Vaswani et al. 2017; Devlin et al. 2019) and explore the trade-off between a light-weight attention mechanism and more parameter-heavy alternatives (Section 5).

Our results (Sections 6, 7) suggest that our text-based models are able to learn from the interviews to predict the player's performance metrics, while the performance-based baselines are not able to predict much better than a coin flip or the most common class, a phenomenon we try to explain in Section 7.

Interestingly, the models that exploit both the textual signal and the signal from past performance metrics improve on some of the most challenging predictions. These results are consistent with the hypothesized relationship of mental state and performance, and support claims in the literature that such an "emotional state" has predictive power on player performance (Lazarus 2000; Hanin 2007).

Our contributions to the sports analytics and natural language processing (NLP) literature are as follows: (1) We provide the first model, as far as we know, that predicts player actions from language. (2) Our model is the first that can predict relative player performance without relying on past performance. (3) On a more conceptual level, our results suggest that the player's "emotional state" is related to player performance.

We support our findings with a newly proposed approach to qualitative analysis (Section 8). As neural networks are notoriously difficult to directly interpret, we choose to analyze text-based neural network models via topic modeling of the texts associated with the model's predictions. Alternative approaches for model explanations do not allow for reasoning over higher-level concepts such as topics. Hence, we believe this could be a beneficial way to examine many neural models in NLP and view this as an additional contribution we present in this paper.

This analysis includes a comparison of our best performing models and finds that our BERT-based model is most associated with topics that are intuitively related to each prediction task, suggesting that the hypothesized "emotional state" from the sports psychology literature could have been learned. Additionally, we find that this correlation becomes stronger as the confidence of the model in its prediction increases, meaning that a higher probability for such topics corresponds to higher model confidence. Finally, we compare our models and observe that better performing models yield higher correlation with more informative topics.

In conclusion, we believe that this article provides evidence for the transmission of language into human actions. We demonstrate that our models are able to predict real-world variables via text, extending a rich NLP tradition and literature about tasks such as sentiment analysis, stance classification, and intent detection that also extract information regarding the text author. We hope this research problem and the high-level topic will be of interest to the NLP community. To facilitate further research we also release our data and code.

2. Related Work

Previous work on the intersection of language, behavior, and sports is limited because of the rarity of relevant textual data (Xu, Yu, and Hoi 2015). However, there is an abundance of research on predicting human decision-making (e.g., Hartford, Wright, and Leyton-Brown 2016; Plonsky et al. 2017; Rosenfeld and Kraus 2018), on using language to predict human behavior (Niculae et al. 2015; Sim, Routledge, and Smith

2016), and on predicting outcomes in basketball (Cervone et al. 2014; Ganguly and Frank 2018). Because we aim to bridge the gap between the different disciplines, we survey the relevant work in each.

2.1 Prediction and Decision-Making

Previous decision-making work is both theoretical—modeling the incentives individuals face and the equilibrium observed given their competing interests (Gilboa 2009), and empirical—aiming to disentangle causal relationships that can shed light on what could be driving actions observed in the world (Kahneman and Tversky 1979; Angrist and Pischke 2008).

There are some interesting attempts at learning to better predict human action (Erev and Roth 1998; Wright and Leyton-Brown 2010; Hartford, Wright, and Leyton-Brown 2016), but the task at hand is usually addressed in lab conditions or using synthetic data. In a noisy environment it becomes much harder to define the choice set, that is, the alternatives the agent faces, and to observe a clear outcome, the result of the action taken. In our setting we can only observe proxies to the choices made, and they can only be measured discretely, whenever a play is complete. Moreover, we cannot easily disentangle the outcome of the play from the choices that drove it, because actions are dependent on both teammates and adversaries.

Our work attempts to integrate linguistics signals into a decision prediction process. Language usage seems to be informative about the speaker’s current state of mind (Wardhaugh 2011) and his personality (Fasold and Stephens 1990). Yet this is rarely explored in the context of decision-making (Gilboa 2009). Here, we examine whether textual traces can facilitate predictions in decision-making.

2.2 NLP and Prediction of Human Behavior

NLP algorithms, and particularly deep neural networks (DNNs), often learn a low-dimensional language representation with respect to a certain objective and in a manner that preserves valuable information regarding the text or the agent producing it. For example, in sentiment analysis (Pang, Lee, and Vaithyanathan 2002) text written by different authors is analyzed with respect to the same objective of determining whether the text conveys positive or negative sentiment. This not only reveals something about the text, but also about the author—her personal stance regarding the subject she was writing about. One can view our task to share some similarity with sentiment classification as both tasks aim to learn something about the emotional state of the author of a given text.

A key difference between the two tasks, however, that poses a greater challenge in our case, is that in our task the signal we are aiming to capture is not clearly visible in the text, and requires inferring more subtle or abstract concepts than positive or negative sentiment. Given a movie review, an observer can guess if it is positive or negative rather easily. In our case, it is unclear where in the text the clue is regarding the players’ mental state, and it is even less clear how it will correspond to their actions. Moreover, the text in our task involves a form of structured dialog between two speakers (the player and the interviewer), which entails an additional level of complexity on top of the internal structures present for each speaker independently.

In a sense, our question is actually broader. We want to examine whether textual traces can help us in the challenging problem of predicting human action. There is a longstanding claim in the social sciences that one could learn information about a

person's character and his behavior from their choice of language (Fasold and Stephens 1990; Bickerton 1995; Wardhaugh 2011), but this claim was not put to test in a real-world setting such as those we are testing in. Granted, understanding character from language and predicting actions from language are quite different. However, if it is the case that neural networks could learn a character-like context using the final action as the supervision sign, it could have substantial implications for language processing and even the social sciences.

In the emerging field of computational social science, there is a substantial effort to harness linguistic signals to better answer scientific questions (Danescu-Niculescu-Mizil et al. 2013). This approach, also known as text-as-data, has led to many advancements in the prediction of stock prices (Kogan et al. 2009), understanding of political discourse (Field et al. 2018), and analysis of court decisions (Goldwasser and Daumé III 2014; Sim, Routledge, and Smith 2016). Our work adds another facet to this literature, trying to identify textual signals that enable the prediction of actions that are not explicitly mentioned in the text.

2.3 Prediction and Analysis in Basketball

Basketball is at the forefront of sports analytics. In recent decades, there have been immense efforts to document every aspect of the game in real-time, and currently for every game there are data capturing each play's result, player and ball movements, and even crowd generated noise. Researchers have used this data to solve prediction tasks about game outcomes (Kvam and Sokol 2006; Ganguly and Frank 2018), points and performance (Cervone et al. 2014; Sampaio et al. 2015), and possession outcome (Cervone et al. 2016).

Recent work has also explored mechanisms that facilitate the analysis of the decisions that players and coaches make in a given match (Bar-Eli and Tractinsky 2000; Kaya 2014). Some have tried to analyze the efficiency and optimality of decisions across the game (Goldman and Rao 2011; Wang et al. 2018), whereas others have focused on the decisions made in the final minutes of the game, when they are most critical (McFarlane 2018). Also, attempts have been made to model strategic in-game interactions in order to simulate and analyze counterfactual scenarios (Sandholtz and Bornn 2018) and to understand the interplay in dynamic space creation between offense and defense (Lamas et al. 2015). We complement this literature by making text-based decision-related predictions. We address the player's behavior and current mental state as a factor in analyzing his actions, whereas previous work in sports analytics focused only on optimality considerations. Following the terminology of the sports psychology literature, we attempt to link players' emotional/mental state, as manifested in the interviews, to the performance, actions, and risk-taking in the game (Hanin 1997; Uphill, Groom, and Jones 2014).

3. Data

We created our data set with the requirement that we have enough data on both actions and language, from as many NBA seasons as possible and for a variety of players. Although the number of seasons is constrained by the availability of transcribed interviews, we had some flexibility in choosing the players. To be able to measure a variety of actions and the corresponding interviews across time, we chose to focus on players who were important enough to be interviewed repeatedly and crucial enough for their team so that they play throughout most of the game. These choices allowed us to measure

player performance not only at the game level, but also in shorter increments, such as the period level.

Our data set is therefore a combination of two resources: (1) a publicly available play-by-play data set, collected from basketball-reference.com; and (2) the publicly available interviews at ASAPsports.com, collected only for players who were interviewed in more than three different seasons. Interviews were gathered from the 2004–2005 basketball season up until June 2018. As this data set comes from a fairly unexplored domain with regard to NLP, we follow here with a basic description of the different sources. For a more detailed description and advanced statistics such as common topics, interview length, and player performance distributions, please see Tables 2, 3 and 4.

We processed the play-by-play data to extract individual metrics for each player in each game for which that player was interviewed. The metrics were collected at both the game and the period level (see Section 4 for the description of the metrics). We aggregated the performance metrics at the period level to capture performance at different parts of the game and reduce the effects of outliers.⁴ This is important because performance in the first quarter could have a different meaning than performance in the last quarter, where every mistake could be irreversible. Each interview consists of question-answer pairs for one specific player, and hence properties like the interview length and the length of the different answers are player-specific. Key players are interviewed before each game, but we have data mostly for playoff games, because they were the ones that were transcribed and uploaded.⁵ This bias makes sense since playoff interviews are more in-depth and they attract a larger audience. Overall, our data set consists of 2,144 interviews, with some players interviewed twice between consecutive games. After concatenating such interviews we are left with 1,337 interviews from 36 different players, and the corresponding game metrics for each interview. The total number of interview-period metric pairs is 5,226.

We next describe our in-game play-by-play data and the pre-game interviews, along with the processing steps we apply to each.

3.1 In-Game Play-by-Play

Basketball data are gathered after each play is done. As described in our “basketball dictionary” in Table 1, a play is any of the following events: Shot, Assist, Block, Free Throw, Rebound, Foul, Turnover, Violation, Time-out, Substitution, Jump Ball, and Start and End of Period. We ignore Time-outs, Jump Balls, Substitutions, and Start/End of Period plays as they do not add any information with respect to the metrics that we are monitoring. If a shot was successful, there could be an assist attributed to the passing player. Also, we observe for every foul the affected player and the opponent charged, as well as the player responsible for each shot, miss, free throw, and lost ball. For every shot taken, there are two location variables, indicating the shot’s coordinates on the court, with which we calculate relative distance from the basket (see Figure 1). We use those indicators to produce performance metrics for each period.

For each event there are 10 variables indicating the five-player lineup per team, which we use to monitor whether a player is on court at any given play. In a typical NBA

⁴ There are four periods in a basketball game, not including overtime. We do not deal with overtime performance as it might be less affected by the player pre-game state, and more by the happenings in the four game periods.

⁵ See Section 3.2 for an explanation on NBA playoffs.

Table 1

Descriptions for basketball terms used in our data set. Explanations and rules derived from the official NBA rule book at: <https://official.nba.com/rulebook/>, and the Basketball Wikipedia page at: <https://en.wikipedia.org/wiki/Basketball>.

Term	Description
Shot	Attempting to score points by throwing the ball through the basket. Each successful shot is worth 3 points if behind the 3 point arc, and 2 otherwise.
Assist	Passing the ball to a teammate that eventually scores without first passing the ball to any other player.
Block	Altering an attempted shot by touching the ball while still in the air.
Free Throw	Unopposed attempts to score by shooting from behind the free throw line. Each successful free throw is worth one point.
Rebound	Obtaining the ball after a missed shot attempt.
Foul	Attempting to unfairly disadvantage an opponent through certain types of physical contact.
Turnover	A loss of possession by a player holding the ball.
(Shot Clock) Violation	Failing to shoot the ball before the shot clock expires. Results in a turnover to the opponent team.
Time-out	A limited number of clock stoppages requested by a coach or mandated by the referee for a short meeting with the players.
Substitution	Replacing one player with another during a match. In basketball, substitutions are permitted only during stoppages of play, but are otherwise unlimited.
Jump Ball	A method used to begin or resume the game, where two opposing players attempt to gain control of the ball after an official tosses it into the air between them.
Period	NBA games are played in four periods (quarters) of 12 minutes. Overtime periods are 5 minutes in length. The time allowed is actual playing time; the clock is stopped while the play is not active.

game, there are about 450 plays. Because we are only collecting data for key players, they are present on court during the vast majority of the game, totalling an average of 337 plays per player per game, for an average of 83 plays per period. For each period, we aggregate a player's performance through the following features: Points, Assists, Turnovers, Rebounds, Field goals made and missed, Free throws made and missed, and mean and variance of shot distance from basket, for both successful and unsuccessful attempts. We build on these features to produce metrics that we believe capture the choice of actions made by the player (see Section 4). Table 2 provides each player's mean and standard deviation values for all performance metrics. The table also provides the average and standard deviation of the metrics across the entire data set, information that we use to explain some of our findings in Section 7 and modeling decisions in Section 4.

3.2 Pre-game Interviews

NBA players are interviewed by the press before and after games, as part of their contract with their team and with the league. The interviews take place on practice day, which is the day before the game, and on-court before, during, and after the game. An NBA season has 82 games per team, for all 30 teams, spread across 6 months, from

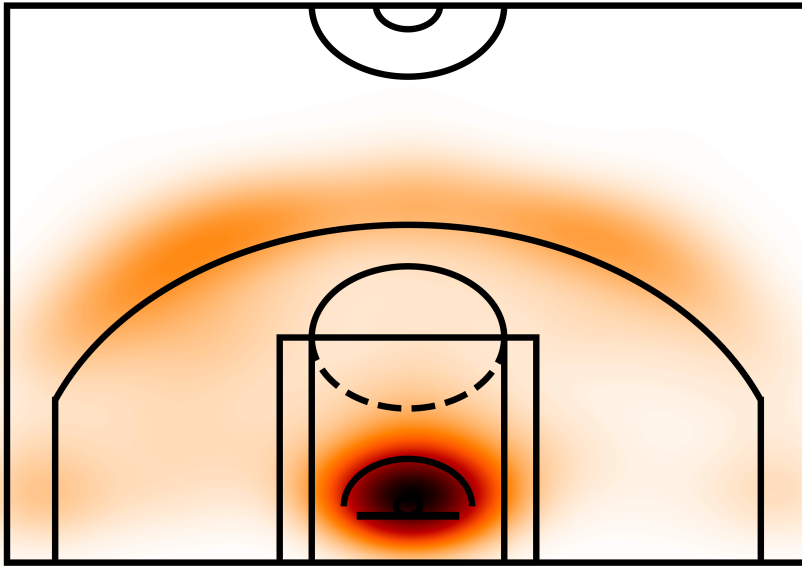


Figure 1
 Shot location of all attempted shots for all the players in our data set. A darker color represents more shots attempted at that location. Black lines represent the structure of one of the two symmetric halves of an NBA basketball court.

October to April. Then, the top eight teams from each conference, Eastern and Western, advance to the playoffs, where teams face opponents in a knockout tournament composed of a best-of-seven series. Playoff games gather much more interest, resulting in more interviews, which are more in-depth and with much more on the line for players and fans alike. Our data set is hence composed almost solely from playoff game data.

Interviews are open-ended dialogues between an interviewer and a key player from one of the teams, with the length of the answers depending solely on the players, and the number of questions depending on both sides.⁶ Questions tend to follow on player responses, in an attempt to gather as much information about the player’s state of mind as possible. For example:

Q: “On Friday you spoke a lot about this new found appreciation you have this postseason for what you’ve been able to accomplish. For most people getting to that new mindset is the result of specific events or just thoughts. I’m wondering what prompted you specifically this off-season to get to this new mindset?”

LEBRON JAMES: “It’s not a new mindset. I think people are taking it a little further than where it should be. Something just—it was a feeling I was after we won in Game 6 in Toronto, and that’s how I was feeling at that moment. I’m back to my usual self.”

The degrees of freedom given result in a significant variance in interview lengths. Sentences vary from as little as a single word to 147, and interviews vary from 4

⁶ The most famous short response, by football player Marshawn Lynch, can be seen at: <https://www.youtube.com/watch?v=G1kvwXsZtU8>.

Table 2

Performance metric mean and standard deviation (in parentheses) per player in our data set. We report here the actual values of the performance metrics rather than deviations from the mean. For the definition of the performance metrics, see Section 4.

Player	PF	PTS	FGR	PR	SR	MSD2	MSD3	# Plays
Al Horford	2.07 (1.07)	12.5 (6.71)	0.52 (0.18)	0.26 (0.19)	0.22 (0.17)	5.97 (4.74)	6.81 (6.69)	299.14 (57.97)
Andre Iguodala	2.19 (1.44)	10.42 (6.44)	0.6 (0.2)	0.26 (0.27)	0.42 (0.22)	9.56 (8.5)	8.42 (6.6)	315.0 (68.38)
Carmelo Anthony	3.72 (1.27)	22.78 (7.38)	0.41 (0.1)	0.41 (0.26)	0.22 (0.13)	5.67 (3.61)	6.37 (4.12)	354.0 (51.21)
Chauncey Billups	2.84 (1.42)	18.42 (5.64)	0.5 (0.15)	0.23 (0.21)	0.41 (0.15)	13.7 (13.94)	9.54 (6.84)	368.61 (53.57)
Chris Bosh	2.77 (1.56)	15.87 (7.18)	0.52 (0.19)	0.57 (0.34)	0.12 (0.15)	5.45 (3.94)	4.24 (7.25)	312.11 (49.5)
Chris Paul	3.43 (1.17)	19.8 (7.43)	0.51 (0.1)	0.22 (0.15)	0.31 (0.14)	9.81 (5.27)	9.72 (6.45)	341.14 (57.69)
Damian Lillard	2.08 (1.24)	27.42 (8.07)	0.48 (0.1)	0.43 (0.25)	0.39 (0.13)	10.51 (5.73)	9.19 (5.23)	370.9 (39.93)
DeMar DeRozan	2.73 (1.19)	26.0 (10.52)	0.53 (0.09)	0.48 (0.21)	0.08 (0.09)	5.71 (1.58)	2.12 (3.64)	345.45 (30.37)
Derek Fisher	3.13 (1.61)	8.67 (5.04)	0.54 (0.22)	0.26 (0.21)	0.36 (0.22)	13.06 (14.27)	7.46 (8.26)	282.97 (60.32)
Dirk Nowitzki	2.55 (1.52)	24.36 (8.29)	0.49 (0.14)	0.48 (0.22)	0.17 (0.12)	7.02 (3.01)	8.19 (8.4)	359.12 (61.25)
Draymond Green	4.0 (1.38)	13.02 (6.59)	0.54 (0.19)	0.3 (0.18)	0.39 (0.16)	8.49 (9.61)	7.34 (6.75)	359.68 (47.89)
Dwyane Wade	2.88 (1.46)	23.07 (8.09)	0.5 (0.12)	0.4 (0.18)	0.09 (0.09)	4.49 (2.36)	4.25 (6.7)	350.26 (55.72)
James Harden	2.9 (1.58)	23.8 (9.69)	0.47 (0.14)	0.32 (0.19)	0.43 (0.14)	9.5 (6.08)	8.13 (6.01)	351.27 (66.4)
Kawhi Leonard	2.56 (1.69)	13.0 (5.3)	0.47 (0.18)	0.46 (0.32)	0.33 (0.15)	8.51 (6.82)	8.03 (6.08)	277.17 (70.58)
Kevin Durant	2.58 (1.44)	28.34 (6.86)	0.54 (0.11)	0.44 (0.24)	0.29 (0.09)	8.92 (4.13)	9.75 (5.69)	378.85 (52.26)
Kevin Garnett	3.0 (1.31)	14.83 (5.56)	0.54 (0.2)	0.44 (0.33)	0.02 (0.04)	4.7 (2.16)	0.0 (0.0)	318.31 (64.31)
Kevin Love	2.33 (1.34)	15.75 (9.17)	0.44 (0.15)	0.47 (0.27)	0.44 (0.16)	11.0 (7.95)	8.13 (4.79)	281.58 (58.15)
Klay Thompson	2.51 (1.49)	19.34 (8.65)	0.48 (0.11)	0.45 (0.28)	0.48 (0.15)	16.17 (14.97)	8.92 (4.18)	352.96 (58.37)
Kobe Bryant	2.93 (1.59)	28.07 (7.1)	0.48 (0.09)	0.38 (0.2)	0.24 (0.13)	8.21 (4.21)	7.6 (5.91)	373.7 (53.15)
Kyle Lowry	3.33 (1.32)	21.56 (9.9)	0.49 (0.14)	0.3 (0.2)	0.48 (0.17)	14.09 (11.57)	8.94 (3.97)	334.67 (46.15)
Kyrie Irving	2.44 (1.5)	25.2 (8.34)	0.52 (0.11)	0.37 (0.19)	0.28 (0.14)	9.19 (5.8)	11.49 (7.31)	339.68 (70.44)
Lamar Odom	3.92 (1.64)	12.29 (5.19)	0.52 (0.18)	0.4 (0.27)	0.14 (0.14)	3.06 (2.49)	3.94 (7.82)	309.29 (56.57)
LeBron James	2.49 (1.39)	28.75 (8.66)	0.53 (0.12)	0.34 (0.16)	0.22 (0.1)	5.81 (3.27)	8.2 (6.07)	380.43 (56.21)
Manu Ginobili	3.02 (1.24)	14.84 (7.47)	0.5 (0.19)	0.39 (0.24)	0.44 (0.14)	9.6 (7.8)	7.98 (5.76)	276.0 (65.68)
Pau Gasol	2.97 (1.2)	16.54 (5.99)	0.56 (0.14)	0.36 (0.25)	0.01 (0.03)	2.72 (1.88)	0.0 (0.0)	356.95 (70.03)
Paul George	2.58 (1.54)	21.21 (8.2)	0.5 (0.11)	0.39 (0.18)	0.43 (0.11)	11.03 (4.44)	10.88 (5.76)	326.11 (64.57)

Table 2
(continued)

Player	PF	PTS	FGR	PR	SR	MSD2	MSD3	# Plays
Paul Pierce	3.62 (1.5)	19.56 (7.85)	0.52 (0.2)	0.47 (0.24)	0.31 (0.19)	8.2 (5.38)	9.12 (7.56)	351.69 (77.83)
Rajon Rondo	2.74 (1.51)	12.19 (6.53)	0.5 (0.21)	0.23 (0.11)	0.08 (0.09)	3.22 (2.27)	3.97 (8.03)	354.26 (59.83)
Ray Allen	2.56 (1.35)	14.9 (7.28)	0.5 (0.2)	0.45 (0.3)	0.5 (0.17)	13.56 (8.91)	9.26 (6.16)	342.85 (71.59)
Richard Hamilton	3.61 (1.31)	20.83 (6.91)	0.5 (0.16)	0.36 (0.25)	0.07 (0.06)	5.1 (2.57)	2.32 (4.65)	382.09 (61.51)
Russell Westbrook	2.85 (1.51)	24.3 (8.54)	0.45 (0.11)	0.33 (0.14)	0.21 (0.1)	5.16 (3.28)	6.46 (5.86)	363.52 (55.8)
Shaquille O’Neal	3.68 (1.7)	15.79 (6.96)	0.61 (0.22)	0.71 (0.23)	0.0 (0.0)	1.43 (1.08)	0.0 (0.0)	275.37 (89.38)
Stephen Curry	2.48 (1.36)	26.42 (8.42)	0.48 (0.11)	0.37 (0.18)	0.55 (0.11)	18.0 (8.59)	10.67 (4.05)	362.49 (62.61)
Steve Nash	1.73 (1.2)	19.09 (6.38)	0.55 (0.13)	0.25 (0.15)	0.24 (0.12)	8.42 (3.77)	8.93 (7.0)	334.45 (46.15)
Tim Duncan	2.65 (1.31)	18.43 (7.53)	0.51 (0.15)	0.46 (0.28)	0.01 (0.03)	2.55 (1.41)	0.44 (3.27)	324.07 (58.05)
Tony Parker	1.65 (1.14)	18.02 (6.99)	0.52 (0.16)	0.32 (0.19)	0.1 (0.09)	5.27 (3.24)	6.45 (9.09)	317.44 (52.21)
data set Average	2.791	20.214	0.511	0.38	0.265	7.347	6.922	336.77
data set Std.	1.489	9.438	0.153	0.239	0.204	6.054	6.771	66.44

sentences to 753. Table 3 provides aggregated statistics about the interviews in our data set, as well as the number of interviews, average number of question-answer (Q-A) pairs, average number of sentences, and average number of words for each player.

In order to give further insight, we trained an LDA topic model (Blei, Ng, and Jordan 2003) for each player over all interviews in which he participated, and present the top words of the most prominent topic per player in Table 4. Unsurprisingly, we can see that most topics involve words describing the world of basketball (e.g., game, play, team, championship, win, ball, shot) and the names of other players and teams, yet with careful observation we can spot some words relating to the player’s or team’s performance in a game (e.g., dynamic, sharp, regret, speed, tough, mental, attack, defense, zone). Generally, most topics contain similar words across players, yet some players show interesting deviations from the “standard” topic.⁷

4. The Task

Our goal in this section is to define metrics that reflect the player’s in-game decisions and actions and formulate prediction tasks based on our definitions. Naturally, the performance of every player in any specific game is strongly affected by global properties such as his skills, and is strongly correlated with his performance in recent games. We hence define binary classification tasks, predicting whether the player is going to

⁷ The LDA model is used here for data exploration purposes only, specifically, to show the general topic distribution per player in our data set.

Table 3

Number of interviews and averages of number of Q-A pairs, sentences, and words in an interview per player in our data set.

Player	# of Interviews	Avg. # of Q-A pairs	Avg. # of sentences	Avg. # of words
Al Horford	14	6.43	45.29	685.4
Andre Iguodala	26	12.69	111.08	1888.6
Carmelo Anthony	18	14.28	86.78	1075.8
Chauncey Billups	31	12.19	92.81	1545.6
Chris Bosh	47	11.53	97.96	1311.2
Chris Paul	35	12.49	82.66	1165.4
Damian Lillard	12	7.92	69.00	1115.5
DeMar DeRozan	11	14.36	84.91	1259.1
Derek Fisher	39	6.87	54.00	1149.7
Dirk Nowitzki	33	12.15	114.39	1737.7
Draymond Green	59	14.97	140.88	2161.9
Dwyane Wade	72	18.93	173.58	2494.7
James Harden	30	10.73	63.77	858.6
Kawhi Leonard	18	8.50	37.50	462.9
Kevin Durant	67	17.73	138.25	2094.2
Kevin Garnett	29	11.72	92.45	1459.1
Kevin Love	24	11.79	89.54	1508.6
Klay Thompson	53	13.42	112.25	1674.9
Kobe Bryant	44	25.93	142.27	1861.1
Kyle Lowry	9	14.44	92.67	1321.8
Kyrie Irving	25	16.04	125.00	2377.6
Lamar Odom	24	10.62	61.00	805.2
LeBron James	122	22.60	189.43	2875.5
Manu Ginobili	55	8.84	68.13	1032.8
Pau Gasol	39	11.38	80.41	1281.6
Paul George	19	12.58	88.63	1220.8
Paul Pierce	32	15.28	122.78	1965.2
Rajon Rondo	27	12.04	74.19	1021.8
Ray Allen	39	8.31	63.36	1068.1
Richard Hamilton	23	12.00	63.83	1099.2
Russell Westbrook	40	18.48	108.05	1567.5
Shaquille O'Neal	19	12.63	70.53	1043.8
Stephen Curry	71	17.70	156.92	2762.9
Steve Nash	22	13.50	80.05	1132.0
Tim Duncan	54	13.13	86.26	1380.9
Tony Parker	55	12.75	80.84	1156.3
Data set average	37.14	14.52	110.28	1520.09
Data set standard deviation	22.11	3.53	6.26	568.08

perform above or below his mean performance in the defined metrics. Across the data set, we found that the difference between mean and median performance is insignificant and both statistics are highly correlated, hence we consider them as equivalent and focus on deviation from the mean.

Table 4 Top 10 words in the most prominent topic for each player. A topic model was trained for each player on all his interviews in the data set.

	live	angel	trip	basically	beautiful	allow	attack	next	week	league
Al Horford	year	know	lot	rakuten	see	good	warrior	come	play	thing
Andre Iguodala	game	tough	year	come	kobe	play	court	take	hand	back
Carmelo Anthony	NBA	teammate	award	twyman	thank	year	story	maurice	chauncey	applause
Chauncey Billups	really	game	know	good	team	come	play	thing	want	look
Chris Bosh	know	bowl	good	team	really	play	lot	shot	time	bowling
Chris Paul	straight	breather	buckle	bad	begin	ne	steph	stage	sick	show
Damian Lillard	smith	suggest	tennis	talking	rival	skin	sit	sick	shut	shown
DeMar DeRozan	game	know	team	good	team	really	feed	come	thing	back
Derek Fisher	good	great	team	time	back	game	lot	first	come	always
Dirk Nowitzki	game	thing	team	year	know	good	come	time	really	great
Draymond Green	game	team	play	know	good	year	come	last	really	feel
Dwyane Wade	game	good	know	shot	play	open	team	time	last	point
James Harden	game	good	may	minute	morning	normal	noticing	time	order	padding
Kawhi Leonard	gear	matter	good	game	team	come	thing	shot	talk	want
Kevin Durant	play	know	play	thing	lot	team	really	day	come	want
Kevin Garnett	know	game	year	play	lot	know	good	last	ball	feel
Kevin Love	game	team	sharp	sharpness	shore	shrug	smith	speed	sulk	thigh
Klay Thompson	regret	scary	play	night	come	take	really	something	much	talk
Kobe Bryant	game	good	play	dynamic	complete	contender	anything	cavalier	cake	bucket
Kyle Lowry	challenge	curious	deep	great	time	moment	tonight	team	big	would
Kyrie Irving	game	play	come	know	last	happen	team	good	championship	would
Lamar Odom	really	win	year	team	last	able	time	play	take	thing
LeBron James	know	game	tough	good	play	sometimes	see	thing	last	happen
Manu Ginobili	game	know	know	play	much	game	expect	tonight	obviously	sure
Pau Gasol	zone	really	know	feel	work	want	take	together	well	see
Paul George	know	team	something	play	year	game	talk	look	really	lot
Paul Pierce	team	know	come	team	come	play	rebound	win	tonight	take
Rajon Rondo	game	great	ball	operate	operate	row	problem	thread	accustom	action
Ray Allen	standing	mental	marquis	orlando	portland	phone	philly	pay	nut	new
Richard Hamilton	relationship	resolve	demand	record	thing	able	game	come	time	different
Russell Westbrook	team	play	good	great	mistake	lot	talk	back	people	really
Shaquille O'Neal	arena	city	fun	would	team	kind	year	really	time	obviously
Stephen Curry	game	play	good	know	team	back	year	well	feel	win
Steve Nash	game	really	know	play	team	come	back	lot	want	really
Tim Duncan	game	play	good	team	time	chance	last	big	want	keep
Tony Parker	good	game	play	never	rebound				defense	

Different players have significantly different variances in their performance (see Table 2) across different metrics. This phenomenon is somewhat inherent to basketball players due to the natural variance in player skills, style, and position. Because of these evident variances, we did not attempt to predict the extent of the deviation from the mean, but preferred a binary prediction of the direction of the deviation. Another reason for our focus on binary prediction tasks is that given our rather limited data set size, and imbalance in number of interviews per player (some players were interviewed less than others, see Table 3), we would like our models to be able to learn across players. That is, the training data for each player should contain information collected on all other players, pushing us toward a prediction task that could be calculated for players with a varying number of training examples and substantially different performance distributions.

Performance Metrics. We consider seven performance metrics:

1. *FieldGoalsRatio* (FGR)
2. *MeanShotDistance2Points* (MSD2)
3. *MeanShotDistance3Points* (MSD3)
4. *PassRisk* (PR)
5. *ShotRisk* (SR)
6. *PersonalFouls* (PF)
7. *Points* (PTS)

We denote with $M = \{FGR, MSD2, MSD3, PR, SR, PF, PTS\}$ the set of performance metrics. The performance metrics are calculated from the play-by-play data. In the notation below, p stands for a player, t for a period identifier in a specific game, and $\#$ is the count operator.⁸ $\#\{event\}^{p,t}$ denotes the number of events of type *event* for player p in a game period t . We consider the following events:

- *shot*: A successful shot.
- *miss*: An unsuccessful shot.
- *2pt*: A 2-point shot.
- *3pt*: A 3-point shot.
- *assist*: A pass to a player that had a successful shot after receiving the ball and before passing it to any other player.
- *turnover*: An event in which the ball moved to the opponent team due to an action of the player.
- *pf*: A personal foul.

⁸ In the game data set, t denotes a specific game.

We further use the notations $Dist^{p,t}$ for a set containing the distances for all the shots player p took in period t , in which the distance of that shot from the basket is recorded, and $pts^{p,t}$ for the total number of points in a certain period. Our performance metrics, m_t^p , are defined for a player p in a game period t , in the following way:

$$MSD_t^p = \text{Mean}(Dist^{p,t}) \quad (1)$$

$$PF_t^p = \#\{pf\}^{p,t} \quad (2)$$

$$PTS_t^p = pts^{p,t} \quad (3)$$

$$FGR_t^p = \frac{\#\{shot\}^{p,t}}{\#\{shot\}^{p,t} + \#\{miss\}^{p,t}} \quad (4)$$

$$SR_t^p = \frac{\#\{3pt\}^{p,t}}{(\#\{miss\}^{p,t} + \#\{shot\}^{p,t})} \quad (5)$$

$$PR_t^p = \frac{\#\{turnover\}^{p,t}}{\#\{assist\}^{p,t} + \#\{turnover\}^{p,t}} \quad (6)$$

For MSD we consider two variants, MSD2 and MSD3, for the mean distance of 2- and 3-point shots, respectively.

4.1 Prediction Tasks

For each metric m we define the player's mean as:

$$\bar{m}^p = \frac{\sum_{t=1}^{T^p} m_t^p}{|T^p|} \quad (7)$$

where T^p is the set of periods in which the player p participated. We further define the per-metric label set Y^m as:

$$Y^m = \{y_t^{p,m} \mid p \in P, t \in T\}, y_t^{p,m} = \begin{cases} 1, & m_t^p \geq \bar{m}^p \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

where P is the set of players and T is the set of periods.⁹

For each player p and period t , we denote with x_t^p the player's interview text prior to the game of t , and with $y_t^{p,m}$ the label for performance metric m . In addition, lagged performance metrics are denoted with $y_{t-j}^{p,m}, \forall j \in \{1, 2, \dots, k\}$ ($k = 3$ in our experiments).¹⁰ We transform each sample in our data set into interview-metric tuples, such that for a given player p and period t we predict $y_t^{p,m}$ given either:

- (a) x_t^p : for the text-only mode of our models.

⁹ Because m_t^p is hardly ever equal to \bar{m}^p , the meaning of $y_t^{p,m} = 0$ is almost always a negative deviation from the mean.

¹⁰ **Lagged performance metrics** refer to the same metric for the same player in the previous periods.

- (b) $\{y_{t-j}^{p,m} | \forall j \in \{1, 2, \dots, k\}, \forall m \in M\}$: for the metric only mode.
- (c) $\{x_t^p, y_{t-j}^{p,m} | \forall j \in \{1, 2, \dots, k\}, \forall m \in M\}$: for the joint text and metric mode.

In this article we consider an independent prediction task for each performance metric, but these metrics are likely to be strongly dependent (Vaz de Melo et al. 2012). Also, we look at each player's actions independently, although there are connections between actions of different players and between different actions of the same player. We briefly discuss observed connections between our models for different tasks and their relation to the similarity between tasks in Section 7. However, as this is the first paper for our task, we do not attempt to model possible interactions between different players or between metrics that often occur in team sports, and leave these to be explored in future work.

4.2 Performance Measures and Decision-Making

Our article is about the transmission of language into actions. In practice we try to predict performance metrics that are associated with such actions. Our measures aim to capture different aspects of the in-game actions made by players. FGR is a measure of risk for the shots attempted. SR is also a measure of risk for attempted shots, yet it tries to capture a player's choice to take riskier shots that are worth more points. MSD2 and MSD3 are measures of the shot location, trying to capture for a given shot type (2/3 points) how far a player is willing to go in order to score. PR considers another offensive aspect, passes, and because it accounts for both turnovers and assists, it captures part of the risk a player is willing to take in his choice of passing. PTS is a more obvious choice; it is the most commonly used metric to observe a player's offensive performance. PF is related to defensive decisions and is correlated with aggressive behavior.

By carefully observing the data presented in Table 2, we can see that different metrics exhibit different levels of volatility across all players in our data set. More volatile metrics, such as field goals ratio (FGR), shot distance (MSD2/3), and shot risk (SR) are rather static at the player level but differ substantially between players. This volatility in shot-related measures across players could be explained by the natural differences in shot selection between players in different positions. For example, back-court players generally tend to take more 3-point shots than front-court players. Events such as 3-point shots are therefore much sparser in nature for many players, and in many periods they occur at most once if at all. This causes the MSD3 (i.e., Mean Shot Distance for 3-point shots) to be 0 many more times compared with other metrics in our data set. This volatility ultimately makes it harder to distinguish what drives variance in these metrics as opposed to more consistent metrics such as PF (Personal Fouls), PTS (Points), and PR (Pass Risk).

A possible explanation for PF and PTS being more consistent in our data set is that they are considered rather critical performance measures to the overall teams' performance. Our data set mainly consists of NBA all-stars (who are key players on their teams), interviewed before relatively important playoff games, and thus they are expected by their teams and fans to be more consistent in these critical measures. While players differ substantially in terms of numbers of assists and turnovers, the pass risk (PR) metric accounts for this by looking at the ratio, resulting in a consistent measure across our data set.

5. Models

Our core learning task is to predict players' in-game actions from their pre-game interview texts. Interviews are texts that contain a specific form of structured open-ended turn-based dialog between two speakers—the interviewer and the interviewee—which to a certain extent hold opposite goals in the conversation. Generally speaking, an interviewer's goal is to reveal pieces of exclusive information by giving the player a chance to reflect on his thoughts, actions, and messages. However, the player's goal is to utilize the opportunity of public speaking to portray his competitive agenda and strengthen his brand, while maintaining a comfortable level of privacy. In-game performance metrics reflect different aspects of a player's in-game actions, which expose some information about the variance in a player's actions and performance between different games.

We formulated multiple binary classification tasks in Section 4, and these tasks pose several challenges from natural language processing perspectives:

- *Time Series*: Almost all samples in our data come from events (playoff series) that exhibit a certain form of time-dependence, meaning that subsequent events in the series may impact each other. This aspect requires careful treatment when designing our models and their features.
- *Remote Supervision Signal*: Our labels stem from variables (performance metrics) that are related to the speaker of the text and are only indirectly implied in the text. In this sense, our supervision signal refers to our input signal in an indirect and remote manner. This is in contrast to learning to predict the deviation from the mean based on past performance metrics, where the input and the output are tightly connected. This is also different from tasks such as sentiment analysis where the sentiment of the review is directly encoded in its text.
- *Textual Structure*: Our input consists of interviews, which exhibit a unique textual structure of a dialog between two speakers, with somewhat opposing roles: an interviewer and an interviewee. We are interested in capturing information from these interviews, relevant to labels related only to the interviewee. Yet, it is not trivial to say whether this information appears in the interviewee's answers alone or what type of context and information the interviewer's questions provide.

In light of these challenges, we design our models with four main questions in mind:

1. Could classification models utilize pre-game interview text to predict some of the variance in players' in-game performance at both game and period levels?
2. Could text be combined with past performance metrics to produce better predictions?
3. How could we explicitly model the unique textual structure of interviews in order to facilitate accurate performance prediction?
4. Could DNNs jointly learn a textual representation of their input interview together with a task classifier to help us capture textual signals relevant to future game performance?

To tackle these questions, we chose to design metric-based, text-based, and combined models, and assign the $-M$, $-T$, and $-TM$ suffixes to denote them, respectively. Within each set of models, we chose to explore different modeling strategies in an increasing order of complexity and specialization to our task. We next provide a high-level discussion of our models, and then proceed with more specific details.

Metric-based models. We implement two standard autoregressive models, which are commonly used tools in time-series analysis, alongside a BiLSTM (Hochreiter and Schmidhuber 1997) model. Both models make a prediction for the next time step (game/period) given performance metrics from the three previous time steps. These models exhibit the predictive power of performance metrics alone, and serve as baselines for comparison to text-based models.

Text-based models. We design our text-based models to account for different levels of textual structure. We start by implementing a standard bag-of-words text classifier, which represents an interview as counts of unigrams. We continue by implementing a word-level CNN (LeCun and Bengio 1995) model, which represents interviews as a sequence of words in their order of appearance. We then implement a sentence-level BiLSTM model, which represents interviews as a sequence of sentences, where each sentence is represented by the average of its word embeddings. Finally, we chose to implement a BERT (Devlin et al. 2019) model, which accounts for the interview structure by representing interviews as sequences of Q-A pairs. Each pair's embeddings are learned jointly by utilizing the model's representations for pairs of sequences, which are based on an attention mechanism (Vaswani et al. 2017) defined over the word-level contextual embeddings of the question and the answer. This serves as an attempt to account for the subtler context a question induces over an answer, and for the role of each speaker in the dialog. These text-based models exhibit the predictive power of text alone in our prediction task.

Combined models. DNNs transform their input signals into vectors and their computations are hence based on matrix calculations. This shared representation of various input signals makes these models highly suitable to multitask and crossmodal learning, as has been shown in a variety of recent NLP works (e.g., Søgaard and Goldberg 2016; Rotman, Vulić, and Reichart 2018; Malca and Reichart 2018). We therefore implemented variants of our best performing LSTM and BERT text-based models that incorporate textual features from the pre-game interview with performance metrics from the previous three time steps. These models help us quantify the marginal effect of adding textual features in predicting the direction of the deviation from the player's mean performance, over metric-based models. We next describe each of our models in details.

5.1 Metric-Based Autoregressive Models

An autoregressive (AR(k)) model is a representation of a type of a random process. It is a commonly used tool to describe time-varying processes, such as player performance. The AR model assumes that the output variable ($y_t^{p,m}$) depends linearly on its own k previous values and on a stochastic term ϵ_t (the prediction error) (Akaike 1969). We focus on AR(3) to prevent loss of data for players with very few examples (previous games) in our data set:

$$y_t^{p,m} = c + \sum_{j=1}^3 \varphi_j y_{t-j}^{p,m} + \epsilon_t \quad (9)$$

We also consider using all lagged metrics as features for predicting a current metric:

$$y_t^{p,m} = c + \sum_{j=1}^3 \sum_{w \in M} \varphi_j^w y_{t-j}^{p,w} + \epsilon_t \quad (10)$$

That is, we make predictions for a given game t , player p , and metric m , based on performance in the previous $k = 3$ games, using either the same metric m (Equation (9)) or all metrics in M (Equation (10)).

We used a standard linear regression and a logistic regression. We tested both models for all k values for which we had enough data, and $k = 3$ was chosen because it performed best in development data experiments. We report results only for the linear regression model, because both models performed similarly.

5.2 The BoW and TFIDF Text Classifiers

The bag-of-words (BoW) and term frequency-inverse document frequency (TFIDF) (Salton 1991) models are standard for text classification tasks (Yogatama and Smith 2014), and they therefore serve as our most basic text-based models. We constructed both BoW and TFIDF feature vectors per interview, and have tried using unigrams and bigrams, alone or in combination. We considered random forest (RF) (Liaw and Wiener 2002), support vector machine (SVM) (Cortes and Vapnik 1995), and logistic regression (LR) (Ng and Jordan 2002) classifiers. Whereas BoW provides a straight forward effective way to represent text, it assumes n -gram (in our case we tried $n = 1, n = 2, n = 1, 2$) independence and therefore does not take the structure of the text into account. TFIDF adjusts for the fact that some words are more frequent in general, but makes the same assumptions. We report results for the RF classifier for both BoW (unigrams) and TFIDF (unigrams + bigrams) feature sets, because these consistently performed better in development data experiments, for BoW and TFIDF respectively. Finally, because these simple models were consistently outperformed by our best text-based DNN models (see Section 7), we did not attempt to incorporate any performance metrics as features into them.

5.3 Deep Neural Networks

DNNs have proven effective for many text classification tasks (Kim 2014; Ziser and Reichart 2018). An appealing property of these models is that training a DNN using a supervision signal results not only in a predictive model, but also with a representation of the data in the context of the supervision signal. This is especially intriguing in our case, where the supervision signal is not clearly visible in the text, and is more related to its speaker.

Moreover, the text in our task is structured as a dialog between two speakers, which entails an additional level of contextual dependence between speakers, on top of the internal linguistic structures of the utterances produced by the individual speakers. These factors pose a difficult challenge from a modeling perspective, yet DNNs are known for their architectural flexibility that allows learning a joint representation for more than one sequence (Chen, Bolton, and Manning 2016), and have shown promising performance in different tasks where models attempt to capture nuanced phenomena in text (Peters et al. 2018).

We consider three models that excel on text classification tasks: CNN (Kim 2014), BiLSTM (Hochreiter and Schmidhuber 1997), and BERT (Devlin et al. 2019). In order to obtain a vectorized representation of an interview's text, we used different text embedding techniques per model, each based on different pre-trained embedding models. Below we describe the various models.

5.3.1 The CNN Model.

Motivation. We implement a standard word-level CNN model for text classification (CNN-T), closely following the implementation described in Kim (2014). This model showed promising results on various text classification tasks such as sentiment classification and stance detection (Kim 2014). By implementing this model we aim to examine the extent to which a standard word-level text classification neural network, which does not explicitly account for any special textual structure except for the order of the words in the text, can capture our performance metrics from text.

Model Description. Interviews are fed into the model as a sequence of words in their order of appearance in the interview. We concatenated the interview's word embedding vectors into an input matrix, such that embeddings of consequent words appear in consequent matrix columns. Because interviews vary in length, we padded all word matrices to the size of the longest interview in our data set. We then used three 2D convolution layers with max-pooling and a final linear classification layer.

5.3.2 The BiLSTM Models.

Motivation. Our CNN model treats an interview as a single sequence of words, and apart from the fact that the order of words is maintained in the input matrix, it does not model any textual structure. By implementing BiLSTM-based models we aim to directly model the interview as a sequence of sentences, rather than of words. We believe that because interviews involve multiple speakers interacting in the form of questions and answers, where each question and answer are comprised of multiple sentences, a sequential sentence-level model could capture signals that word-level models cannot.

We chose to implement our text-based BiLSTM (LSTM-T) as a sentence-level sequential model, where each sentence is represented by the average of its pre-trained word embeddings (Adi et al. 2016). Because BiLSTM is a general sequential model, it also fits naturally as an alternative time-series model for performance metrics only (LSTM-M), similar to the AR(k) model described in Equation (10). The various model variants allow us to examine the independent effects of text and metrics on our prediction tasks, using the same underlying model. Moreover, we can now examine the effect of combining text and metric features together in a BiLSTM model (LSTM-TM) by concatenating the metric feature vectors used as input to LSTM-M with the final textual vector representation produced by LSTM-T (see Figure 2).

Model Description. We next provide the technical implementation details of each of our BiLSTM-based models.

LSTM-T. The BiLSTM model for text is fed with the sentences of the interview, in their sequential order. Each sentence is represented by the average of its word embeddings. The BiLSTM's last hidden-state forward and backward vectors are concatenated and

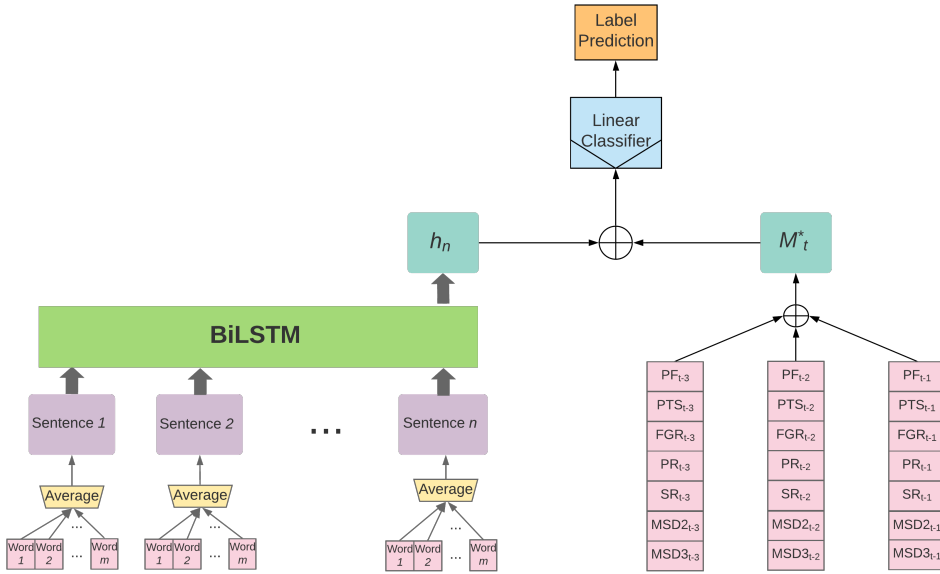


Figure 2

The LSTM-TM model. $h_n = h_n^{forward} \oplus h_n^{backward}$, $|h_n| = |h_n^{forward}| + |h_n^{backward}|$. \oplus denotes the vector concatenation operator.

fed into two linear layers with dropout and batch normalization, and a final linear classification layer (see the left part of Figure 2).

LSTM-M. The BiLSTM model for metrics, which mimics the AR($k = 3$) model of Equation (10), is fed at each time step with the performance metric labels from the last three time steps. We concatenate the last hidden states (forward and backward) and feed the resulting vector as input to a linear classifier. This model is almost identical to LSTM-T, differing only in the input layer.

LSTM-TM. The BiLSTM model, which combines text and metrics, utilizes a similar mechanism as LSTM-T to produce the text vector representation. We then concatenate a vector containing all metrics from the past three time steps, to the text vector. The resulting vector is fed into a binary classifier, similar to the one described for LSTM-T (see Figure 2).

5.3.3 The BERT Models.

Motivation. We are seeking to capture information regarding the player’s pre-game state through the interview text, which comprises a series of consecutive Q-A pairs. In an interview, a player controls only his answers, where his choice of language can be observed in the context of the questions he is asked. Although the player does not have any control over the questions, these can be viewed as a second-order approximation of the player’s state because an interviewer is purposefully phrasing the questions directed at the player. Alternatively, one can view the questions as external information that we cannot attribute to the player based solely on that fact. We choose to proceed

with the former approach, to view the questions as a valuable context to the player's answers.

Since the unique structure of an interview encourages a form of speaker roles and contextual dependence, which may seem similar to other "looser" forms of discourse, in this work we choose to focus our modeling on the local dependencies within each pair of a question and its immediate answer. In future work we plan to further explore the interview structure in our modeling.

Interview Representation. Our CNN model treats an interview as a single sequence of words, and our BiLSTM model treats an interview as a single sequence of sentences where each sentence is represented by the average of its word embeddings. Neither of these models take into account any other characteristics of the interview structure. Although there are CNN and LSTM-based models that aim to capture document structure, for example, hierarchy (Yang et al. 2016), adapting these to capture the subtleties of an interview structure is a non-trivial task.

BERT provides a method for producing a single joint contextual representation for two related text sequences (such as Q-A pairs), which attempts to represent both texts and the relations between them. We found this feature useful for our task and a natural fit for modeling interview structure, as it allowed us to break up each interview to its Q-A pairs, input them in sequence to BERT, and produce a respective sequence of Q-A vectors. We follow a similar method for producing Q-A vectors as described in the BERT paper (Devlin et al. 2019) and provide further details in our model description below.

From a technical perspective, handling texts that greatly vary in length requires some creativity, if we do not want to lose data by truncating long texts to a fixed maximum length. Moreover, it is empirically shown that many recurrent models, for example, LSTM, suffer performance degradation with increasing sequence length (Luong, Pham, and Manning 2015). Our choice of breaking up each interview into its Q-A pairs allows us also to handle shorter sequences at the interview level, as opposed to longer sentence or word level sequences. We let BERT carry out the heavy task of handling the word sequences for each Q-A pair, because it can handle a sequence of up to 512 tokens. We hypothesize that these factors contribute to a more effective interview representation.

Model Description. Interviews are fed into the BERT model as a sequence of Q-A pairs in their order of appearance in the interview. We follow the terminology and methodology presented in the BERT paper (Devlin et al. 2019), which considers the [CLS] token vector from the last hidden layer of the BERT encoder as a representation of an entire input sequence for classification tasks. When a single input is composed of two sequences of text (a Q-A pair in our case), *text_A* represents the first sequence (a Question in our case) and *text_B* represents the second sequence (an Answer in our case). Each sequence ends with the special [SEP] token, which represents the end of a single sequence and acts as a separator between the two sequences. For each Q-A pair we produce a Q-A vector, by extracting the vector associated with the special [CLS] token from the last hidden layer of the BERT encoder. This results in a sequence of Q-A vectors per interview (see Figure 3).

To produce a single vector representation per interview we implement two alternative models, BiLSTM (BERT-L-T) and Attention (BERT-A-T); both are detailed below. The final interview vector is fed into a linear classification layer activated with a sigmoid function (Finney 1952), to produce a binary prediction. At training, the BiLSTM parameters (BERT-L-T) and the attention parameters (BERT-A-T) are jointly trained with the

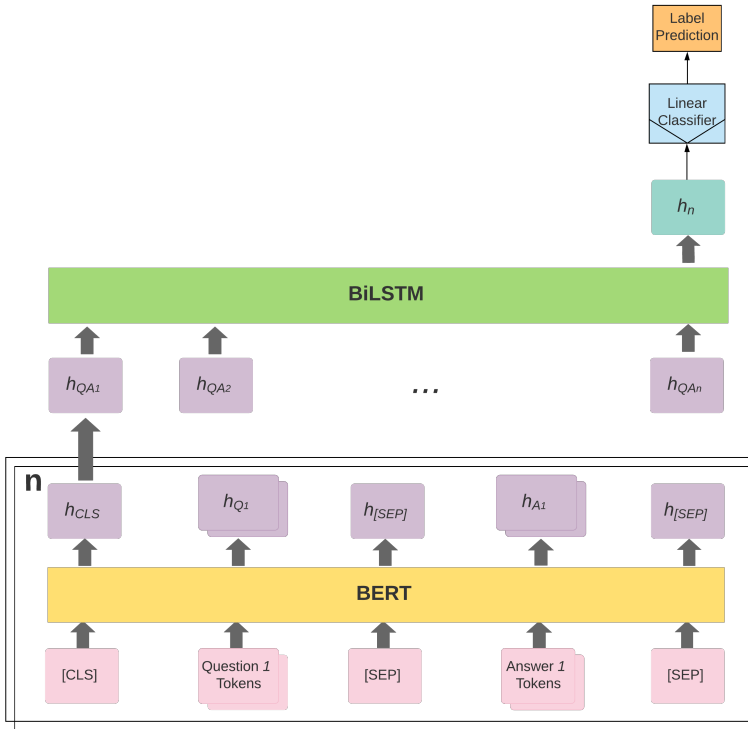


Figure 3 The BERT-L-T model. n denotes the number of Q-A pairs in a given interview. Each Q-A pair is fed into BERT to produce a Q-A vector, and the resulting vectors are then fed in sequence to the BiLSTM. h_n is generated in the same way as in the LSTM-TM model (see Figure 2).

classifier parameters. In both cases we use a pre-trained BERT model as a source of text representation (BERT feature-based approach [Devlin et al. 2019]¹¹), and do not fine tune its text representation or classification parameters on our data, to avoid heavy computations.

BERT-L-T. A BiLSTM is sequentially fed with the Q-A vectors, and its last hidden states (forward and backward) are concatenated to serve as the interview vector. See Figure 3 for an illustration of the model architecture.

BERT-A-T. A simple attention mechanism (described in Yang et al. 2016) is used over the sequence of Q-A vectors, and produces a pooled vector that serves as the interview representation. See Figure 4 for an illustration of the model architecture. In almost all of our experiments BERT-A-T and BERT-L-T performed similarly, yet the BERT-A-T model proved to be slightly but consistently superior (see Section 7). We hypothesize that the attention mechanism serves as an efficient and effective method of pooling our Q-A vectors, which results in a much lighter model in terms of the number of learned parameters.

¹¹ The pre-trained model was downloaded from: <https://github.com/google-research/bert>.

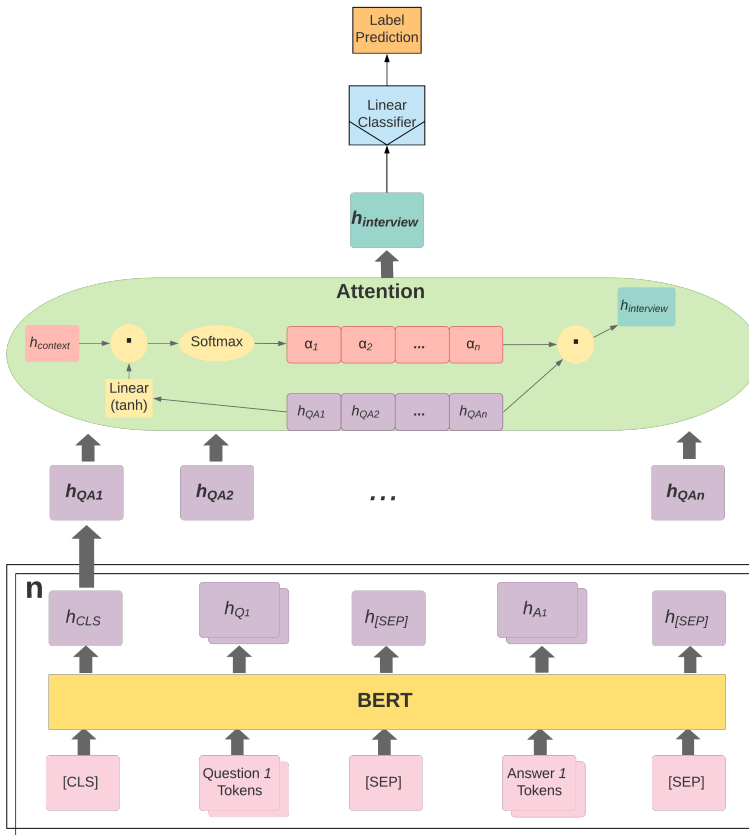


Figure 4 The BERT-A-T model. Attention is applied over a sequence of Q-A vectors, which are produced by feeding the interview’s Q-A pairs into BERT. $h_{context}$ is randomly initialized and jointly learned with the attention weights during the training process.

BERT-A-TM. We implemented a variant of the BERT-A-T model, where before the interview vector is fed into the classifier, it is concatenated with all performance metric labels from the last three games. This model lets us explore the combined value of textual and performance metric signals. See Figure 5 for an illustration of the model architecture.

6. Experiments

6.1 Tasks and Data

We perform two sets of experiments, differing in the level of metric aggregation: (a) game level; and (b) period level.¹² Our period-level task does not distinguish between different periods within a game (that is, the model does not distinguish between, e.g.,

¹² Recall that each game is composed of 4 periods.

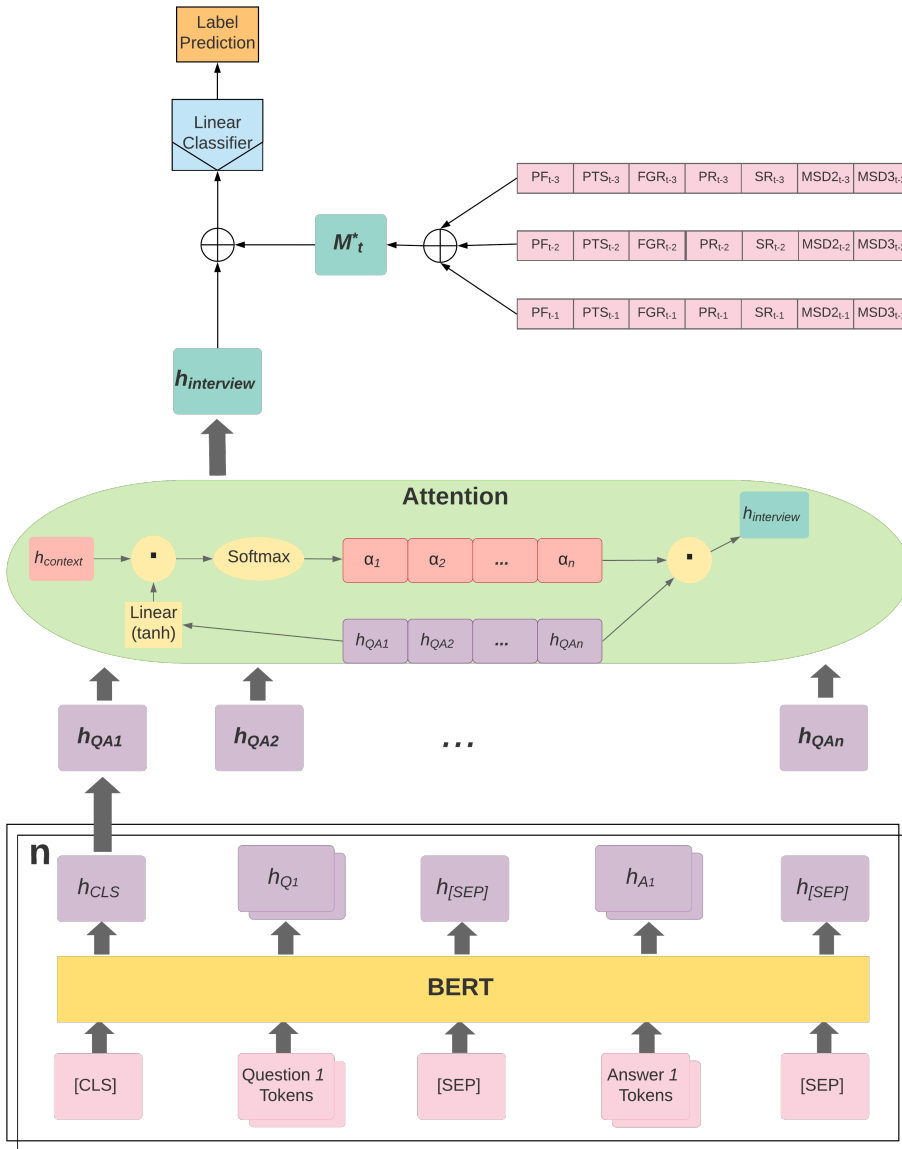


Figure 5
The BERT-A-TM model. We use the same notation as presented in Figure 4.

the second and the third period). In order to solve this task we hence train a classifier on data aggregated at the period level from the various periods in our data set. We experiment with both levels of aggregation in order to explore different aspects of the players’ actions and how they manifest in different parts of the game. Although game-level data is less volatile and can capture more general differences in a player’s performance, it could fail to show behavioral fluctuations that are more subtle, such as “clutch” decisions, momentum performance boosts, or a short series of mistakes. The period-level data can catch those subtleties and tell a more fine-grained story, though it is more sensitive to rare events, such as 3-point shots and fouls.

The differences between these two sub-tasks are demonstrated by the per-metric label distributions (see Table 2). Events such as 3-point shots are sparser in nature—many periods they occur at most once if at all. This causes the MSD of those shots to be 0 and leads to extreme class imbalance, making the classification task considerably more difficult.

Events such as shots in general, as captured by the PTS and FGR metrics, occur more regularly, and thus result in balanced classes at both the game and period levels. Balanced classes are generally desired in binary classification tasks, since imbalanced classes could easily bias models toward the common class in the training data, making it almost impossible for us to determine whether the models captured even the slightest effects from the data. This is especially desired in light of research question #4 presented in Section 5, where we set a goal to understand whether DNNs could learn a textual representation capable of capturing textual signals for our tasks. We would hence like to avoid the potential effects of imbalanced classes, which could inhibit our models from learning such textual representations.

The question of balanced data also stems in our task with respect to the interviewed players, since we do not have an equal number of interviews for all players (see Table 3). This could potentially bias our models toward specific players who are more prevalent in the data set. This could also complicate splitting our data set into training, development, and test sets. For each subset, we would ideally prefer to maintain the same ratio of interviews per player as in the entire data set, in addition to maintaining the same positive to negative classes ratio.

In this study, we chose to utilize a stratified 5-fold cross validation process (see Section 6.3), in order to maintain the positive to negative class ratio across our training, development, and test subsets. We did not attempt to explicitly maintain the ratio of interviews per player, because our aforementioned stratified process yielded subsets that fairly maintained this ratio. In future research, we plan on exploring the effects of different interviews per player ratios, to examine whether certain players exhibit linguistic or performance patterns different from other players, and whether our models could capture such patterns or be biased by them.

6.2 Models

We consider the following models (described in further detail in Section 5), and use the $-T$, $-M$, and $-TM$ suffixes to denote model variants for textual, metric, and combined features, respectively:

- $AR(3)-M$ - a linear autoregressive model that considers the last three time steps of the predicted performance metric.
- $AR(3)-M^*$ - a linear autoregressive model that considers the last three time steps of all performance metrics.
- $LSTM-M$ - a BiLSTM model that considers the last three time steps of all performance metrics.
- $BoW-RF-T$ - a Random Forest classifier that utilizes a unigram bag-of-words features set.
- $TFIDF-RF-T$ - a Random Forest classifier that utilizes a TFIDF feature set defined over unigrams and bigrams.

- *CNN-T* - a word-level CNN model.
- *LSTM-T* - a sentence-level BiLSTM model.
- *LSTM-TM* - a model similar to LSTM-T, except that the text representation is combined with the last three time steps of all performance metrics, and the result is fed to the classification layer.
- *BERT-L-T* - a model that explicitly accounts for the Q-A structure of the input interviews, with BERT representations and LSTM sequence modeling.
- *BERT-A-T* - a model that explicitly accounts for the Q-A structure of the input interviews, with BERT representations and an attention mechanism.
- *BERT-A-TM* - a model similar to BERT-A-T, except that the text representation is combined with the last three time steps of all performance metrics, and the result is fed to the classification layer.

Recall our four research questions from Section 5. Our experiments are designed to compare between text and metric-based models, demonstrating the predictive power of text-based models in our task. In addition, they are designed to highlight the effects of different modeling strategies, in an increasing order of complexity and specialization to our task. Finally, we compare to the common class (CC) baseline, which assigns to every test set example the most common training label. We chose to add this baseline in order to examine the performance of our models in comparison to a more naive and “data-driven” approach that does not model either text nor past metrics (Sim, Routledge, and Smith 2016).

6.3 Cross-Validation

We randomly sampled 20% of our interviews and generated a held-out test set for each performance metric, per game and period tasks, each consisting of interviews and their related performance metrics.¹³ We then implemented a 5-fold cross validation procedure for each metric label, in each fold randomly sampling 80% of the remaining interviews for training and 20% for development. All our training, development, and test sets are stratified: The ratio of positive and negative examples in each subset is identical to the ratio in the entire data set.¹⁴

6.4 Implementation Details and Hyperparameters

All models were developed in Python, utilizing different packages per model.

Autoregressive Models. We developed all models utilizing the *statsmodels* package (Seabold and Perktold 2010).

Bag-of-Words Models. We developed all models with *scikit-learn* (Pedregosa et al. 2011).

¹³ Recall that in our period-level task we do not distinguish between the different periods within a game.

¹⁴ We achieved this by utilizing the *StratifiedShuffleSplit* and *StratifiedKFoldCV* utility methods from *scikit-learn*, using a random seed of 212.

Table 5

The ADAM optimizer hyperparameters.

Parameter	Value
Learning Rate	$5e^{-04}$
Fuzz Factor ϵ	$1e^{-08}$
Learning rate <i>decay</i> over each update	0.0

Table 6

The CNN-T model hyperparameters.

Layer	Filter Size
Convolution 1	3
Convolution 2	4
Convolution 3	5
Linear Output	1

6.4.1 DNN Models. For all neural network models, we used Dropout (Srivastava et al. 2014) with $p = 0.2$ and batch normalization for linear layers, ReLU as the activation function for all internal layers, and sigmoid as the activation function for output layers. Training is carried out for 500 epochs with early stopping and a batch size of 8 samples (interviews). Because of the variance in sentence and interview length, we used various batch padding (to the maximum length in batch) and masking techniques. We used binary cross entropy as our loss function, and the ADAM optimization algorithm (Kingma and Ba 2015) with the parameters detailed in Table 5.

The CNN-T Model. We utilize GloVe word embeddings (Pennington, Socher, and Manning 2014), trained on the 2014 Wikipedia dump + the Gigaword 5 corpus (6B tokens, 400K word types, uncased) where each word vector is of dimension $d = 100$.¹⁵ We developed this model with Keras (Chollet et al. 2015) over TensorFlow (Abadi et al. 2016). The hyperparameter values of the model are given in Table 6.

The BiLSTM Models. For our text-based BiLSTM models (LSTM-T and LSTM-TM), we use the same GloVe word embeddings as in the CNN model described earlier. The size of the hidden textual representations at the forward and backward LSTMs is 100. Our LSTM-M model's hidden state vector size is 7 because we have $|M| = 7$ metrics. We developed these models with PyTorch (Paszke et al. 2017). The hyperparameter values of the model are given in Table 7.

BERT Models. For our BERT models, we utilize BERT's pre-trained models as a source of text representation. We experimented with two uncased pre-trained BERT models, both trained on the BookCorpus (800M words) (Zhu et al. 2015) and Wikipedia (2, 500M words): *BERT-Base* ($L = 12$ layers, $H = 768$ hidden vector size, $A = 12$ attention heads, $P = 110M$ parameters) and *BERT-Large* ($L = 24$, $H = 1,024$, $A = 16$, $P = 340M$), both

¹⁵ <http://nlp.stanford.edu/data/glove.6B.zip>.

Table 7
The LSTM-T model hyperparameters.

Layer	Input Size	Output Size
Input (Embedding)	$ Vocabulary $	100
$LSTM^{forward} \oplus LSTM^{backward}$	100	200
Linear 1	200	100
Linear 2	100	32
Linear Output	32	1

Table 8
The BERT-L-T model hyperparameters. H is the pre-trained BERT model’s hidden vector size ($H_{base} = 768, H_{large} = 1,024$)

Layer	Input Dimensions	Output Dimensions
BERT Pretrained Encoder	Interview text	$H \times \# \text{ Q-A pairs}$
$LSTM^{forward} \oplus LSTM^{backward}$	$H \times \text{Max} \# \text{ Q-A pairs in batch}$	$2H$
Linear Output	$2H$	1

Table 9
The BERT-A-T model hyperparameters. H is defined as in Table 8.

Layer	Input Dimensions	Output Dimensions
BERT Pretrained Encoder	Interview text	$H \times \# \text{ Q-A pairs}$
Attention	$H \times \text{Max} \# \text{ Q-A pairs in batch}$	H
Linear Output	H	1

publicly available via source code provided by Google Research’s GitHub repository.¹⁶ The *BERT-Large* model slightly outperformed *BERT-Base* in all of our experiments; hence we report results only for *BERT-Large*. We developed these models with PyTorch (Paszke et al. 2017), utilizing and modifying source code from HuggingFace’s “PyTorch Pretrained BERT” GitHub repository.¹⁷ Table 8 details the hyperparameters used for the BERT-L-T model and Table 9 details the hyperparameters used for the BERT-A-T and BERT-A-TM models.

We further experiment with our BERT models, by continuing the Language Model pre-training process for both the *BERT-base* and *BERT-large* uncased pre-trained models, on the interviews from our data set. Our goal in this experiment is to evaluate whether further pre-training of BERT on interview data would yield text representations that better capture features relevant to the basketball domain and hopefully improve prediction performance on our tasks.

We utilized the standard *Masked Language Model* (MLM) and *Next Sentence Prediction* (NSP) pre-training objectives of BERT (see (Devlin et al. 2019)). We ran the pre-training process for 1 and 3 epochs on the interview texts at the sentence level (to accommodate the NSP task), and tuned all BERT layers in this process. After completing the

¹⁶ <https://github.com/google-research/bert>.

¹⁷ <https://github.com/huggingface/pytorch-pretrained-BERT>.

pre-training process, we used the new pre-trained BERT models as part of new variants of BERT-A-T and BERT-A-TM, and evaluate their performance on all seven tasks for both the game and the period levels. We denote these models as *BERT-EPT-A-T* and *BERT-EPT-A-TM*, respectively, where EPT stands for “extended pre-training.” Our results indicate that the BERT models with extended pre-training are less effective than the standard BERT models that are not pre-trained on interview text. We hence report our results with the standard BERT models and analyze the extended pre-training process in Section 7.

7. Results

Examining and analyzing our results, we wish to address the four research questions posed in Section 5. That is, we wish to assess the interviews’ predictive power without and alongside past metrics (questions #1 and #2, respectively), the benefit of modeling the interviews’ textual structure (question #3), and the ability of DNNs to learn a textual representation relevant for predicting future performance metrics (question #4).

Overview. The results are presented in Table 10 (top: game level, bottom: period level). First, they suggest that pre-game interviews have predictive power with respect to performance metrics on both game and period-level tasks (question #1). This is evident by observing that text-based ($-T$) models generally performed better than the most CC baseline and metric-based ($-M$) models. Performance for all BERT-based and LSTM-based models is superior to CC and metric-based models at the game level, yet at the period-level results are rather mixed. Second, they suggest that combining pre-game interviews with past performance metrics yields better performing models (question #2). This can be seen in the performance gain of our combined ($-TM$) models over their respective text-based models, and the overall best performance of the BERT-A-TM model in most tasks. Third, they support the use of structure-aware DNNs for these prediction tasks (question #3). This can be seen by the general performance gain of text-based models as their modeling complexity of textual structure rises, especially in game-level tasks. Furthermore, our DNN models generally outperformed non-neural models, suggesting that DNNs are able to learn a textual representation suitable to our tasks (question #4). We shall examine the results in further detail below, in light of our four research questions.

The Predictive Power of Interviews. Game-level BERT-A-T, our top performing text-based model, outperforms the CC baseline and all metric-based models, in all seven tasks, with improvements over the CC baseline ranging up to an added accuracy of: 7.1% on personal fouls (PF), 7.7% on points (PTS), 7.8% on field goal ratio (FGR), 5.8% on pass risk (PR), 6.1% on shot risk (SR), 6.6% on mean 2-point shot distance (MSD2), and 1.9% on mean 3-point shot distance (MSD3). Game-level LSTM-T outperforms the most CC baseline and all metric-based models in five of the seven tasks.

For four period-level tasks, PR, SR, MSD2, and MSD3, the CC baseline and metric-based models outperform text-based and combined models. We hypothesize that this is because at many periods the participation of many of the players is limited, which results in a below-average performance. For all tasks at the game level, as well as for PF, PTS, and FGR at the period level, this is much less frequent and the text is then much more informative.

Interestingly, for most game-level tasks, metric-based models (that rely only on performance metric information) are not able to predict much better than a coin flip or

Table 10

Game-level (top) and period-level (bottom) accuracy on a 0–100 scale. Best accuracy on each performance metric is highlighted in bold. CC stands for the most common class baseline. Models that involve text perform best in all game-level tasks and in three of seven period-level tasks.

Model	PF	PTS	FGR	PR	SR	MSD2	MSD3
CC	50.4	52.4	50.9	52.8	57.3	55.3	58.9
AR(3)-M	43.7	49.6	48.9	51.9	57.3	53.7	59
AR(3)-M*	48.1	54.9	51.5	47.8	57.5	55.3	56.3
LSTM-M	50.1	50.5	48.2	48.8	58.2	56.9	55.9
BoW-RF-T	50.8	50.8	51.1	53.7	57.8	54.9	59.3
TFIDF-RF-T	51.5	53.7	53.3	53.3	57.6	58.0	57.6
CNN-T	51.9	54.9	50.4	48.5	57.5	53.7	57.8
LSTM-T	56.7	58.2	55.7	58.2	55.2	55.8	58.2
BERT-L-T	54.9	55.6	55.6	57.5	59.5	57.8	60.5
BERT-A-T	57.5	60.1	58.7	58.6	63.4	61.9	60.8
LSTM-TM	57.5	58.2	55.5	57.7	61.6	59.7	55.8
BERT-A-TM	59.3	60.7	60.5	60.1	61.2	59.7	60.8

Model	PF	PTS	FGR	PR	SR	MSD2	MSD3
CC	52.2	54.1	51.5	64.8	64.3	64	75.1
AR(3)-M	52.6	53.6	48.8	65	64.9	65.7	75.9
AR(3)-M*	53.3	54.2	51.7	65	63.2	65.7	75.9
LSTM-M	50.1	51.5	50.3	62.7	62.4	62.3	74.2
BoW-RF-T	52.3	52.5	49.3	60	61.6	58.2	67.1
TFIDF-RF-T	50.2	53.9	50.3	63.1	63.5	63.7	74.5
CNN-T	51.6	53.3	49.4	59.2	62.5	57	68.1
LSTM-T	51.6	53.7	52.3	64.1	64.9	63.1	74
BERT-L-T	53.2	56	53.6	63.8	63.6	64.3	74.5
BERT-A-T	55.6	53.7	52.3	64.3	63.7	64.2	75.1
LSTM-TM	52.3	58.3	56.6	63.6	63.4	63.4	74.2
BERT-A-TM	56.3	58.5	57.8	64.1	64.7	64.9	74.7

the most CC baseline. Only in three cases does a metric-based model outperform these baselines by more than 1%: game-level PTS, period-level PF, and period-level MSD2. These results emphasize the achievement of text-based prediction that succeeds where standard approaches fail.

The Predictive Power of Text and Performance Metric Combination. BERT-A-TM outperforms BERT-A-T, its text-only counterpart (which outperforms all other models across all seven game-level tasks), in four out of seven game-level tasks (PF, PTS, FGR, and PR are on par for MSD3) and in five out of seven period-level tasks. Game-level BERT-A-TM performs particularly well on the personal fouls (PF) and pass risk (PR) tasks, outperforming the most common class baseline (CC) by 8.9% and 7.3%, respectively. Interestingly, both metrics tend to be similar across players (see Table 2). Deviations from the mean in these metrics reflect an increased or decreased level of aggressiveness (PF for defensive and PR for offensive decisions), suggesting that this quality is somewhat more visible in the language shown in the interviews.

More volatile metrics, such as field goals ratio (FGR), shot distance (MSD2/3), and shot risk (SR) are rather static at the player level but differ substantially between players

(see Table 2). This makes it harder to distinguish what drives variance in those metrics. Our results on those tasks are not as strong as those of the PF, PTS, and PR tasks, but besides MSD3 we still observe significant improvement for most text-based ($-T$) and combined models ($-TM$) over the alternative models (see game-level results in Table 10).

A closer look into the data reveals a potential explanation for the superiority of BERT-A-TM on period-level PF, PTS, and FGR: Because these performance metrics are less volatile between periods, it is useful for BERT-A-T to use past performance metrics to better predict current player performance, compared with the text-only alternative.¹⁸ Adding performance metric information is hence particularly useful in these setups.

The game-level LSTM-TM model substantially outperforms the LSTM-T model, its text-only counterpart, on SR and MSD2, but the two models perform similarly on the other tasks, with the exception of MDS3, where LSTM-T outperforms LSTM-TM. Period-level LSTM-TM outperforms LSTM-T on PF, PTS, and FGR, yet LSTM-T outperforms LSTM-TM on SR. Overall, combining text and metrics with the LSTM-based models proves to be valuable in some of the tasks, but certainly not in all of them. Given the comparison between BERT-A-TM and BERT-A-T, and between LSTM-TM and LSTM-T, we can conclude that BERT better captures the combination between text and past performance metrics compared with LSTM.

We also look at the variation in our models' performance across all five folds, to test for their robustness. For this, we calculated the standard deviation of our models across all folds and have found that in all seven game-level tasks and seven period-level tasks, the average standard deviations of BERT-A-T and BERT-A-TM were lower than the average standard deviations of each of the non-neural models (BoW-RF-T, TFIDF-RF-T, and the AR models). On average, the standard deviation of the BERT-A-T and BERT-A-TM models is 1% (absolute, i.e., 1 accuracy point), a fifth of the standard deviation of the TFIDF-RF-T, the best-performing non-neural model. Some non-neural models are less noisy than TFIDF-RF-T, but have a standard deviation of at least 1.5% and are still much noisier than the BERT-A-T and BERT-A-TM models.

To summarize, BERT-A-TM is our overall best performing model, outperforming all other models in a total of 8 (5 game-level and 3 period-level tasks) out of 14 tasks. In all seven game-level prediction tasks and in three of the period-level tasks (in total 10 out of 14 tasks), it is a BERT-A model that performs best. In eight of these cases it is BERT-A-TM and only in two is it BERT-A-T. This clearly indicates the added value of the textual signal on top of the signal in past metrics.

The Value of DNN Modeling: Textual Structure and Representation Learning. With regard to our third and fourth questions, Table 10 reveals a general performance gain when using text-based DNN models, as they capture more intricate aspects of the interview structure. Notably, at both the game- and the period-level the text-based BERT-A-T model outperforms the TFIDF-RF-T non-neural text-based model (in seven of seven game-level comparisons and in six of seven period-level comparisons). Moreover, it is clear from the table that overall the text-based BERT-A-T model outperforms the text-based LSTM-T model, which in turn outperforms the text-based CNN-T model. This leads to two conclusions. First, it suggests that DNNs are able to learn a textual representation suitable for our tasks, which might be needed due to the remote nature

18 All three performance metrics have an average standard deviation of 0.7 at the period level, substantially below the other four performance metrics, which exhibit an average standard deviation of 1.4.

of the supervision signal, as discussed in Section 5 (question #4). Second, it suggests that modeling the textual structure of interviews is valuable for our tasks (question #3).

In particular, modeling an interview on a Q-A level better captures the interview structure compared with simpler word or sentence-level modeling. In addition, we hypothesize that the attention mechanism handles sequences of jointly represented Q-A pairs better than more rigid sequential models such as LSTMs. This observation is further supported by the better performance of the attention-based BERT-A-T model compared to BERT-L-T, which uses an LSTM instead of attention on top of the BERT representations (BERT-A-T performs better in seven of seven game-level tasks, and both models perform similarly on the period-level tasks). These observations clearly demonstrate the benefits of modeling an interview’s textual structure, in an increasing level of complexity and nuance with respect to the unique characteristics of interviews.

Extended BERT Pre-training. When examining the BERT-EPT-A-T and BERT-EPT-A-TM models, we observe a slight yet consistent degradation in prediction performance throughout almost all tasks, in comparison with both the BERT-A-T and the BERT-A-TM models. There is an average accuracy degradation of 0.6% over all tasks: 0.7% on the game level, and on the period level the results are mostly on par, with the exception of PTS, FGR, and SR metrics where BERT-EPT-A-TM is somewhat better. Moreover, we observe an increase in overall result variance when comparing our BERT-EPT-A models (average standard deviation of 1.8%) to the BERT-A models (average standard deviation of 1%). This suggests that the extended pre-training process yields less stable models. We hypothesize that continuing the pre-training process might lead to BERT overfitting on our data, at the cost of “forgetting” valuable features from its original pre-trained representations. This could be explained by the following observations:

1. Our data set size is orders of magnitude smaller (about 2M words in total) compared with the BookCorpus (800M words) and Wikipedia (2,500M words) data sets on which BERT was originally pre-trained.
2. Our pre-trained models that ran for one epoch outperformed our pre-trained models that ran for three epochs, by an average of 0.2%. This suggests that longer pre-training would slightly increase the “forgetting” effect and harm prediction performance.
3. The NSP task might be inadequate for interview text, because it does not allow for capturing the unique structures present in interviews, such as the dependence between speakers’ utterances, which are usually composed of multiple sentences each.

In light of our experimental results, and specifically our observation on the possible limitations of the NSP task for interview processing, we believe that investigating the process of pre-training BERT for interview text is an interesting direction for future work. For example, one idea is to replace the standard NSP task with a similar task, designed for Q-A pairs, with the goal of predicting whether a given Q and A are a real pair in an interview. In future work, we would like to further explore different possible pre-training methods that might be better-suited for interviews, by designing them to capture the unique structures present in interviews and the roles of the participating speakers.

Per-Player Model Performance. In the analysis so far we have adhered to results on aggregated performance, without observing differences between players. To provide an analysis of the model’s performance per player, we present in Figure 6 the relative performance of the BERT-A-T model at the game level, for each player and for each task. We shall use the definitions below to explain the figure structure: Let BERT-A-T’s accuracy score for a given metric $m \in M$, over all examples in the test set I_{test} , be defined as:

$$ACC^m = \frac{\sum_{i \in I_{test}} \mathbb{1}\{\hat{y}_i^m = y_i^m\}}{|I_{test}|} \quad (11)$$

where \hat{y}_i^m denotes the label predicted by BERT-A-T and y_i^m denotes the true label for example i . Let BERT-A-T’s accuracy score for a given metric $m \in M$ and a player $p \in P$, over the subset of all test set examples I_{test}^p in which player p participates, be defined as:

$$ACC^{p,m} = \frac{\sum_{i \in I_{test}^p} \mathbb{1}\{\hat{y}_i^m = y_i^m\}}{|I_{test}^p|} \quad (12)$$

Each point in Figure 6 is defined as the difference between $ACC^{p,m}$ and ACC^m :

$$\Delta ACC^{p,m} = ACC^{p,m} - ACC^m \quad (13)$$

We use this difference measure to facilitate the visualization of BERT-A-T’s relative performance in terms of accuracy for all players in all tasks, on a single graph.

Observing this figure, some interesting patterns arise. First, model performance in SR prediction is significantly better for front-court players (e.g., Tim Duncan, Shaquille O’Neal, and Pau Gasol), who make significantly fewer attempts to shoot behind the 3-point arc, in a manner that could be quite predictable.¹⁹ Second, the performance of BERT-A-T is significantly lower in predicting the distance of the 3-point shots taken by those players (the average of this distance is captured by the MSD3 metric). This could be the result of the infrequent nature of these types of shots by these players. Comparatively, performance of back-court players, such as Kyle Lowry, Manu Ginobili, and Steve Nash, who frequently attempt 3-point shots, are better predicted by our BERT-A-T model.

8. Qualitative Analysis

Thus far we have shown the predictive power of our models, but we would also like to get an insight as to what in the text is indicative of the player’s actions and decisions. Relying on the sports psychology and analytics literature, we would like to test the efficacy of theories such as IZOF (Hanin 1997) and its successors (see discussion of such theories in Sections 1 and 2). That is, we would like to observe whether the success of our models in predicting players’ actions is related to the players’ hypothesized “emotional state” as reflected in the text.

The rise of deep learning models, such as those we use here, has produced substantially better prediction models for a plethora of tasks, most notably for those that rely on unstructured data (Peters et al. 2018; Devlin et al. 2019). This improved predictive

¹⁹ Court structure, including the location of the 3-point arc, is presented in Figure 1.

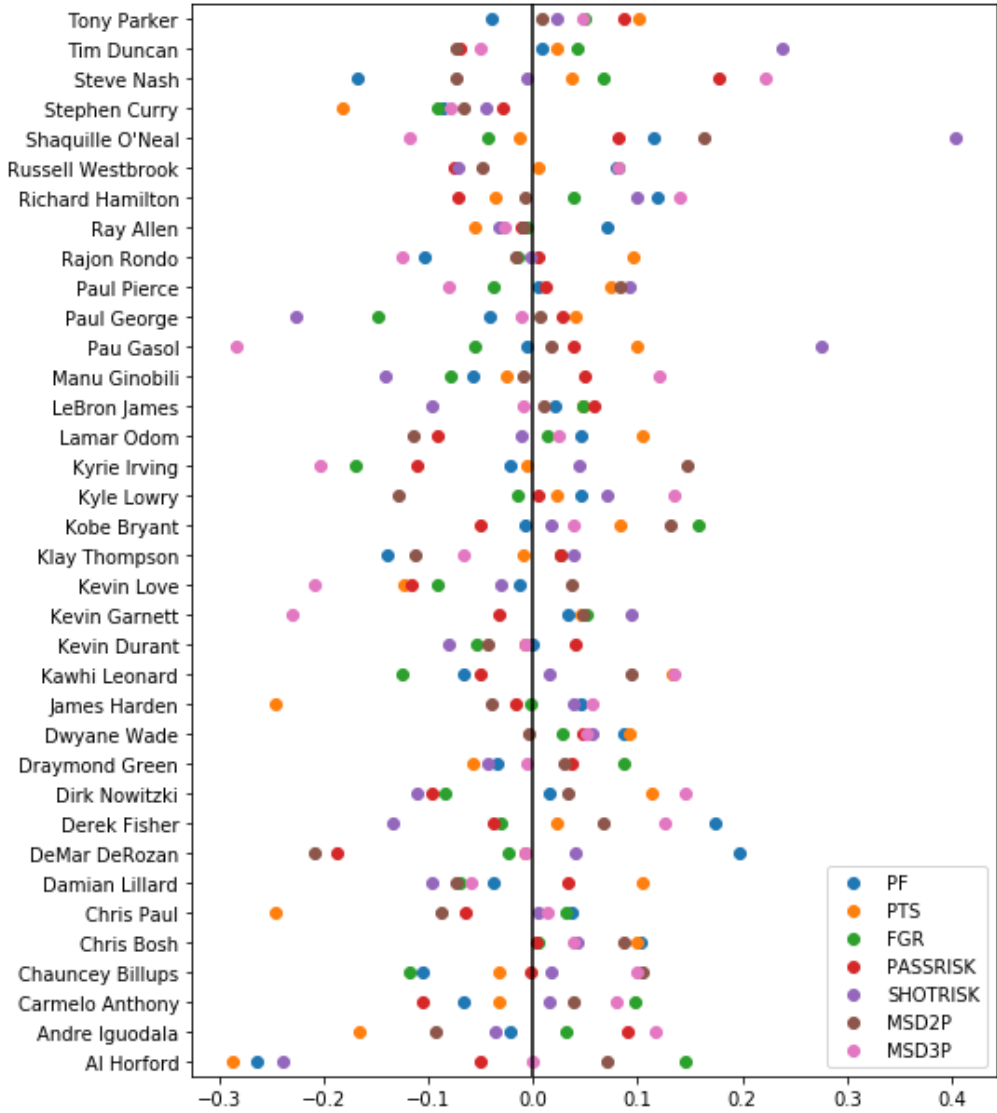


Figure 6
BERT-A-T prediction accuracy per player, relative to its accuracy for all players, for each prediction task. Each point in the graph is defined by Equation (13).

power, however, has come at the expense of model explainability and understandability. Understanding predictions made by DNNs is notoriously difficult, as their layered structure, which is coupled with nonlinear activations, does not allow for tracing and reasoning over the effect of each input feature on the model’s output. In the case of text-based models this problem is amplified, as features are usually composed of adjacent sequences of words, and not abstract linguistic concepts that might exist in the text and push the model toward specific predictions.

Following the meteoric rise of such models, there have been many attempts to build tools that allow for model explanation and interpretation (Ribeiro, Singh, and Guestrin 2016; Lundberg and Lee 2017). However, such tools often rely on local perturbations or shallow correlations. They are ill-suited for text-based models and for reasoning on higher-level concepts, such as our players' states. When attempting to reason about abstract concepts such as "emotional state," it is not clear how to highlight the effects of different features on the predictions a model makes, when its input features are word sequences. To be able to estimate such effects we need to represent the models' output in a space where we can reason about high level concepts. Specifically, we decided to represent such concepts as interview topics.

8.1 LDA Topic Modeling for DNN Interpretation

Following this reasoning, we qualitatively interpret the predictions of our models using latent Dirichlet allocation (LDA) (Blei, Ng, and Jordan 2003). Importantly, we do not perform predictions with LDA, but instead use the topics it induces in order to interpret the results of our DNN models. To the best of our knowledge, the idea of interpreting the predictions of DNNs in text classification tasks using LDA topics has not been proposed previously. LDA models the interviews as mixtures of topics, where each topic is a probability distribution over the vocabulary. Our goal in this analysis is to find the topics that are most associated with the predictions our DNN models make in each of the seven performance classification tasks. Our reasoning is that LDA-based topics may provide a latent space suited for intuitive reasoning about the predictions of DNN models, allowing enough dimensions for observing differences in higher-level concepts, while keeping it relatively compact for proper analysis.

Interpreting a supervised DNN prediction model utilizing an auxiliary unsupervised LDA model, which itself learns a latent representation of the data, raises a question about the predictive power of the LDA model in the original prediction task. Suppose the LDA topics prove to hold the same predictive power as the DNN or they are perfectly correlated with the DNN's predictions; then the LDA model could serve as an interpretable alternative to the uninterpretable DNN. This is not the usual case with most DNN prediction models, which generally outperform LDA-based counterparts in most text-based prediction tasks. Therefore, we are interested in finding LDA topics that correlate with the DNN predictions, keeping in mind that we need to quantify this correlation in order to understand how well the topics explain the DNN predictions. We chose to perform two types of analyses:

- Associating a specific topic with the positive predictions of the analyzed classifier, for each prediction task (see Table 11 and Figure 7). This yields a rather informative and intuitive analysis, which sheds light on what a prediction model managed to consistently capture in the text. Yet, the selection of a single topic might limit the interpretation to a single specific aspect and miss other aspects.
- Analyzing the correlations between all LDA topics and the predictions of the analyzed classifier, for each performance task (see Figure 8). This analysis is complementary to the previous one: it is multidimensional and hence gives a higher-level view rather than delving into the details of one explaining topic.

Table 11

The 10 most likely words according to the topic with the largest probability difference between positive and negative BERT-A-T predictions, z^{m+} . We refer to these as the *positive class topics*. Results are presented at the game level, for each prediction task.

PF	PTS	FGR	PR	SR	MSD2	MSD3
Aggressive	Fun	Year	Try	Shot	Get	Game
Defensively	Star	Team	Offensively	Miss	Shot	Last
Guard	See	Season	Physical	Make	Ball	Night
Adjustment	Great	Championship	Intensity	Three	Make	Make
Transition	Think	Think	Pace	Field	Defense	Series
Roll	Time	Career	Attack	Credit	Think	Win
Turnover	Good	Work	Paint	Confident	Able	Little
Paint	Enjoy	Great	Lane	Opportunity	Try	Think
Defensive	Fan	Win	Communication	Look	Run	Better
Offense	Basketball	Experience	Space	Ball	Go	Loss

We describe each analysis in further detail below.

8.2 Associating Topics with Classifier Predictions

We train a topic model²⁰ and optimize the number of topics on our entire training set I_{train} for maximal coherence (Lau, Newman, and Baldwin 2014), resulting in a set Z of 36 topics. Then, for each label we split the test set I_{test} into positively and negatively classified interviews, according to the BERT-A-T predictions, our best performing text-based model. We note that, because we are interested in interpreting our model’s predictions, we perform the split according to the model predictions and not according to the gold standard.

Following this split, we then search for the topic that is on average most associated with the model’s positive predictions (i.e., the topic with the largest probability difference between positive and negative model predictions). We denote the topic distribution (mixture) of an interview i with θ^i (as defined in Blei, Ng, and Jordan [2003]), and $p(z|\theta^i) = \theta_z^i$ as the probabilities of words in interview i to be generated by topic z . Intuitively, θ_z^i can be thought of as the degree to which topic z is referred to in interview i (Blei, Ng, and Jordan 2002). The computations for both positive and negative topics are described in Equations (14) and (15).

$$PositiveClassTopic^m = z^{m+} = \operatorname{argmax}_{z \in Z} \left\{ \sum_{i \in I_{test}} \hat{y}_i^m \cdot \theta_z^i \right\} \tag{14}$$

$$NegativeClassTopic^m = z^{m-} = \operatorname{argmax}_{z \in Z} \left\{ \sum_{i \in I_{test}} -\hat{y}_i^m \cdot \theta_z^i \right\} \tag{15}$$

²⁰ Using the *gensim* library (Řehůřek and Sojka 2010).

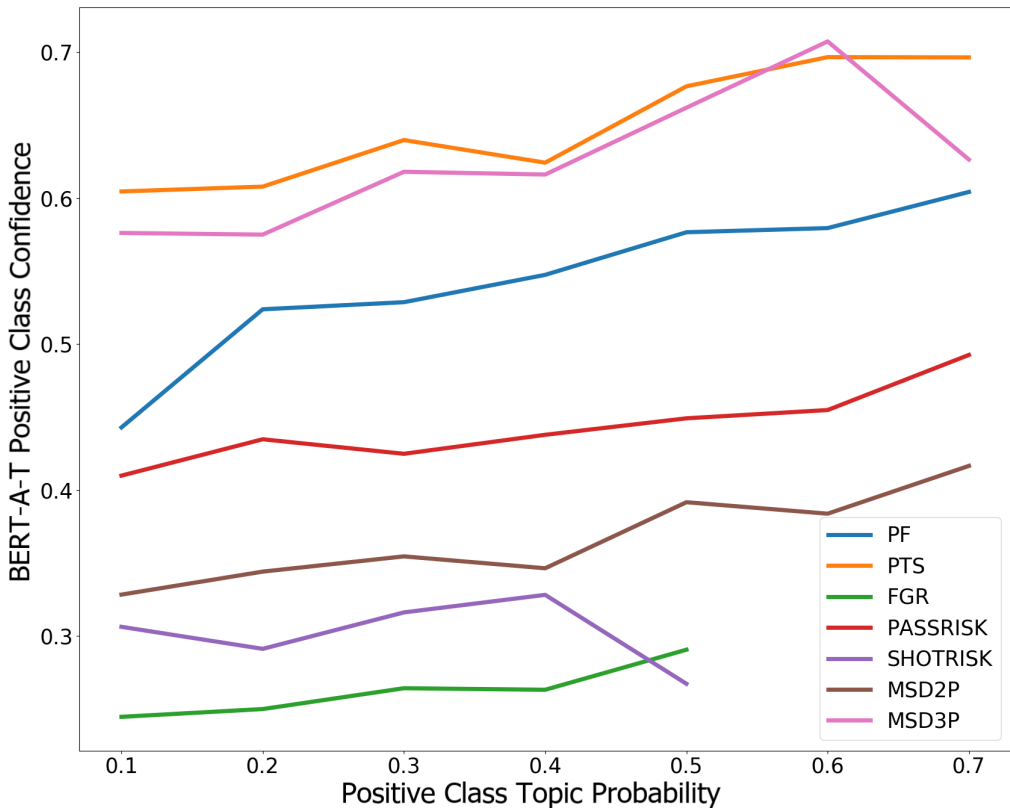


Figure 7
 BERT-A-T’s averaged positive class prediction confidence ($\hat{p}(y_i^m = 1)$) as a function of the positive class topic probability ($\theta_{z^{m+}}^i$) assigned to each interview. The computation of $f(\theta_{z^{m+}}^i; j)$ is described by Equation (16).

where:

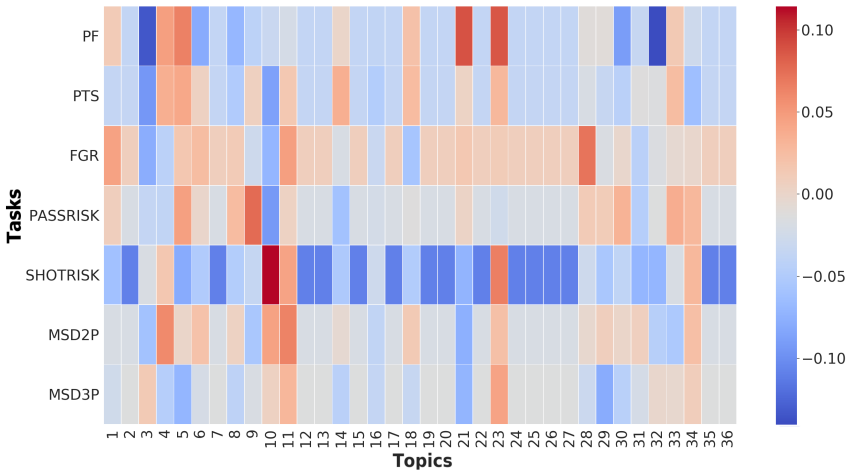
$$\hat{y}_i^m = \begin{cases} 1, & \hat{p}(y_i^m = 1) \geq 0.5 \\ -1, & \hat{p}(y_i^m = 1) < 0.5 \end{cases}$$

and $\hat{p}(y_i^m = 1)$ is the positive class probability according to the DNN.²¹ We then investigate the z^{m+} topic, which we denote as the **positive class topic**, to observe what our model has learned. From now on we shall refer to $\hat{p}(y_i^m = 1)$ as the **DNN’s positive class prediction confidence** and to $\theta_{z^{m+}}^i$ as the **positive class topic probability**.

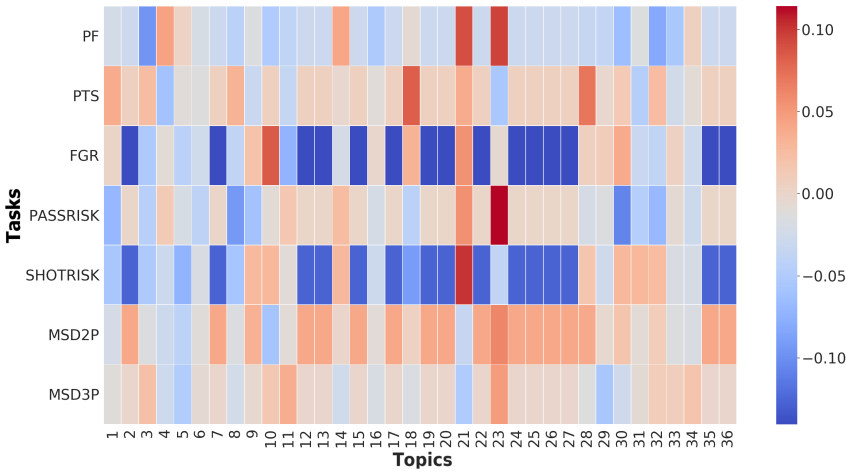
Following Sievert and Shirley (2014),²² we print out the words that are most associated with the z^{m+} topic according to their estimated term frequency within the selected

21 For our DNNs to produce class probabilities, we use a binary Cross-Entropy loss function (Goodfellow, Bengio, and Courville 2016); see Section 6.4.1.

22 Note that this work addresses topic model visualization, rather than neural network interpretation.



(a)



(b)

Figure 8 Correlation heat-maps of LDA topic probability ($\theta_{z_m}^i$) and the DNN positive prediction confidence ($\hat{p}(y_i^m = 1)$) ((a) LSTM-T; (b) BERT-A-T), for each prediction task.

topic. The top words belonging to those topics, for the game-level BERT-A-T classifiers, are presented in Table 11.

As can be seen in the table, the positive class topics seem intuitively related to the label, capturing not merely naive sentiment or emotion, but more refined, task-related words. For positive personal fouls (PF) predictions, the model picks up concepts related to aggressive and defensive play. The topic for points (PTS) suggests it is most positively correlated with joyfulness, implying that the model has learned to associate a positive

sentiment with more points. The field goal ratio (FGR) topic conveys game importance and long-term thinking, implying a learned link between a player’s performance and the game’s significance. Pass risk (PR) and shot risk (SR) positive topics show a connection to players willingness to take more risk, as they are associated with words such as “try” and “confident,” respectively. Finally, the mean shot distances metrics, MSD2 and MSD3, seem unrelated to their topics, which is unsurprising at least for MSD3 that BERT-A-T does not predict well (see results in Table 10).

In Figure 7 we plot $f(\theta_{z^{m+}}^i; j)$, the averaged BERT-A-T positive prediction confidence $\hat{p}(y_i^m = 1)$, as a function of $\theta_{z^{m+}}^i$, the probability of the positive class topic z^{m+} in the interviews, for each metric m . We compute each point in the plot, by calculating $f(\theta_{z^{m+}}^i; j)$ for each interval $j \in J = \{0.1, 0.2, \dots, 1\}$ as defined:

$$f(\theta_{z^{m+}}^i; j) = \frac{\sum_{i \in I_{test}^j} \hat{p}(y_i^m = 1)}{|I_{test}^j|}, I_{test}^j = \{i \mid i \in I_{test}, \theta_{z^{m+}}^i \in (j - 0.1, j]\} \tag{16}$$

We calculate this for visualization purposes: for each positive class topic probability ($\theta_{z^{m+}}^i$) interval of size 0.1, we compute the average BERT-A-T positive prediction confidence ($\hat{p}(y_i^m = 1)$) over all interviews with $\theta_{z^{m+}}^i$ falling in the interval. As demonstrated in Figure 7, we observe that the probability assigned to positive topics ($\theta_{z^{m+}}^i$) from Table 11 increases monotonously with BERT-A-T’s averaged positive predicted probability (confidence) for deviation above the player’s mean performance ($\hat{p}(y_i^m = 1)$), in six out of the seven tasks (SR being the exception).

8.3 Topic Correlation with LSTM-T and BERT-A-T

We finally investigate the predictions of our two best-performing text-based models, LSTM-T and BERT-A-T, in terms of the LDA topics. Because LDA is trained on free text and does not observe the predictions of any DNN model, its topics can be used to analyze two different DNNs: LSTM-T and BERT-A-T in this case.

The heat-maps in Figure 8 present the correlations for each metric m , between $\theta_{z^m}^i$, the probability of each topic $z \in Z$, and $\hat{p}(y_i^m = 1)$, the DNN’s positive prediction confidence, for both LSTM-T and BERT-A-T. Observing the results, it is clear that BERT-A-T’s predictions are more correlated with the LDA topics, compared with the LSTM-T (darker colors indicate higher correlations). Looking closer at the heat-maps, we notice some interesting patterns.

First, SR and MSD2 seem to exhibit opposing topic correlation patterns when examining the BERT-A-T model’s predictions (bottom figure). This implies that topics associated with a higher probability of taking more 3-point shots are also associated with 2-point shots that are closer to the rim. The correlation exhibited by the BERT-A-T model could be explained by the growing tendency of players to take more 3-point shots at the expense of long-range 2-point shots, a phenomenon widely observed in recent years in the NBA.²³ This phenomenon also serves as an example of attempting

23 See the substitutability of long-range 2-point shots and 3-point shots in: <http://www.nbaminer.com/shot-distances/>.

to maximize the expected payoff (Von Neumann and Morgenstern 1944). If shot-takers are in a situation in which they are unable to minimize their risk (i.e., they cannot take a 2-point shot close to the rim and must take a shot further out), they choose to increase their risk for a higher payoff and take a longer-range 3-point shot.

Second, we also note that topic 23, which is associated with PR for BERT-A-T, is also positively correlated with PF for both BERT-A-T and LSTM-T. PR's positive topic exhibits top-words such as "Physical" and "Intensity" (as can be seen in Table 11), and PF's positive topic exhibits top-words such as "Aggressive," "Defensively," and "Guard." This suggests that topic 23 captures some aspects of the concept of physical intensity and aggressiveness on both offense (PR) and defense (PF), and moreover that the DNNs capture this as well, to a certain extent.

Finally, the BERT-A-T classifiers for SR and FGR are generally correlated with similar topics. Particularly, it seems that both classifiers are positively correlated with topics that are highly associated with shot-related words.²⁴ Although this may seem counter-intuitive, notice that the corresponding LSTM-T classifiers do not show this correlation and they also perform significantly worse on those tasks (as seen in Table 10). Overall, we can see that our topic analysis enables a level of intuitive reasoning, which serves as a new tool for providing insights on both the data and the properties of the prediction models (DNNs).

9. Conclusions

We explored the task of predicting the relative performance of NBA players based on their pre-game interviews, building on the extensive computational work on performance prediction in sports analytics and on text classification in NLP. We hypothesized that these interviews hold valuable information regarding the players' current state and that this information could shed light on their in-game actions and performance.

To facilitate such a study, we collected a data set consisting of pre- and post-game interviews alongside in-game performance metrics from the game following the interviews, for 36 prominent NBA players. Most of the games in our data set are part of a playoff series where the stakes are typically higher, player and team performance or outcomes are harder to predict, and key players are expected to take on bigger roles, in comparison to regular season games.

Based on standard basketball in-game performance metrics, we introduced seven decision related metrics, each aiming to examine a different aspect of a player's in-game actions and performance. We formulated binary text classification tasks, attempting to predict a player's deviation from his mean performance in each metric, to examine whether pre- and post-game interview texts hold predictive power of the player's in-game actions. We formulated four research questions, trying to assert: (1) if text classification models could utilize pre-game interviews for predicting performance, (2) if text could be combined with past performance metrics for better predictions, (3) if text classification models gain from modeling an interview's textual structure, and (4) if DNNs could jointly learn a textual representation together with the task classifier, in a way that improves prediction accuracy over standard bag-of-words features.

²⁴ We chose not to present all topics and their corresponding top-words as most are not informative and do not add information that helps us answer our research questions.

We demonstrated that deep neural networks, mainly BERT and to some extent LSTM, are capable of using interview-based signals to predict players' performance indicators. Moreover, we showed that our text-based models perform better than commonly used autoregressive metrics-based models, and that models that combine the two signals yield even better predictions. Also, we have shown that all game-level metrics and most period-level metrics can be predicted, to varying degrees.

In conducting this research, we were not interested only in predictive power, but also in understanding the phenomena at hand. Hence, it was important for us to be able to understand the predictions of the model. However, DNN interpretation is challenging, which hurts our ability to understand our models' predictions in terms of difference in language usage.

Thus, in order to interpret our DNN models in terms of linguistic concepts, we presented an LDA-based method. Our idea is based on examining topics that are on average most associated with the predictions of the model. In this analysis, we found that in six of seven cases our best performing text-only model, BERT-A-T, is most associated with topics that are intuitively related to each prediction task, revealing that the model has successfully learned task specific representations.

In particular, in this work we have attempted to set the stage for future exploration on several axes. First, much more research can be done on prediction models in scenarios where the signal is not stated directly in the text, in contrast to better-explored cases such as sentiment classification and intent detection. Moreover, the connection between language and decision making can also be further explored, specifically in real-world rather than lab conditions. Models for predicting behavior using language could be useful in strategic settings such as multiplayer games, and can also be useful in medical settings, where predicting the patient's current state, which may not be explicitly discussed in the text, could have life-saving implications.

We consider our task a domain specific instance of a more general question: How should language be used as a predictive signal for actions in real-world scenarios. We hope that our discussion, observations, and algorithms, as well as data set and code, will facilitate future work by the community.

In future work we will consider more advanced time-series analysis tools along with the text, and better incorporate the interview's structure into our model. Our experiments have shown that incorporating the Q-A structure of the interview does improve the predictions, but this is only a first step in this direction, and more work can be done on this frontier. Also, we will aim to learn various performance metrics jointly, and to model the interactions between the actions of different players. This will hopefully yield better, more interpretable models for understanding the connection between language and actions.

Another interesting direction is taking into account the development of players' performance over time. It could be that measuring players across fewer seasons could lead to better estimates, as players change along their careers. On average players are represented in our data set for six seasons, which corresponds to their prime in terms of average performance. That is, we are generally capturing players at their peak performance, where quality tends to remain more consistent. In the future, given sufficient data per player, it would be interesting to integrate the time factor into our models.

Finally, another interesting theoretical question that arises is the extent to which language can really tell us about decisions that are made in later situations. It would be interesting to investigate and model these connections, and perhaps develop a theoretical bound for the predictive power that language could have in such situations.

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