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1 **Predictors of Time to COVID-19 Infection in the National Basketball Association:**
2 **A Retrospective Case-Control Study**

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29 **Running Head:** COVID-19 Infection in the NBA

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31

1 **Abstract**

2 A case-control study was conducted between 12/01/2021–01/31/2022 to identify factors
3 which increase risk for COVID-19 among athletes in the National Basketball Association
4 (NBA). Behavioral factors and stadium attendance significantly decreased time to
5 COVID-19 infection, but local COVID-19 rates were not associated in a multivariable
6 model.

7

8 **Key Words:** COVID-19, infectious disease, epidemiology, survival analysis

ACCEPTED MANUSCRIPT

Background

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a virus globally accounting for at least 601 million cases of coronavirus disease 2019 (COVID-19) as of August 2022, with a high number of cases that have been detected among professional sports athletes.¹ The closely monitored, publicized, and high-stakes economic pressures faced by many professional sports organizations, such as the U.S. National Basketball Association (NBA), provides the means for robust analysis of individuals placed in different risk-modifying circumstances, including travel to geographic areas with different COVID-19 burden, time spent in densely-packed arenas, and time spent in close contact with other athletes. Previous studies have examined COVID-19 NBA-related risk characteristics including a retrospective cohort study examining case characteristics of NBA players who participated in the 2020 closed campus occupational health and safety program (i.e., “NBA Bubble” that utilized isolation protocols in Orlando, Florida²), a study using PCR results from NBA players to assess infectivity for the Omicron variant,³ and a 2022 study examining infection rates among NBA players and staff who were fully boosted.⁴ This study builds on this prior research by specifically analyzing NBA player-level activity-related risk factors that may significantly influence risk for time to COVID-19 infection with an emphasis on high-infectivity periods of the 2021-2022 NBA season when the Omicron variant became the dominant strain in the US.

Methods

This retrospective observational case-control study included all players in the 2021-2022 NBA season that were on an active team roster during the study period. Outcome data consisted of probable COVID-19 infection, estimated by proxy as those players placed on indefinite leave (IL) due to entering the NBA health and safety protocols. NBA health and safety protocols require that players are placed on IL if they receive a positive or inconclusive result from a reverse transcription polymerase chain reaction (RT-PCR) test for COVID-19.⁵ Fully vaccinated players (with a booster) in the 2021-2022 NBA season were only required to test if symptomatic or exposed to an individual with COVID-19, and player vaccinations were not mandated. Other players, including those without a booster, were subject to daily testing during the study time period.

Athletes with a positive test would be placed on IL until one of two scenarios occur. The first scenario requires two negative RT-PCR tests at least 24 hours apart. The second scenario requires 6 total days to pass, over 24 hours after a fever without medication, and a cycle threshold greater than 30. Vaccinated players with an inconclusive test would require two negative RT-PCR tests on consecutive days, whereas unvaccinated players would require five negative RT-PCR tests on consecutive days. Unvaccinated players would also be required to quarantine if they were flagged via contact tracing as being potentially exposed to a person who is

1 positive for COVID-19. Players may also be placed on indefinite leave under NBA
2 health and safety protocols for other reasons, such as hip surgery.⁶ Though no specific
3 reason is published for a player being placed on IL due to the NBA's health and safety
4 protocols for privacy reasons, news reports from the study time period reported that
5 much of the variability was due to infection with COVID-19,^{7,8} possibly due to the
6 perception of relative rarity for other reasons that may be related to the NBA health and
7 safety protocol.

8 IL data were collected from the sports archive website Pro Sports Transactions
9 Archive.⁹ Data for NBA player-level activity-related risk factors were available from the
10 Application Programming Interface (API) for the nba.com website (games played,
11 home/away games, minutes played, stadium attendance).¹⁰ COVID-19 county-level
12 infection rates were collected from Johns Hopkins University.¹ Dates for data collection
13 and analysis spanned from the start of December 2021 to the end of January 2022,
14 representing sixty days during the early 2021-2022 NBA season. These dates were
15 selected to optimally influence the impact of a single variant on time to event modeling.

16 Cox proportional hazard models were computed to assess for bivariate and
17 multivariable associations between NBA player-level activity-related risk factors and
18 time to COVID-19 infection. The outcome is conceptualized as time to first event, and
19 therefore reinfection was not modeled as part of this study. Throughout the study
20 period, games played was treated as an accumulating tally, percentage away games
21 was calculated as a moving average, and minutes played on a given day was computed
22 as a sum of minutes played during the study period. Non-behavioral risk factors
23 (stadium attendance and county-level COVID-19 rates for areas where games were
24 played) were not transformed prior to modeling. For visualization with Kaplan-Meier
25 plots, risk factors were computed as player means and then players were separated into
26 quartiles, with the exception of games played in which quartiles were computed from
27 player maxima. Analysis and visualization was conducted R version 4.1.2.

28 Results

29 Data were available for 621 athletes in the study period. Approximately half (50.7%) of
30 athletes were placed on the NBA IL COVID-19 protocol and were likely infected with
31 COVID-19 during the sixty-day period, with the probability of avoiding infection falling
32 precipitously in the second half of the study period (month of January) (**Fig1A**). All five
33 risk factors were individually significantly associated with time to COVID-19 infection,
34 with athletes in the lowest quartiles of behavioral risk factors (**Fig1B, Fig1E, Fig1F**)
35 appearing to have better protection from COVID-19 infection when compared to athletes
36 in lower quartiles of environmental risk factors (**Fig1C, Fig1D**). Assuming proportional
37 hazards, the hazard ratio for COVID-19 infection was 11.51 ($p<0.001$) per unit increase
38 in the average county-level COVID rate per 100,000 population. Also, with each
39 additional game played, the risk of COVID-19 infection increased by 4.4% (HR=1.04,
40

1 $p<0.001$) and with each additional game played “away”, the risk of COVID-19 infection
2 increased by 23.3% (HR=3.33, $p<0.001$). For the average stadium attendance, the
3 lowest quartile had the least risk for contracting COVID-19 and the hazard ratio between
4 the lowest quartile and the fourth quartile was the highest (HR=1.31, $p<0.001$).
5 Multivariable Cox proportional hazards modeling with all risk factors revealed that the
6 average COVID-19 rate for counties where games were played was no longer
7 statistically significant when accounting for effects from the other four risk factors
8 **(Appendix Table 1)**.

11 **Discussion**

12 Results from this study suggest that NBA player-level activity-related behaviors,
13 particularly those related to the amount of time played on the court and travel to away
14 games, may impact athlete risk for COVID-19 infection. Specifically, NBA players with
15 more game activity may have higher exposure to staff, opposing players, fans, and
16 other vectors of transmission, particularly as they may be at higher risk of exposure
17 when playing unmasked or engaged in other activities (e.g., media interviews, etc.)
18 despite consistent testing. Similarly, travel dynamics of teams playing home and away
19 games and the corresponding COVID-19 restrictions for each state may influence risk
20 both on and outside the court where players may be susceptible to different levels of
21 exposure. Our findings suggest that the influence of these player-level behavioral
22 factors may outweigh that of environmental factors, such as local population COVID-19
23 infection rates. Athletes with more minutes played or greater game-related travel may
24 have similar non-sporting behaviors that may influence non-NBA activity exposure to
25 COVID-19 infection (e.g., more interactions with media, fans, or public activities during
26 away games), and these risk-influencing behaviors may not be as common in athletes
27 with fewer minutes played.

28 Results have the potential to inform clinicians and public health surveillance
29 efforts, particularly as relates to assessing risk characteristics among a defined
30 population of young, healthy, and highly vaccinated adults when compared to the
31 general population. Specifically, higher infectivity among NBA players may indicate that
32 certain behavioral risk factors have the potential to translate to elevated risk in similarly
33 situated individuals with analogous sociobehavioral characteristics (i.e., frequent travel,
34 group performances, etc.). Additionally, higher infection rates in the NBA cohort may be
35 an early warning sign of greater community spread, as the general population has lower
36 vaccination coverage, less testing and quarantine, and is generally older. Hence, the
37 application of modeling approaches that take into account multimodal factors such as
38 those explored in this study has the potential to enhance traditional surveillance
39 methods and also generate evidence for more targeted public health interventions
40 among at-risk populations.

1 A major limitation of this study is lack of validation of the endpoint, COVID-19
2 infection, measured by proxy from being placed on IL. Though the proportion of NBA
3 athletes placed on IL appears to coincide with COVID-19 infection rates in the US
4 population,¹¹ and other studies have found high rates of infection in this population
5 during this same time period,⁴ future studies addressing related research questions
6 should seek to use endpoint data from diagnostic testing. An additional limitation was
7 that data were not available on the vaccination status of players at different time periods
8 as the season progressed (as these data were not publicly available, though the NBA
9 reported vaccination rates above 90% in September 2021). Further research should be
10 conducted to determine potential sociobiological mechanisms underlying associations
11 observed in this study, as well as applicability of study results to broader attempts to
12 improve syndromic surveillance of novel and emerging infectious diseases
13
14

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16

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20

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22

23 Data Availability: The datasets used and/or analyzed for the current study are available
24 from the authors upon reasonable request.
25

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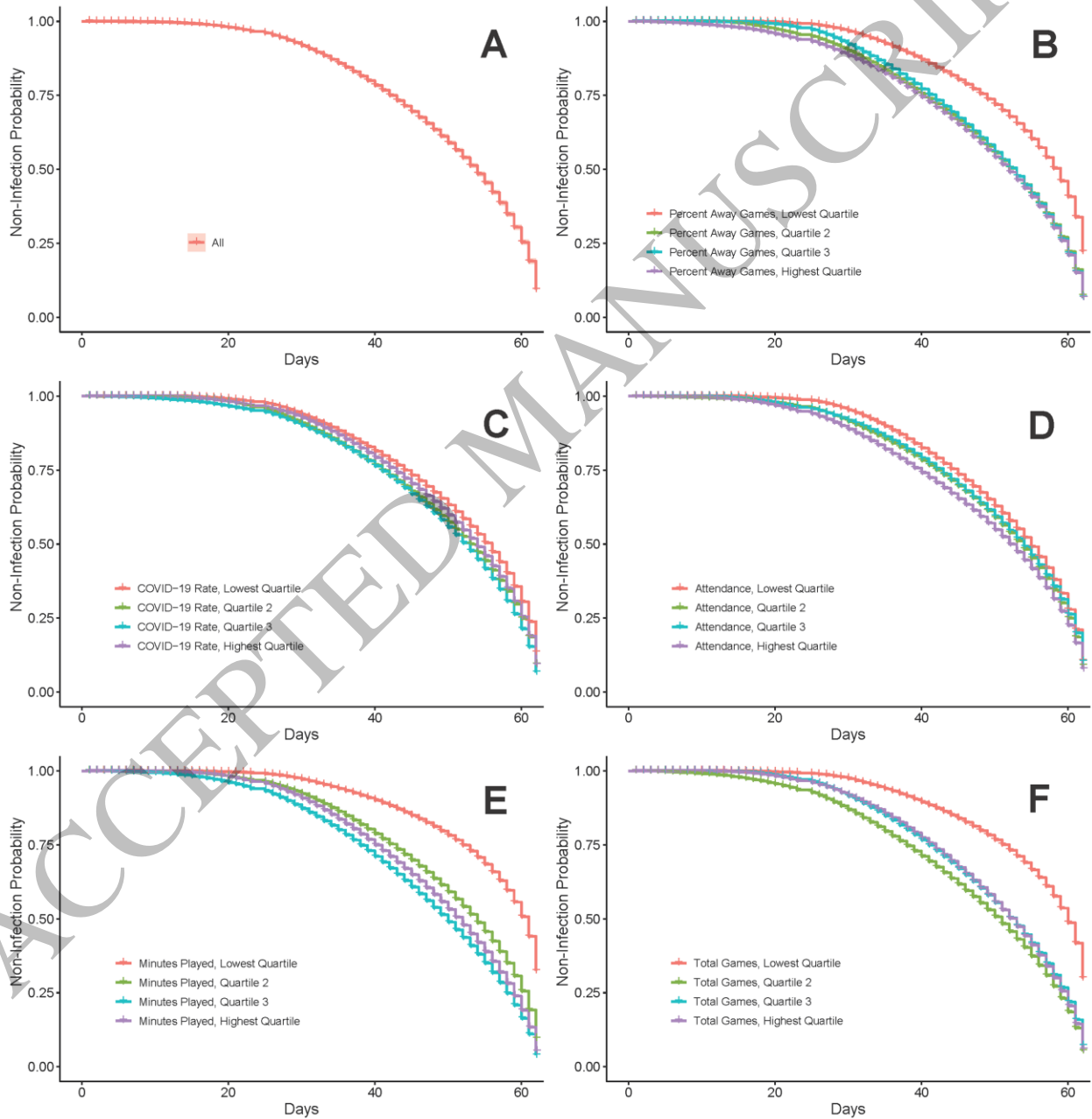
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4 **Figure 1.** Kaplan Meier plots for the probability of avoiding infection overall (A), by
5 quartiles of average percent away games (B), quartiles of average local COVID-19 rates
6 (C), quartiles of average stadium attendance (D), quartiles of average minutes played
7 (E), and quartiles of total games played (F).



8
9
10 **Figure 1**
165x170 mm (x DPI)