Journal of Science and Medicine in Sport 25 (2022) 1008–1016

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Associations between time zone changes, travel distance and performance: A retrospective analysis of 2013–2020 National Hockey League Data

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ARTICLE INFO

Article history:
Received 30 May 2022
Received in revised form 8 September 2022
Accepted 10 October 2022
Available online 12 October 2022

Keywords:
Circadian rhythms
Recovery
Performance
Travel
Athletes

ABSTRACT

Objectives: Many studies have investigated the role that travel plays in athletic performance. However, these studies lacked a holistic representation of travel. For instance, they do not consider travel distance and uniquely focuses on travel direction.
Design: An open source (www.evolving-hockey.com) provided NHL (2013–2020) game data. In total, this resulted in 17,088 regular season games.
Methods: Linear and quadratic versions of time zone change (TZΔ) and adjusted jet lag (AJL) were formulated. TZΔ captured circadian delay/advance based on travel for a game, with each TZ going eastward and westward reflected by −1 and +1, respectively. AJL advances TZΔ by allowing TZ acclimation, with each day resulting in a 1-unit change towards circadian neutral. AJL is a season-long rolling summation, which was computed using two different travel approaches: Approach A (AJL_A) assumes travel the day before each game, whereas Approach B (AJL_B) was designed to prioritize being home. A standardized flight tracker determined travel distance for each game. Team ability differences, characterized as difference in total season points, served as an analytic covariate. Outcome variables included goal differential, difference between actual and expected Fenwick save percentage (dFSv%), and goals saved above average (GSAA).
Results: GameDistance ($\beta = -0.14, p = 0.0007$), AJL_B^2 ($\beta = -0.15, p = 0.0006$), and their interaction ($p = 0.0004$) associated with GoalDifferential. GameDistance ($\beta = -0.18$, $p = 0.02$) and AJL_B^2 ($\beta = 0.12$, $p = 0.03$) associated with dFSv%, whereas only AJL_B^2 ($\beta = 0.03$, $p = 0.05$) associated with GSAA.
Conclusions: Results suggest that circadian change, in both direction, and greater traveled distance can negatively impact NHL athletes.

Practical Implications

- When teams are traveling, considering the distance and the direction is fundamental.
- Prioritizing recovery before 2 games in 48 h should be implemented at the team level.
- Regardless of travel direction, circadian misalignment has a detrimental impact on performance and calls into implementing pretravel strategies for athletes and teams.

Abbreviations: AdjTZΔ, adjusted time zone change; DiffActExpFS%, difference in actual versus expected Fenwick save percentage; DiffActExpGoalDiff, difference in actual versus expected goal differential; FSv%, Fenwick save percentage; GoalDifferential, goal differential; GSAA, goals saved above average; MLB, Major League Baseball; NBA, National Basketball Association; NFL, National Football League; NHL, National Hockey League; TZΔ, time zone change.

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https://doi.org/10.1016/j.jsams.2022.10.005

1. Introduction

In recent years, there has been increased attention directed towards the influential role of sleep and circadian factors on athletic performance, especially for professional athletes.[1] Degraded sleep and circadian health are both inherent consequences for professional athletes in sports such as Major League Baseball (MLB), National Football League (NFL), National Basketball Association (NBA), and the National Hockey League (NHL), due largely to the frequent travel across time zones required to accommodate highly congested competition schedules. In addition, the culture of professional sport historically glorifies athletes capable of performing under strenuous conditions (e.g., chronic sleep deprivation). Concerningly, this longstanding perspective has become a norm within professional sports,[2] which contributes to deteriorated physical and mental health for the athletes.

The uptick in attention to the negative effects of schedule-related travel demands on athlete wellbeing and competition equity has led to recent changes across many professional sports. The NBA has eliminated teams playing 4 games within 5 days, while also considerably reducing the number of back-to-back games.[3] In 2013, the NHL instituted a realignment of both conferences (East and West) as well as each division (Atlantic, Metropolitan, Central and Pacific). This realignment was implemented to reduce travel demands by having teams play more games against teams that share regional proximity.[4] A reduction in travel not only attenuates physical and mental fatigue associated with travel, but also lessens the frequency and magnitude of disruption to an athlete's circadian rhythm by limiting travel across time zones.

It has long been established that a rapid transition across time zones can desynchronize the internal clock, ultimately exerting an external pressure on our environment thus producing symptoms known as jet lag.[5] The circadian rhythm is an endogenous system that plays a key role in global biological, physical, cognitive, and psychological functionality.[6] Given the widespread impact of the circadian rhythm on functionality, it should be no surprise that disruption to the circadian rhythms can significantly impact athletic performance and competitive equity.[7–9] For example, Winter and colleagues[9] showed that MLB teams with a circadian advantage had a significantly higher likelihood of winning their game, across games from the 1997–2006 seasons. Song and colleagues[10] showed a similar circadian relationship when analyzing data from the 1992–2011 MLB seasons, whereby teams traveling eastward established a competitive advantage due to circadian differences. Investigations into these dynamics within the NFL have yielded comparable findings. Smith and colleagues[11] showed a significant advantage for west coast teams traveling eastward for evening games when analyzing NFL games across 40 seasons. Furthermore, Roy and Forest[12] evidenced that the effects of travel direction and game timing translate across sports. This investigation demonstrated a competitive advantage in the NHL, NBA, and NFL for teams traveling eastward for an evening game. However, recent research has suggested that competitive inequity due to travel is not specific to a single travel direction. McHill & Chinoy[13] evidenced that time zone change, regardless of travel direction, had detrimental impacts on performance.

Despite the increased attention to travel-related impact on competitive equity, athletic performance, and athlete wellbeing, the Roy and Forest[12] investigation is the only study to date that has analyzed these relationships within the NHL. A limitation of this investigation is the fact that this study utilized data collected pre and post the division realignment that occurred in 2013.[12] This division realignment provided each team with the ability to play more games against teams in the same time zone. Therefore, their results do not provide an accurate depiction of the impact of travel on competitive equity following the changes made by the NHL to reduce the impact of travel on game outcomes and player wellbeing. Establishing an improved estimation of the impact of travel and travel-related factors on game outcomes following the organizational changes made in 2013 is critical for guiding teams on key factors that influence game outcomes. The parity in the NHL is arguably greater than any other professional sport. Based on calculations from the study team, an average of only 2.92 total season points separated teams eligible for the playoffs versus those that did not qualify across the six seasons spanning 2013–2014 to 2018–2019. This marginal difference showcases the high parity across the NHL. Furthermore, this statistic highlights the notion that factors with the potential to affect team performance and game outcomes, such as circadian change and travel, should be at the forefront of consideration for professional teams given that even modest influence on outcomes could have a major effect on franchise success across the entirety of a season.

Therefore, there is a need to investigate the impact of travel-related factors, such as circadian change and travel distance, on NHL game results to establish a more accurate understanding of the influence of these factors on team performance, game outcomes, and overall competition equity. For this investigation, we utilized data from regular games over the 2013–2014 to 2019–2020 seasons in the NHL, which are the seven seasons immediately following division realignment in 2013. We designed this study to advance the literature by estimating the associations of travel-related factors, including travel distance and circadian change, and their interaction with global NHL game outcomes as well as game-specific statistics that may prove more sensitive to the deleterious effects of travel, while controlling for relevant covariates. We hypothesized that (i) greater circadian misalignment (either delayed or advanced) will be associated with poorer NHL performance; (ii) greater distance traveled will be associated with poorer NHL performance; (iii) circadian change and distance traveled will interact to influence NHL performance and (iv) circadian changes and distance traveled affect game performance and outcomes, such as differences in ability between competing teams, presence or absence of home-ice advantage, and whether the game occurred on the second half of a back-to-back game sequence.

2. Methods

National Hockey League (NHL) game data from the seven consecutive seasons immediately following division realignment were included in this study: 2013–2014, 2014–2015, 2015–2016, 2016–2017, 2017–2018, and 2019–2020. Game data was retrieved from an open source (www.evolving-hockey.com), which is a website that not only provides access to game information (e.g., opponent and location of game) and traditional game statistics (e.g., goals scored and goals allowed), but also advanced game statistics (e.g., goals saved above average) for each game. The first six seasons were comprised of 82 games for every team, while COVID-19 not only shortened the seventh season (2019–2020) but also created variability in the number of games played by each team. Specifically, teams played between 68 and 71 games during the COVID-19 shortened season. In total, this resulted in 17,088 regular season games from the seven consecutive seasons. Season total points for each team across the seven seasons was derived from a secondary, open-source website managed by hockey reference (https://www.hockey-reference.com/leagues/franchise_points.html). A standardized distance calculator was utilized to determine air-based travel distances (https://www.distancecalculator.net/), with distance provided in kilometers. Distance values reflected the great circle distance, which is the shortest distance between two points on the surface of a sphere.

Goal differential (GoalDifferential) was computed by subtracting the opponent's goals scored for a game from the team's goals scored for a game; difference in actual versus expected goal differential (DiffActExpGoalDiff) was computed by subtracting a team's expected goal differential, which is a statistic provided by Evolving-Hockey based on game expectations from GoalDifferential; difference in actual versus expected Fenwick save percentage (DiffActExpFS%) was computed by subtracting a team's expected Fenwick save percentage (FSv%) from their actual FSv% with this metric provided by Evolving-Hockey; goals saved above average (GSAA) for a given game served as outcome variables for analyses. GoalDifferential and DiffActExpGoalDiff were chosen due to their representation of global team performance whereas DiffActExpFSv% and GSAA encompass specific hockey abilities.

For more information on these advanced analytic metrics, we recommend reviewing the glossary available at Evolving-Hockey https://evolving-hockey.com/glossary/standard-goalie-tables/.

Time zone change (TZΔ) was determined for each game, which captured the raw circadian change (delay or advance) based on travel for a game. Each time zone change in the eastward and westward directions was reflected by −1 and +1, respectively. For example, if a team crossed three time zones in the eastward direction for a game, then their TZΔ for the game would be −3. For the first game and the game immediately following the all-star break of each season, it was assumed that travel began in the team's home city.

Additionally, adjusted time zone change (AdjTZΔ) was also formulated for each game. AdjTZΔ advances TZΔ by allowing acclimation to a novel time zone, with each day of acclimation resulting in a 1-unit (hour) change towards circadian neutral. AdjTZΔ is a season-long rolling summation. Since different travel schedules will affect the number of available acclimation days, AdjTZΔ was computed using two different travel approaches (AdjTZΔ_A and AdjTZΔ_B) to see if differences might emerge based on subtle changes in travel schedules. The rules utilized to determine travel dates for each of these approaches are as follows:

AdjTZΔ_A: *Always the day before*

I. Travel occurred universally on the day immediately preceding the next game. For example, if a game was scheduled for March 5th and the team needed to travel for this game, then the travel was assumed to occur on March 4th.
II. When there was prolonged duration between games (≥5 games), such as the all-star break, it was assumed that teams returned home and readjusted to circadian neutral across this period.

AdjTZΔ_B: *Prioritize being home*

I. Travel occurred on the day immediately preceding the next game if the team was traveling from home to a road location (location sequence: home-road) or traveling from a road location to another road location (location sequence: road-road). For example, if a team finished a road or home game on March 3rd and was set to play next on the road on March 5th, then the travel was assumed to occur on March 4th.
II. Travel occurred on the same day of the most recent game if the team was traveling back home from a road location (location sequence: road-home). For example, if a team finished a road game on March 3rd and was set to play next at home on March 5th, then the travel was assumed to occur on March 3rd immediately following the conclusion of the road game.
III. When there was prolonged duration between games (≥5 games), such as the all-star break, it was assumed that teams returned home and readjusted to circadian neutral across this period

Since we hypothesized that global circadian misalignment, whether that be both circadian delayed and advanced, would affect performance, quadratic terms of circadian factors were constructed for analytical modeling ($TZΔ^2$, $AdjTZΔ\_A^2$, $AdjTZΔ\_B^2$). Additionally, we performed tests of the quadratic terms to determine statistical merit for inclusion in analytical modeling. These tests regressed outcome variables on both the linear and quadratic version of each circadian change variable. Inconsistencies emerged across the results from the quadratic testing, whereby the quadratic term at times displayed a stronger relationship than the linear term, and vice-versa. Generally, modest differences in relationship strength with outcome variables were observed between linear and quadratic terms. Absent of strong support from statistical assessment, we determined it appropriate to proceed with assessing both the linear and quadratic relationships across more complicated analytical models due to our theoretical conceptualization of how circadian misalignment may affect performance.

Distance traveled for a given game (GameDistance) and total distance accumulated across the season (SeasonDistance) were formulated. GameDistance represented the number of kilometers traveled by a team for a particular game, which was computed as the distance from the previous game's location to the focal game's location. Mirroring the approach utilized for the circadian change variables, it was assumed that the team traveled from their home city for both the first game of the season and game immediately following the all-star break. Additionally, a difference in GameDistance (DiffGameDistance) was computed, which captured the difference in travel distance for a given game between the team of focus and their opponent. SeasonDistance was a rolling summation across the season capturing the total number of kilometers traveled up to that point in the season. Both GameDistance and DiffGameDistance were mean centered before use in analytical modeling. Additionally, both GameDistance and DiffGameDistance were scaled using the scale function in RStudio® (R, Boston, MA), which divides the centered versions of the terms with their standard deviations. This step was performed to address convergence issues that would arise in statistical modeling due to major differences in variable unit scaling.

Three additional covariates were formulated to include in fully adjusted models that account for characteristics likely to exert influence on performance and game outcomes. A difference in season total points (TeamAbility) was computed by subtracting the opponent's overall season total points from the team's overall season total points, with this variable purposed to control for differences in team ability. Additionally, given that home-ice advantage has an established influenced on games outcome,[14,15] a categorical variable was created to control for this influence (Home/Away). Finally, the NHL schedule requires several times throughout the season that teams play on consecutive nights, which is more commonly referred to as a back-to-back sequence. It has been demonstrated in other sports, such as the NBA, that these back-to-back sequences have the potential to influence the game outcomes and performance.[16–18] Therefore, a categorical variable was also created to capture whether the game of focus occurred on the tail end of a back-to-back sequence (Back-to-Back).

For use in statistical analyses, TeamAbility was mean centered, whereas the categorical covariates were dichotomized to be zero-centered and unit-weighted (−0.5 vs 0.5): Home/Away (Home vs. Away) and Back-to-Back (No vs. Yes).

Linear mixed-effect regressions were employed to estimate associations of circadian change and travel distance with GoalDifferential, DiffActExpGoalDiff, DiffActExpFSv%, and GSAA. Initially, univariate regressions between predictor and outcome variables were performed. In univariate regressions that assessed the quadratic relationship of a time zone change variable, the linear term was also included in the model but was not interpreted.

Bivariate linear mixed-effect regressions were then executed to evaluate the associations of circadian change and travel distance with GoalDifferential, DiffActExpGoalDiff, DiffActExpFSv%, and GSAA while controlling for one another. Additionally, a two-way interaction term between a circadian change variable and travel distance variable were included in the bivariate regressions to assess for moderating influence. For the bivariate analyses, circadian change variables were narrowed to the linear and quadratic versions of TZΔ, Adj TZΔ_A, and Adj TZΔ_B, with GameDistance selected as the only variable to represent travel distance.

Lastly, fully adjusted models were constructed that regressed outcomes variables on a circadian change variable, GameDistance, TeamAbility, Home/Away, and Back-to-Back.

Due to the nonindependence in the data from repeated measures across NHL teams and seasons, all linear mixed-effect regressions nested the individual game data within both NHL team and season. Regression coefficients (β), standard error (SE), lower and upper limit from 95 % confidence interval (95 % CI [LL, UL]), and associated p value are reported from the linear mixed-effect regressions.

All statistical analyses were performed in RStudio® (R, Boston, MA).

3. Results

Results from univariate linear mixed-effect regressions estimating associations with both GoalDifferential and DiffExpActGoalDiff are presented in Table 1. No significant associations between the linear or quadratic circadian change variables and GoalDifferential were observed. Significant associations between GameDistance ($\beta = -0.044$; $p = 0.04$) and DiffGameDistance ($\beta = -0.063$; $p = 0.03$) with GoalDifferential were observed. No significant associations between circadian change and travel distance variables with DiffActExpGoalDiff were observed.

Results from univariate linear mixed-effect regressions estimating associations of circadian change and travel distance variables with both DiffActExpFSv% and GSAA are presented in Table 2. No significant associations between circadian change variables or travel distance variables and specific hockey performance outcome variables were observed. However, it is worth noting that GameDistance showed a statistical trend with DiffActExpFSv% ($\beta = -0.105$, $p = 0.06$).

Table 3 presents the results from bivariate regressions related to global team performance outcomes, including GoalDifferential and DiffActExpGoalDiff. Game Distance showed a strong association with GoalDifferential when the circadian change variable being controlled for was TZΔ ($\beta = -0.138$; $p = 0.0007$) or AdjTZΔ_A ($\beta = -0.114$; $p = 0.004$), but not AdjTZΔ_B. In terms of circadian change, only the quadratic AdjTZΔ_B ($\beta = -0.153$; $p = 0.0006$) showed a significant association with GoalDifferential when controlling for GameDistance. Lastly, two significant interactions were observed between GameDistance and circadian change: AdjTZΔ_A: GameDistance ($\beta = 0.025$; $p = 0.05$) and AdjTZΔ_B: GameDistance ($\beta = 0.565$; $p = 0.0004$). No significant associations or interactions from bivariate regressions related to DiffActExpGoalDiff were observed.

Table 4 presents the results from bivariate regressions related to specific hockey outcomes, including DiffActExpFSv% and GSAA. GameDistance significantly associated with DiffActExpFSv% when controlling for TZΔ ($\beta = -0.180$; $p = 0.02$), but not when circadian change was represented by AdjTZΔ_A or AdjTZΔ_B. No other significant associations or interactions were observed in regressions related to DiffAcExpFSv%. Similarly, no significant associations or interactions were observed in regressions related to GSAA.

Table 5 presents the results from the fully adjusted regressions related to global team performance, including GoalDifferential and DiffActExpGoalDiff. No significant associations of circadian change variables nor GameDistance with GoalDifferential or DiffActExpGoalDiff were observed, when controlling for TeamAbility, Home/Away and Back-to-Back sequence. TeamAbility and Home/Away were universally strong predictors of GoalDifferential, whereas Back-to-Back demonstrated a significant association with GoalDifferential except for when the model included TZΔ as the circadian change variable. No covariates displayed significant associations with DiffActExpGoalDiff.

Table 6 presents the results from the fully adjusted regressions related to specific hockey performance outcomes, including DiffActExpFSv% and GSAA. Significant associations emerged between the quadratic AdjTZΔ_B^2 ($\beta = 0.119$; $p = 0.03$) and GameDistance ($\beta = -0.176$; $p = 0.02$) with DiffActExpFSv% when controlling for TeamAbility, Home/Away and Back-to-Back. In addition, significant associations also emerged between AdjTZΔ_B^2 ($\beta = 0.027$; $p = 0.05$) and GSAA while controlling for identical covariates. Lastly, TeamAbility displayed significant associations with both DiffActExpFSv% and GSAA across all fully adjusted regressions.

Table 1
Univariate regressions: associations of circadian change and travel distance with global team performance.

Predictor	β	SE	95 % CI [LL, UL]	*p* value
Outcome variable: GoalDifferential				
TZΔ	−0.018	0.027	−0.071, 0.035	0.51
TZΔ^2	0.009	0.014	−0.018, 0.036	0.52
AdjTZΔ_A	−0.022	0.028	−0.076, 0.033	0.44
AdjTZΔ_A^2	0.008	0.014	−0.020, 0.036	0.57
AdjTZΔ_B	−0.020	0.035	−0.090, 0.049	0.58
AdjTZΔ_B^2	−0.023	0.016	−0.054, 0.008	0.16
GameDistance (scaled)	−0.044	0.021	−0.085, −0.004	0.04*
DiffGameDistance (scaled)	−0.063	0.022	−0.106, −0.019	0.03*
Outcome variable: DiffActExpGoalDiff				
TZΔ	−0.093	0.120	−0.328, 0.142	0.53
TZΔ^2	0.032	0.054	−0.074, 0.138	0.56
AdjTZΔ_A	−0.155	0.149	−0.447, 0.138	0.50
AdjTZΔ_A^2	0.024	0.049	−0.071, 0.119	0.66
AdjTZΔ_B	−0.114	0.125	−0.358, 0.130	0.52
AdjTZΔ_B^2	0.029	0.057	−0.082, 0.014	0.65
GameDistance (scaled)	−0.081	0.127	−0.331, 0.168	0.63
DiffGameDistance (scaled)	−0.211	0.237	−0.675, 0.253	0.54

This table presents results from linear mixed-effect regressions that assessed univariate associations of circadian change and travel distance with global team performance outcomes, including difference is goals scored and allowed for a game (GoalDifferential) and difference in actual versus expected goal differential (DiffActExpGoalDiff). Circadian change variable includes time zone for the game (TZΔ) as well as adjusted TZΔ using approach A (AdjTZΔ_A) and B (AdjTZΔ_B), with each of these modeled both as linear (X) and quadratic (X^2) terms. Regressions assessing the quadratic relationship also included the linear term. Travel distance variables were modeled linearly and included the estimated distance traveled by a team for a given game (GameDistance) as well as difference in GameDistance between opponent and team for a given game, with both scaled in preparation and calculated in kilometers (km). Associative effect (β), standard error (SE), lower limit (LL) and upper limit (UL) from 95 % confidence interval (CI), and *p* value are presented for each predictor.

Table 2
Univariate regressions: associations of circadian change and travel distance with specific hockey performance.

Predictor	β	SE	95 % CI [LL, UL]	*p* value
Outcome variable: DiffActExpFSv%				
TZΔ	−0.026	0.073	−0.170, 0.118	0.73
TZΔ^2	−0.025	0.030	−0.084, 0.034	0.42
AdjTZΔ_A	−0.011	0.070	−0.147, 0.125	0.88
AdjTZΔ_A^2	−0.013	0.033	−0.078, 0.051	0.70
AdjTZΔ_B	−0.015	0.073	−0.159, 0.129	0.84
AdjTZΔ_B^2	0.023	0.039	−0.053, 0.100	0.56
GameDistance (scaled)	−0.105	0.048	−0.200, −0.011	0.06
DiffGameDistance (scaled)	−0.034	0.042	−0.116, 0.047	0.43
Outcome variable: Goal Above Save Average GSAA				
TZΔ	−0.017	0.015	−0.046, 0.013	0.28
TZΔ^2	0.002	0.008	−0.015, 0.019	0.82
AdjTZΔ_A	−0.014	0.014	−0.042, 0.013	0.32
AdjTZΔ_A^2	0.004	0.008	−0.012, 0.020	0.64
AdjTZΔ_B	−0.014	0.021	−0.056, 0.028	0.52
AdjTZΔ_B^2	0.013	0.009	−0.004, 0.030	0.14
GameDistance (scaled)	−0.010	0.012	−0.033, 0.013	0.44
DiffGameDistance (scaled)	−0.001	0.011	−0.022, 0.021	0.94

This table presents results from linear mixed-effect regressions that assessed univariate associations of circadian change and travel distance with specific hockey performance, including difference in actual versus expected Fenwick save percentage (DiffActExpFSv%) and goals saved above average (GSAA). Circadian change variable includes time zone for the game (TZΔ) as well as adjusted TZΔ using approach A (AdjTZΔ_A) and B (AdjTZΔ_B), with each of these modeled both as linear (X) and quadratic (X^2) terms. Regressions assessing the quadratic relationship also included the linear term. Travel distance variables were modeled linearly and included the estimated distance traveled by a team for a given game (GameDistance) as well as difference in GameDistance between opponent and team for a given game, with both scaled in preparation and calculated in kilometers (km). Associative effect (β), standard error (SE), lower limit (LL) and upper limit (UL) from 95 % confidence interval (CI), and *p* value are presented for each predictor.

4. Discussion

The present study investigated the impact of circadian change and travel distance on global team and specific hockey skill performance using data from seven consecutive National Hockey League (NHL) seasons spanning 2013–2020. Circadian change was characterized by not only raw time zone change (TZΔ), but also an adjusted TZΔ (Adj TZΔ) that allowed for acclimation to a given time zone. AdjTZΔ was

Table 3
Bivariate regressions: associations of circadian change and travel distance with global team performance.

Predictor	β	SE	95 % CI [LL, UL]	*p* value
Outcome variable: GoalDifferential				
Time zone change (TZΔ) × GameDistance				
TZΔ	−0.027	0.056	−0.0137, 0.082	0.63
TZΔ^2	0.048	0.049	−0.049, 0.144	0.34
GameDistance (scaled)	−0.138	0.037	−0.211, −0.066	0.0007*
TZΔ: GameDistance (scaled)	0.003	0.022	−0.039, 0.045	0.89
TZΔ^2: GameDistance (scaled)	0.011	0.016	−0.020, 0.042	0.50
Adjusted time zone change, Approach A (AdjTZΔ_A) × GameDistance				
AdjTZΔ_A	−0.042	0.051	−0.143, 0.058	0.42
AdjTZΔ_A^2	0.004	0.038	−0.071, 0.079	0.92
GameDistance (scaled)	−0.114	0.033	−0.0179, −0.049	0.004*
AdjTZΔ_A: GameDistance (scaled)	0.010	0.021	−0.030, 0.051	0.63
AdjTZΔ_A^2: GameDistance (scaled)	0.025	0.012	0.000, 0.049	0.05*
Adjusted time zone change, Approach B (AdjTZΔ_B) × GameDistance				
AdjTZΔ_B	−0.059	0.062	−0.181, 0.063	0.36
AdjTZΔ_B^2	−0.153	0.043	−0.236, −0.070	0.0006*
GameDistance (scaled)	−0.011	0.028	−0.065, 0.043	0.69
AdjTZΔ_B: GameDistance (scaled)	0.021	0.029	−0.035, 0.078	0.48
AdjTZΔ_B^2: GameDistance (scaled)	0.056	0.015	0.028, 0.085	0.0004*
Outcome variable: DiffExpActGoalDiff				
Time zone change (TZΔ) × GameDistance				
TZΔ	−0.097	0.212	−0.513, 0.319	0.65
TZΔ^2	0.603	0.620	−0.611, 1.818	0.49
GameDistance (scaled)	−0.603	0.554	−1.689, 0.484	0.47
TZΔ: GameDistance (scaled)	−0.019	0.106	−0.226, 0.188	0.87
TZΔ^2: GameDistance (scaled)	−0.120	0.154	−0.422, 0.183	0.57
Adjusted time zone change, Approach A (AdjTZΔ_A) × GameDistance				
AdjTZΔ_A	−0.068	0.201	−0.462, 0.327	0.74
AdjTZΔ_A^2	0.391	0.482	−0.554, 1.336	0.57
GameDistance (scaled)	−0.446	0.434	−1.297, 0.405	0.49
AdjTZΔ_A: GameDistance (scaled)	−0.031	0.096	−0.219, 0.158	0.77
AdjTZΔ_A^2: GameDistance (scaled)	−0.064	0.122	−0.304, 0.176	0.71
Adjusted time zone change, Approach B (AdjTZΔ_B) × GameDistance				
AdjTZΔ_B	−0.052	0.244	−0.531, 0.427	0.84
AdjTZΔ_B^2	0.006	0.303	−0.588, 0.601	0.99
GameDistance (scaled)	−0.150	0.236	−0.611, 0.312	0.64
AdjTZΔ_B: GameDistance (scaled)	−0.032	0.108	−0.243, 0.179	0.77
AdjTZΔ_B^2: GameDistance (scaled)	0.027	0.083	−0.136, 0.191	0.80

This table presents results from the bivariate linear mixed-effect regressions that estimated the associations of circadian change, travel distance, and their interaction with global team performance outcomes, including difference is goals scored and allowed for a game (GoalDifferential) and difference in actual versus expected goal differential (DiffActExpGoalDiff). Circadian change variable includes time zone for the game (TZΔ) as well as adjusted TZΔ using approach A (AdjTZΔ_A) and B (AdjTZΔ_B). Models included linear (X) and quadratic (X^2) versions of these variables. Travel distance was represented solely by the estimate distance traveled by a team for a given game (GameDistance), which was modeled linearly, scaled in preparation, and calculated in kilometers (km). Interaction terms between linear and quadratic circadian change variables and GameDistance were included to assess for moderating influence. Associative effect (β), standard error (SE), lower limit (LL) and upper limit (UL) from 95 % confidence interval (CI), and *p* value are presented for each predictor.

Table 4
Bivariate regressions: associations of circadian change and travel distance with specific hockey performance.

Predictor	β	SE	95 % CI [LL, UL]	*p* value
Outcome variable: DiffActExpFSv%				
Time zone change (TZΔ) × GameDistance				
TZΔ	−0.089	0.162	−0.407, 0.229	0.60
TZΔ^2	−0.081	0.110	−0.297, 0.134	0.47
GameDistance (scaled)	−0.127	0.082	−0.288, 0.034	0.15
TZΔ: GameDistance (scaled)	0.032	0.067	−0.010, 0.163	0.66
TZΔ^2: GameDistance (scaled)	0.047	0.035	−0.022, 0.115	0.20
Adjusted time zone change, Approach A (AdjTZΔ_A) × GameDistance				
AdjTZΔ_A	0.027	0.152	−0.272, 0.325	0.86
AdjTZΔ_A^2	−0.027	0.115	−0.251, 0.198	0.82
GameDistance (scaled)	−0.163	0.094	−0.346, 0.021	0.12
AdjTZCΔ_A: GameDistance (scaled)	−0.017	0.070	−0.155, 0.121	0.82
AdjTZCΔ_A^2: GameDistance (scaled)	0.035	0.037	−0.037, 0.107	0.36
Adjusted time zone change, Approach B (AdjTZΔ_B) × GameDistance				
AdjTZΔ_B	−0.085	0.146	−0.370, 0.200	0.57
AdjTZΔ_B^2	0.027	0.114	−0.195, 0.250	0.82
GameDistance (scaled)	−0.180	0.067	−0.311, −0.049	0.02*
AdjTZΔ_B: GameDistance (scaled)	0.046	0.062	−0.078, 0.167	0.48
AdjTZΔ_B^2: GameDistance (scaled)	0.030	0.038	−0.044, 0.104	0.45
Outcome variable: GSAA				
Time zone change (TZΔ) × GameDistance				
TZΔ	−0.023	0.034	−0.089, 0.044	0.51
TZΔ^2	0.007	0.028	−0.048, 0.062	0.80
GameDistance (scaled)	−0.029	0.022	−0.072, 0.014	0.20
TZΔ: GameDistance (scaled)	0.004	0.013	−0.021, 0.029	0.76
TZΔ^2: GameDistance (scaled)	0.004	0.009	−0.014, 0.021	0.69
Adjusted time zone change, Approach A (AdjTZΔ_A) × GameDistance				
AdjTZΔ_A	−0.003	0.031	−0.064, 0.058	0.92
AdjTZCΔ_A^2	0.011	0.025	−0.039, 0.060	0.68
GameDistance (scaled)	−0.032	0.021	−0.072, 0.009	0.16
AdjTZΔ_A: GameDistance (scaled)	−0.005	0.012	−0.028, 0.019	0.71
AdjTZΔ_A^2: GameDistance (scaled)	0.003	0.008	−0.013, 0.020	0.69
Adjusted time zone change, Approach B (AdjTZΔ_B) × GameDistance				
AdjTZΔ_B	−0.031	0.038	−0.106, 0.044	0.43
AdjTZCΔ_B^2	0.015	0.030	−0.044, 0.074	0.64
GameDistance (scaled)	−0.031	0.019	−0.068, 0.005	0.12
AdjTZΔ_B: GameDistance (scaled)	0.011	0.016	−0.021, 0.042	0.51
AdjTZΔ_B^2: GameDistance (scaled)	0.005	0.011	−0.016, 0.026	0.63

This table presents results from the bivariate linear mixed-effect regressions that estimated the associations of circadian change, travel distance, and their interaction with specific hockey performance outcomes, including difference in actual versus expected Fenwick save percentage (DiffActExpFSv%) and goals saved above average (GSAA). Circadian change variable includes time zone for the game (TZΔ) as well as adjusted TZΔ using approach A (AdjTZΔ_A) and B (AdjTZΔ_B). Models included linear (X) and quadratic (X^2) versions of these variables. Travel distance was represented solely by the estimate distance traveled by a team for a given game (GameDistance), which was modeled linearly, scaled in preparation, and calculated in kilometers (km). Interaction terms between linear and quadratic circadian change variables and GameDistance were included to assess for moderating influence. Associative effect (β), standard error (SE), lower limit (LL) and

computed using two different approaches to travel (AdjTZΔ_A and AdjTZΔ_B) that differed slightly in travel design. Fully adjusted models accounted for multiple covariates known to affect performance and competitive equity, including differences team ability, whether the game was played at home or on the road, and whether the game occurred on the tail end of a back-to-back sequence. Results suggested that increased distance traveled, and circadian change can potentially be deleterious for specific hockey skill performance. However, findings did not suggest that circadian change or distance traveled significantly influenced global team performance and overall game outcomes, evidenced by the nonsignificant findings across analyses in fully adjusted linear mixed-effect regressions related to Goal differential (GoalDifferential) and difference in actual versus expected goal differential (DiffActExpGoalDiff). Unsurprisingly, being an inferior team, playing on the road, and playing on the tail end of a back-to-back sequence had detrimental impact on NHL performance, which provides further support to prior research that demonstrated similar effects.[14] Ultimately, these results will be useful for players, coaches, medical staff, schedule makers, and organizational leaders of the NHL. These results provide insight into the influential impact of the strenuous competition calendar that is used by the NHL, which negatively influences performance and creates competition inequity. Modifications at the organizational level can lead to changes in the NHL schedule that reduce competitive inequity, while teams can leverage strategies to reduce to negative impact of circadian change and travel distance, when appropriate. Results at the granular level and their implications are discussed in the subsequent paragraphs.

Table 5
Fully adjusted regressions: associations of circadian change, travel distance, and relevant covariates with global team performance.

Predictor	β	SE	95 % CI [LL, UL]	*p* value
Outcome variable: GoalDifferential				
Circadian change variable: time zone change (TZΔ)				
TZΔ	−0.008	0.025	−0.056, 0.041	0.76
$TZΔ^2$	0.010	0.020	−0.030, 0.050	0.62
GameDistance (scaled)	0.008	0.033	−0.056, 0.072	0.80
TeamAbility	0.032	0.001	0.029, 0.035	<0.0001*
Home/Away	−0.530	0.040	−0.608, −0.453	<0.0001*
Back-to-Back	−0.147	0.281	−0.700, 0.405	0.60
Circadian change variable: adjusted time zone change, Approach A (AdjTZΔ_A)				
AdjTZΔ_A	−0.011	0.024	−0.057, 0.036	0.66
$AdjTZΔ\_A^2$	0.012	0.020	−0.027, 0.052	0.55
GameDistance (scaled)	0.004	0.031	−0.057, 0.065	0.90
TeamAbility	0.032	0.001	0.029, 0.035	<0.0001*
Home/Away	−0.527	0.039	−0.603, −0.451	<0.0001*
Back-to-Back	−0.147	0.050	−0.245, −0.049	0.006*
Circadian change variable: adjusted time zone change, Approach B (AdjTZΔ_B)				
AdjTZΔ_B	−0.015	0.035	−0.083, 0.053	0.67
$AdjTZΔ\_B^2$	0.014	0.019	−0.023, 0.051	0.47
GameDistance (scaled)	0.009	0.027	−0.043, 0.061	0.74
TeamAbility	0.032	0.001	0.029, 0.034	<0.0001*
Home/Away	−0.539	0.040	−0.617, −0.460	<0.0001*
Back-to-Back	−0.146	0.054	−0.251, −0.041	0.02*
Outcome variable: DiffActExpGoalDiff				
Circadian change variable: time zone change (TZΔ)				
TZΔ	−0.178	4.276	−8.560, 8.203	0.98
$TZΔ^2$	0.259	4.540	−8.640, 9.157	0.96
GameDistance (scaled)	−0.293	4.389	−8.894, 8.309	0.96
TeamAbility	0.025	4.401	−8.600, 8.651	1.00
Home/Away	−0.744	4.472	−9.509, 8.020	0.95
Back-to-Back	0.048	4.258	−8.298, 8.393	1.00
Circadian change variable: adjusted time zone change, Approach A (AdjTZΔ_A)				
AdjTZΔ_A	−0.173	4.301	−8.603, 8.256	0.97
$AdjTZΔ\_A^2$	0.217	4.115	−7.847, 8.282	0.98
GameDistance (scaled)	−0.241	4.224	−8.520, 8.038	0.97
TeamAbility	0.026	4.451	−8.697, 8.749	1.00
Home/Away	−0.752	4.156	−8.900, 7.393	0.88
Back-to-Back	0.041	4.321	−8.411, 8.493	1.00
Circadian change variable: adjusted time zone change, Approach B (AdjTZΔ_B)				
AdjTZΔ_B	−0.215	4.011	−8.076, 7.647	0.98
$AdjTZΔ\_B^2$	0.231	3.886	−7.386, 7.848	0.98
GameDistance (scaled)	−0.178	4.053	−8.122, 7.766	0.97
TeamAbility	0.026	3.944	−7.7-5, 7.756	1.00
Home/Away	−0.807	4.087	−8.817, 7.203	0.93
Back-to-Back	0.041	3.821	−7.448, 7.531	1.00

This table presents results from the fully adjusted linear mixed-effect regressions that estimated the associations of circadian change and travel distance with global team performance outcomes, including difference in goals scored and allowed for a game (GoalDifferential) and difference in actual versus expected goal differential (DiffActExpGoalDiff). Circadian change variables include time zone for the game (TZΔ) as well as adjusted TZΔ using approach A (AdjTZΔ_A) and B (AdjTZΔ_B). Models included linear (X) and quadratic (X^2) versions of these variables. Travel distance was represented solely by the estimated distance traveled by a team for a given game (GameDistance), which was modeled linearly, scaled in preparation, and calculated in kilometers (km). Relevant covariates included the difference between team and opponent season point total (TeamAbility), whether the game occurred at home or on the road (Home/Away), and whether the game occurred on the tail end of a back-to-back sequence (Back-to-Back) Associative effect (β), standard error (SE), lower limit (LL) and upper limit (UL) from 95 % confidence interval (CI), and *p* value are presented for each predictor.

Table 6
Fully adjusted regressions: associations of circadian change, travel distance, and relevant covariates with specific hockey performance.

Predictor	β	SE	95 % CI [LL, UL]	*p* value
Outcome variable: DiffActExpFSv%				
Circadian change variable: time zone change (TZΔ)				
TZΔ	−0.025	0.073	−0.168, 0.118	0.74
$TZΔ^2$	0.047	0.045	−0.041, 0.136	0.31
GameDistance (scaled)	−0.146	0.074	−0.291, −0.001	0.06
TeamAbility	0.025	0.003	0.019, 0.031	<0.0001*
Home/Away	−0.062	0.124	−0.305, 0.181	0.62
Back-to-Back	0.137	0.125	−0.107, 0.382	0.29
Circadian change variable: adjusted time zone change, Approach A (AdjTZΔ_A)				
AdjTZΔ_A	−0.014	0.072	−0.155, 0.128	0.85
$AdjTZΔ\_A^2$	0.067	0.055	−0.041, 0.178	0.25
GameDistance (scaled)	−0.171	0.087	−0.341, −0.001	0.08
TeamAbility	0.025	0.003	0.019, 0.031	<0.0001
Home/Away	−0.053	0.122	−0.292, 0.185	0.66
Back-to-Back	0.139	0.123	−0.102, 0.380	0.28
Circadian change variable: adjusted time zone change, Approach B (AdjTZΔ_B)				
AdjTZΔ_B	−0.025	0.076	−0.174, 0.124	0.75
$AdjTZΔ\_B^2$	0.119	0.048	0.025, 0.213	0.03*
GameDistance (scaled)	−0.176	0.062	−0.297, −0.056	0.02*
TeamAbility	0.025	0.003	0.019, 0.031	<0.0001*
Home/Away	−0.110	0.122	−0.349, 0.129	0.38
Back-to-Back	0.147	0.121	−0.089, 0.384	0.24
Outcome variable: GSAA				
Circadian change variable: time zone change (TZΔ)				
TZΔ	−0.016	0.017	−0.050, 0.017	0.35
$TZΔ^2$	0.012	0.012	−0.012, 0.036	0.33
GameDistance (scaled)	−0.022	0.022	−0.064, 0.020	0.32
TeamAbility	0.009	0.001	0.007, 0.010	<0.0001*
Home/Away	−0.016	0.031	−0.076, 0.043	0.60
Back-to-Back	0.002	0.031	−0.059, 0.063	0.95
Circadian change variable: adjusted time zone change, Approach A (AdjTZΔ_A)				
AdjTZΔ_A	−0.012	0.017	−0.045, 0.020	0.47
$AdjTZΔ\_A^2$	0.016	0.012	−0.008, 0.039	0.22
GameDistance (scaled)	−0.026	0.021	−0.068, 0.016	0.24
TeamAbility	0.008	0.001	0.007, 0.010	<0.0001*
Home/Away	−0.018	0.030	−0.077, 0.041	0.56
Back-to-Back	0.004	0.031	−0.056, 0.064	0.90
Circadian change variable: adjusted time zone change, Approach B (AdjTZΔ_B)				
AdjTZΔ_B	−0.015	0.022	−0.058, 0.027	0.50
$AdjTZΔ\_B^2$	0.027	0.013	0.002, 0.051	0.05*
GameDistance (scaled)	−0.029	0.018	−0.064, 0.007	0.14
TeamAbility	0.009	0.001	0.007, 0.010	<0.0001*
Home/Away	−0.029	0.032	−0.091, 0.033	0.37
Back-to-Back	0.004	0.031	−0.056, 0.065	0.89

This table presents results from the fully adjusted linear mixed-effect regressions that estimated the associations of circadian change and travel distance with specific hockey performance outcomes, including difference in actual versus expected Fenwick save percentage (DiffActExpFSv%) and goals saved above average (GSAA). Circadian change variables include time zone for the game (TZΔ) as well as adjusted TZΔ using approach A (AdjTZΔ_A) and B (AdjTZΔ_B). Models included linear (X) and quadratic (X^2) versions of these variables. Travel distance was represented solely by the estimated distance traveled by a team for a given game (GameDistance), which was modeled linearly, scaled in preparation, and calculated in kilometers (km). Relevant covariates included the difference between team and opponent season point total (TeamAbility), whether the game occurred at home or on the road (Home/Away), and whether the game occurred on the tail end of a back-to-back sequence (Back-to-Back) Associative effect (β), standard error (SE), lower limit (LL) and upper limit (UL) from 95 % confidence interval (CI), and *p* value are presented for each predictor.

In the univariate model, GoalDifferential significantly associated with the distance traveled (GameDistance) for a given team. Moreover, the difference in GameDistance between competing teams (DiffGameDistance) was also significant. Somewhat surprisingly, circadian change did not significantly associate with GoalDifferential when analyzed in univariate models, regardless of the circadian change variable under evaluation. These relationships imply that teams facing a prolonged travel distance for a given game or have traveled longer for a game than their opponent are at a competition disadvantage for the game. Tangibly, our results posit that every additional 900 kilometers (km) required for game travel coincides with a 0.04 worsened GoalDifferential. Ultimately, this would indicate that when a team such as the Vancouver Canucks is required to travel to Montreal (~3688 km) they potentially are at ~0.16 goal disadvantage before the drop of the puck. Moreover, the relationship between GameDistance and GoalDifferential strengthen in the bivariate models, which controlled for circadian change. Interestingly, circadian change did significantly associate with GoalDifferential in the bivariate models, which controlled for travel distance. However, this was not universal across circadian change variables, with only $AdjTZΔ\_B^2$ displaying a significant association with GoalDifferential. This finding suggests that subtle changes in travel management can have notable impact on performance outcomes. Lastly, these results also provide support for an interaction effect between circadian change and travel distance on global team performance, as evidenced by significant interactions terms between AdjTZΔ_A^2 and AdjTZΔ_B^2 with GameDistance in bivariate regressions related to GoalDifferential. This finding indicates that game scenarios that require longer travel distance and create greater degrees of circadian misalignment are most deleterious for global team performance.

The implication of these results lies in the preparation to lower the burden of these inherent travel-related factors. At a team level, great care should be deployed for any game that occurs out of their geographical division and even more so when the travel distance is extended while crossing several time zones. It could be argued that leaving a day earlier, when possible, to acclimate and reduce the burden of travel-related factors on outcomes in a worthwhile strategy for teams and players. This is commonplace in other sports, such as Major League Baseball (MLB), whereby starting pitchers for an upcoming game may travel in advance of their team to potentially reduce the negative impact of travel. However, this practice has yet to make its way in the NHL culture, to our knowledge.

Quick decision making and cognitive creativity are key elements to individual and team success across sports including hockey.[15] These skills are crucial for competition success as they provide athletes with the ability to adjust swiftly to fast-paced game dynamics, often times in unexpected and surprising fashion that creates an advantage in unique sport-specific situations.[15] Frequent travel results in a multitude of consequences, such as mental and physical fatigue as well as degraded sleep health, that limit cognitive abilities ultimately hampering player decision-making and creativity. Furthermore, degraded cognitive abilities could also create scenarios that leave a player more vulnerable to injuries.[19] The capability to not only improve player performance but also well-being by reducing the negative cognitive impact from frequent travel should be impetus for teams to better attend to travel management throughout the season as well as the NHL to further adjust the schedule to mitigate this burden on players. As fatigue is recognized to be cumulative[20] throughout a prolonged period of demanding cognitive activity, it holds the prospects of deleterious impact on the athlete that requires the upmost attention from the coaching staff to the medical team to better support the success of their athletes.[20,21]

Results from the fully adjusted models implicate that differences in team ability and location of game (home or road) have a stronger impact on game outcomes than game distance and circadian changes. The most recent NHL bubble has allowed an exceptional and unique perspective on the game, which warrants commentary given the findings from our investigation. The bubble allowed the game to be played without fans and, interestingly, this fan-less scenario showed a decrease in visiting team penalties per game,[22] which only adds to the referee's alleged bias towards home teams.[23] The past bubble experience may have been an eyeopener on the impact of home-ice advantage. In fact, during the bubble playoffs, the home team won only 41 % of their game whereas outside the bubble the home teams win percentage is above 50 % which highlight the potential impact of fans on the outcome of an NHL game.[24] Since a penalty can change the momentum of a game and inherently give the opposing team a one-man advantage, which has a sizeable impact on goal likelihood. In 2019, at five-on-five hockey, the league average for goals scored per hour of play was 2.5 and only 4.5 % of all shot attempts translated into a goal whereas on the power play those same rates go up to 6.8 goals per hour and 7.2 % of shot attempts resulted in goals.[25] Therefore, the impact of fatigue and circadian change on tolerance of frustration, among both the referees and players, would warrant more investigation in the NHL.

We also assessed the associations between circadian change and travel distance with specific hockey skill performance that largely focused on goaltender performance quantified by difference in actual versus expected Fenwick save percentage (DiffActExpFS%) and goals save above average (GSAA). We found that travel distance significantly and negatively associated with DiffActExpFS%, when controlling for circadian change that was modeled as AdjTZΔ_B. The results indicate that DiffActExpFS% becomes 0.18 units more negative for every additional 900kms traveled. Stated otherwise, the actual goalie performance based on Fenwick Save Percentage (FS%) is negatively influenced towards performing under expectation due to the influence of travel distance. Since FS% considers the expected goal against, which acknowledges not only the number of shots faced but also the quality shots faced, moving in the more negative direction suggests that the goaltender allowed more goals than they should have based on expectation. This could be driven by a multitude of factors, but, it does seem reasonable to posit that cumulated travel-related consequences, such as mental and physical fatigue, may hinder a goalie's ability to perform at expectation due to potentially impaired reaction time and overall vigilance.[26] Importantly, this relationship maintained in the fully adjusted model that included AdjTZΔ_B as the circadian change variable in the model, which also controlled for differences in team ability, whether the game was played at home or on the road, and whether the game occurred on the tail-end of a back-to-back sequence. And, although the results were nonsignificant across analyses, the same directional relationship was seen between travel distance and GSAA, whereby greater distance traveled for a game associated with a more negative GSAA. Additionally, circadian change, when modeled as the quadratic version of AdjTZΔ_B^2 also significantly associated with DiffActExpFS% and GSAA in the fully adjusted models. Overall, these results highlight the unique influence of travel on goaltender performance, which underlines the potential importance of individualized management for goaltenders. Since goaltenders represent the last rampart, one could argue they carry uniquely higher value than other members of the hockey team. In many ways, their individual impact on overall team success is similar to that of starting pitchers in Major League Baseball (MLB). Over the recent years, some MLB teams have shown a propensity to have their next day starting pitcher travel before the team travels in order to allow for better acclimation to their playing environment. This type of strategy would be difficult to implement in the NHL given that there generally are only 2 goalies on roster and the backup needs to be present for the game if they need to replace the starter. However, future changes to roster construction, such as adding an additional goalie, could open up the potential strategy of differential travel itineraries for goalies on the same team to establish best opportunity for goalie performance and, thus, team success. Regardless of roster evolution, these results showcase the utility of implementing strategies such as light exposure, meal timing and napping to help goalies reduce the impact of travel and time zone changes.[5,27]

A particularly interesting finding from our investigation is that circadian misalignment, regardless of whether one if advanced or delayed, affects global team and specific hockey skill performance. Importantly, these results do not entirely support prior evidence. Smith and colleagues,[11] who investigated 40 years of NFL game including the seasons between 1970 and 1994 and the seasons between 1995 and 2011, showed a clear advantage for teams traveling eastward. Our results suggest that regardless of the direction of eastward or westward travel, the negative impact arises from a greater circadian misalignment. Furthermore, our results provided support that the negative effects of circadian misalignment are heightened by greater distance traveled for a given game. Some of the differences in findings may be explained by differences between the NFL and NHL. NFL teams play only 1 game per 4 or 7-days period whereas NHL teams can play up to 4–5 games per 7-day period. As such, NHL teams are traveling more frequently which invites in the consequence of constant circadian disruption and further circadian misalignment. In contrast, NFL teams generally are afforded the opportunity to return to circadian neutral following a game rather than constantly being misaligned. Stated otherwise, the extensive time spent traveling in the NHL leads to not only greater accumulation of travel-related mental and physical fatigue that negatively impacts performance, but also creates a scenario where players are chronically experiencing circadian misalignment. Overall, the travel-related factors of circadian change, regardless of travel direction, and travel distance, which often associates with mental and physical fatigue, may exert detrimental pressure on an athlete in combination, which is likely to decrease the level of alertness, increase the likelihood of mental mistakes, degrade overall performance, and heighten the risk for sport-related injury.[26]

The results from our fully adjusted models also provide further support that being the superior team, having home-ice advantage, and not playing on the tail-end of a back-to-back sequence remained strong predictors of global team and specific hockey skill performance success. Given that back-to-back games represents a staggering 17.01 % of the NHL schedule between 2013 and 2020, which equates to almost one in every five games, recovery and travel management warrant particular attention. A lot of consideration has been directed towards the increased injury rate that coincide with back-to-back scenarios in the National Basketball Association[16,28,29] but this attention has not translated to the NHL in terms of player performance or injury. Based on the significant disadvantage drawn by playing two games within 24-h and the alleged increased rate for injury, NHL teams should consider travel and schedule management as one of the top priorities and could envision using a load management tactic similar to the NBA where they voluntary rest their key players on precise game throughout the season.[30]

5. Limitations

Despite the robust statistical approach of this investigation, we acknowledge the presence of certain limitations. First, given the retrospective nature of our data collection, we had to rely on total season points to determine our team ability covariate. Yet, we acknowledge that team ability changes markedly across the season due to factors such as injury, player development, and general oscillations in team ability that are common to sports (e.g., hot and cold streaks). Second, we only acknowledge the back-to-back sequence whereas the reality of the strenuous NHL calendar is represented by much more than only two games within 24-h. In fact, teams can experience 5 games within 7 days, which inherently requires navigating game sequence scenarios of 3 games in 4-days that could be more detrimental than the typical two games in 24-h. Finally, we assumed that every single player and team would be affected in the same way by circadian changes whereas the reality of circadian factor is much more complex. Accounting for individual player chronotype was not possible, which limited our ability to understand the impact of circadian change in a more personalized manner. Rather, we had to estimate the influence of circadian change from a global perspective.

6. Conclusion

In summary, this retrospective investigation used open-access National Hockey League (NHL) game across seven consecutive seasons (2013–2020), following the NHL division realignment, to explore the associations of circadian change, travel distance, and their interaction with global team and specific hockey skill performance. Despite the ever-increasing attention to detail across professional sports, one could reasonably argue that travel-related factors, such as circadian change and travel distance remain some of the most overlooked variables in the context of performance. While changes in traveling management may appear modest, they could potentially represent the difference between a win and a loss, as well as the ability to participate in the playoffs and compete for a championship. More research is warranted to isolate the true impact of travel-related factors, such as circadian change and travel distance, on performance to efficiently tailor strategies from which athletes and teams will benefit.

Funding Information

The authors did not receive any funding for this manuscript.

Confirmation of Ethical Compliance

N/A.

Declaration of Interest Statement

The authors do no have any conflict of interest to disclose.

Acknowledgement

We would like to acknowledge the support and help of evolving-hockey.com.

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