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Travel-Induced Sleep Disruption Increases Mental Errors Among Young Professionals: Evidence from a Natural Experiment

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Abstract

Travel across time zones can disrupt sleep and circadian rhythms, but its performance consequences and heterogeneous effects remain difficult to identify. Using Major League Baseball data, we exploit schedule-driven variation in travel direction as a long-term natural experiment with high-frequency behavioural outcomes. We show that eastward travel, which entails a one-hour time loss and compresses the recovery window before the next game, increases the probability of a mental error by about 7.6%. The effect is concentrated among younger players and is independent of tenure, allowing us to disentangle age-related vulnerability from accumulated professional experience. We further find larger effects among teams frequently exposed to eastward travel and evidence consistent with reduced recovery time as an underlying mechanism. These results reveal hidden cognitive costs of cross-time-zone coordination and suggest that scheduling, recovery time, and workload allocation are important inputs into performance management in multi-time-zone operations.

JEL Classification: I12, J24, M54, C23, L83
Keywords: sleep loss; circadian disruption; mental errors; natural experiment; age heterogeneity; travel

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1. Introduction

Globalisation has fundamentally reshaped the modern workforce, creating a greater demand for constant availability and coordination. As businesses increasingly operate across multiple time zones, employees – ranging from executives to frontline staff – are often required to work irregular hours to facilitate economic and social coordination across regions. This shift has increased the importance of business travel: in 2024, nearly 488 million business trips were taken in the United States alone, or about 1.3 million per day. Related spending reached USD 538.5 billion, 7.5% more than in the previous year, highlighting the ongoing importance of travel in professional contexts. The most common trip length was three to four nights.[1]

While international coordination offers clear advantages, such as enhanced communication, stronger relationships, and accelerated decision-making, it also imposes hidden costs. One such cost arises from the misalignment between biological and social time, a phenomenon known as 'social jet lag' (Roenneberg et al. 2012). Disruptions to the sleep-wake cycle, particularly those induced by travel across time zones, can impair mental performance and increase the likelihood of cognitive errors. Sleep loss affects the prefrontal cortex, which governs higher-order cognitive functions such as language, creativity, and divergent thinking (Krause et al. 2017). Executive attention, working memory, and other advanced cognitive processes are especially vulnerable to sleep deprivation (Durmer & Dinges 2005, Alhola & Polo-Kantola 2007), resulting in slower processing speeds, diminished concentration, and impaired decision-making.

The effects of sleep on productivity and cognitive performance remain comparatively understudied in economics. A large share of the existing evidence relies on survey data or on identification from exogenous shocks such as the transition to Daylight Saving Time (DST). For instance, Gibson & Shrader (2018) and Costa-Font et al. (2024) show that sleep is positively associated with labour-market outcomes such as earnings and employment. Field-experimental evidence by Bessone et al. (2021) demonstrates that daytime naps can improve productivity and psychological well-being. Similarly, in a field experiment among U.S. university students, Giuntella et al. (2026) show that sleep-improving interventions increase sleep duration and improve academic performance. Other studies link sleep disruptions following the transition to DST to increased workplace injuries (Barnes & Wagner 2009), reduced digital productivity (Dickinson & Waddell 2024), increased default risk in online lending (Freed 2026), and diminished forecast accuracy among less experienced professionals (Bazley et al. 2025). In educational settings, delayed school start times and sleep loss have been shown to affect student performance (Carrell et al. 2011, Jagnani 2024). Despite this growing literature, less is known about how travel-induced circadian disruption affects high-stakes cognitive performance in

[1] Global Business Travel Association (GBTA) (2026), *The U.S. Business Travel Industry: Business Travel's Impact on Jobs and the U.S. Economy in 2024*, prepared by Rockport Analytics, released 2 June 2026. Key figures are summarised in the GBTA press release: https://www.businesswire.com/news/home/20260602307897/en/ (accessed 2026-11-06).

professional environments.

In this study, we examine the effect of travel-induced reductions in recovery and sleep opportunities on mental performance using high-frequency data from 42 seasons of Major League Baseball (MLB), covering the period from 1983 to 2024. The MLB schedule provides a unique long-term quasi-experimental setting because it generates schedule-driven variation in travel direction and timing across four time zones. This variation allows us to distinguish the physical burden of travel, proxied by distance, from the cognitive costs associated with losing time available for sleep and recovery after eastward travel. The setting offers several advantages: high-resolution behavioural data from expert performers operating under strong performance incentives, a clearly defined and objectively recorded measure of mental mistakes, and detailed information on individual characteristics such as age, tenure, and country of birth. These features allow us to examine potential mechanisms and to distinguish age-related vulnerability from accumulated job experience. The richness of the data and the competitive nature of the environment make the setting well suited for studying performance-relevant consequences of sleep disruption. Moreover, professional athletes operate under demanding schedules, high performance pressure, and frequent travel, making the findings relevant beyond the sports domain (Forbes 2024).

Prior research on travel and performance in sports yields mixed results. Song et al. (2017) document negative jet-lag effects following eastward travel in MLB, while Nutting & Price (2017) and Hasbany et al. (2023) report neutral or even positive effects of eastward travel on NBA team performance, depending on game timing. Zak (2021) finds that travel can *enhance* cognitive performance in chess. These conflicting findings underscore the need for further investigation into the nuanced effects of travel-induced sleep loss on mental performance.

Our empirical analysis focuses on back-to-back games, defined as games played on consecutive days in different ballparks. Such games require teams to travel between games, sometimes within the same time zone and sometimes across time-zone boundaries. Eastward travel involves crossing into a time zone that is (at least) one hour ahead, thereby reducing the time available for sleep and recovery before the next game, whereas westward travel provides an additional hour (or more). Games played in the same ballpark after at least one intervening rest day serve as the control group.

We find robust evidence that eastward travel increases the probability of a mental error in a given inning. In our preferred specification, the estimated effect amounts to about 0.53 percentage points, corresponding to a 7.6% increase evaluated at the sample mean. By contrast, we do not find comparable effects for westward travel or for travel within the same time zone. Since the effect is specific to eastward time-zone transitions and persists when we account for travel distance including a within-route comparison, we interpret the evidence as consistent with travel-induced circadian disruption reducing cognitive performance. The result is robust across model specifications, subsample restrictions, route fixed effects, and placebo tests.

We also investigate mechanisms and heterogeneity in responses to travel-induced sleep disruption. An important unresolved question is why some professionals are more vulnerable to sleep disruption than others. Evidence of smaller performance losses among more experienced professionals may reflect accumulated coping strategies, age-related differences in susceptibility, or both (Bazley et al. 2025, Song 2023). Since age and experience typically move together, distinguishing these explanations is difficult in observational settings. Therefore, a key contribution of our study is that we can disentangle age from tenure, and thus distinguish age-related vulnerability from potential learning or adaptation effects. The adverse effect of eastward travel is concentrated among players in the youngest age group and disappears when errors committed by this group are excluded, whereas analogous exercises based on tenure do not eliminate the effect.

We further show that internationally born players exhibit larger relative effects, and that teams with more frequent prior exposure to eastward travel experience more pronounced performance losses. Finally, we provide evidence consistent with a sleep-loss mechanism: the adverse effect of eastward travel persists when the previous game was long and recovery time before the focal game was therefore compressed, while the point estimates for westward travel turn negative after particularly long previous games, a pattern consistent with the importance of recovery and sleep opportunities.

Our analysis is relevant beyond sport because it examines how demanding schedules affect the quality of performance. We focus on recorded errors to study how limited recovery may affect even highly trained professionals with strong incentives to perform well. Our findings suggest that organisations should consider not only travel distance and workload, but also when demanding tasks take place after travel. While we do not measure sleep duration directly, our results still provide evidence on the performance effects of travel across time zones, with reduced sleep opportunities and disrupted body clocks as possible explanations.

2. Data and Empirical Approach

The analysis is based on detailed play-by-play data from Major League Baseball (MLB), sourced from `Retrosheet.org`. The dataset covers over 100,000 regular season games played between 1983 and 2024. Each team typically plays around 160 games per season, spanning from March/April to September/October. Importantly, consecutive games – referred to as 'back-to-back games' – are the norm rather than the exception.

Our core unit of analysis is the inning level. Each inning consists of two halves (top and bottom) where teams alternate between batting and fielding until three outs are recorded. A standard MLB game comprises nine innings. We focus on team and individual performances in teams while fielding (i.e., on defence), with particular interest in cognitive performance and the occurrence of mental mistakes, as recorded in official MLB box scores.

In detail, we proxy mental performance using defensive *errors* recorded in official MLB

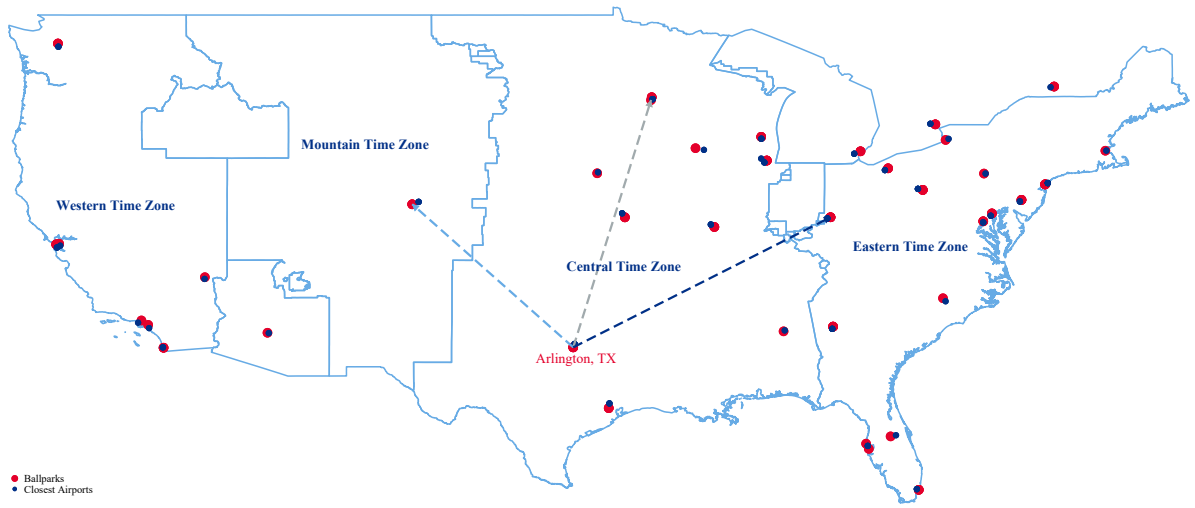
box scores. An error is charged when a fielder fails to complete a play that could reasonably be expected under ordinary conditions, thereby allowing an opponent to reach base, advance, or prolong the inning. Since such mistakes typically occur in routine situations, they provide a useful behavioural indicator of lapses in attention, concentration, and execution rather than of strategic decision-making or differences in task difficulty alone. Errors are recorded in real time by official scorers according to formal scoring rules and are subject to review, which supports consistency and limits measurement error. At the inning level, defensive errors therefore offer a high-frequency, objective measure of performance lapses that is well suited to studying the effects of fatigue, sleep disruption, and circadian misalignment.

Our final sample consists of 264,215 team-inning-level observations, enriched with detailed information on scores, weather conditions, attendance, field characteristics, and game sequences. Additionally, the dataset includes player biographical data (e.g., birthdate, debut date, birthplace) and geographic information on ballparks and nearby airports, enabling precise calculations of travel distances and time-zone transitions.

2.1. The Experiment

Figure 1 illustrates the core identification strategy of our analysis, highlighting the variation in travel patterns, particularly eastward and westward movements across time zones, which we exploit to estimate the causal impact of travel-induced sleep deprivation on cognitive performance.

FIGURE 1 — The experiment



It shows how teams travelling similar distances may experience different time-zone transitions. For example, when travelling to play the Minnesota Twins, the Texas Rangers remain within the Central Time Zone. However, when travelling east to play the Cincinnati Reds, they experience a one-hour time loss, and when travelling west to play the Colorado Rockies, they gain one

hour. This variation in time-zone exposure – conditional on travel distance – is central to our empirical strategy. It allows us to isolate the cognitive effects of circadian disruption from mere travel fatigue. The figure also suggests that airport accessibility is unlikely to confound our results, as the maximum distance between any ballpark and its nearest airport in our sample is approximately 20 miles.

Figure 2 illustrates the distribution of travel distances for games played without an off-day in between within and across time zones. It shows that teams cover similar distances when travelling across time zones east- or westwards. When travelling within a time zone, the maximum distance goes beyond 1,400 miles, and this wide range of within-time-zone travel distances helps create a natural experiment by allowing us to compare trips of similar length with and without time-zone transitions. While eastward and westward trips cover similar distances, within-time-zone trips are on average shorter. We therefore control for distance explicitly (Table 1, columns (4)–(5)) and compare identical routes in both directions (Section 3.2).

Figure 3 provides initial descriptive evidence supporting our identification strategy by relating the share of team-games with at least one defensive error to time-zone differences in back-to-back games. The figure suggests a mild increase in errors following eastward travel, consistent with the hypothesis that sleep disruption leads to lower cognitive performance. Interestingly, a similar pattern emerges for westward travel across more than one time zone, indicating the importance of travel distance alone. This underscores the need to disentangle the impact of travel per se from time-zone-induced sleep loss or gain.

Table B.1 in Appendix B corroborates this finding. Here, we link means of our binary outcome variable (error in inning *i yes*/*no*) to time-zone transitions. The table reveals that error rates tend to increase with eastward travel across time zones, particularly when teams move from the Pacific to the Eastern Time Zone. This pattern supports the hypothesis that losing time due to eastward transitions may impair cognitive performance. However, similar increases are also observed for certain westward transitions, suggesting that time-zone changes alone may not fully explain the variation in error rates.

FIGURE 2 — Distribution of travel distances by category

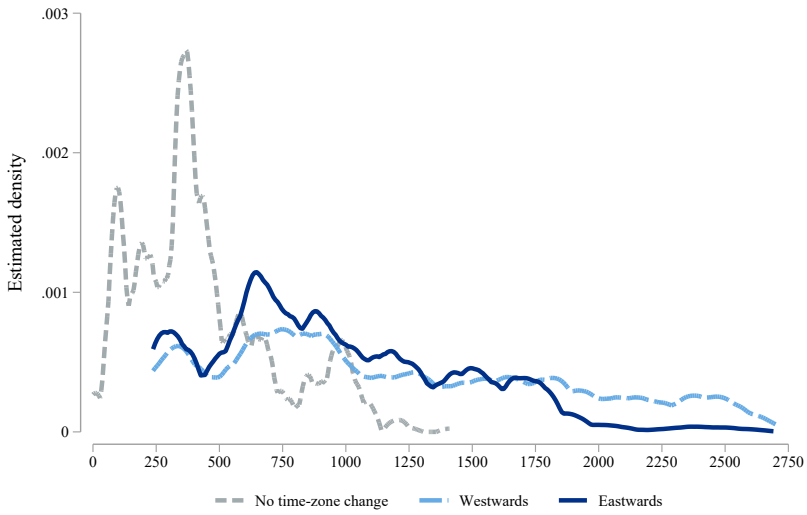
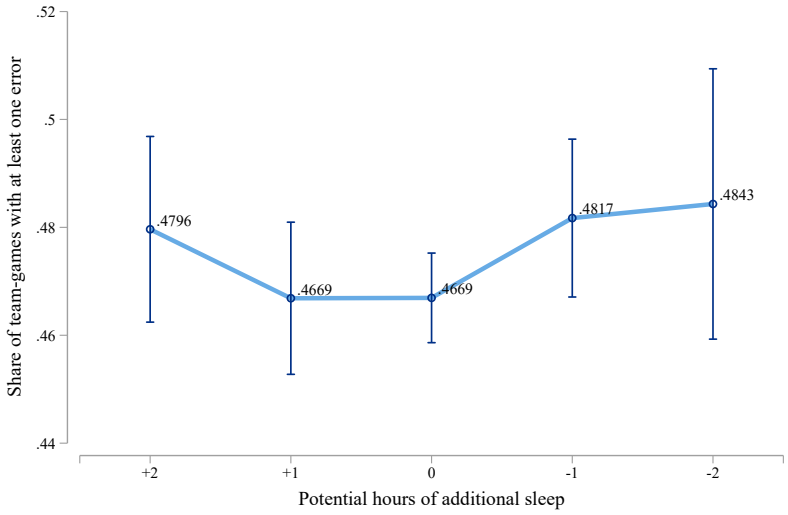


FIGURE 3 — Share of team-games with at least one defensive error by time-zone difference



Notes: Share of team-games in back-to-back games in which the fielding team committed at least one defensive error, by the time-zone difference between game $g-1$ and game g, with 95% confidence intervals. Positive values denote westward travel (time gained), negative values eastward travel (time lost). Note that this descriptive measure is defined at the team-game level, whereas the dependent variable in model (1) is defined at the team-inning level.

2.2. *Empirical Model*

To estimate the effect of travel-induced sleep loss on mental performance, we estimate the following linear probability model:

$$Y^{\text{Error}}_{i,g,t} = \alpha + \beta\,\text{Travel}_{g,t} + \delta_W\,\text{Westward}_{g,t} + \delta_E\,\text{Eastward}_{g,t} + \xi'\mathbf{X}_{i,g,t} + \mu_{t,s} + \nu_{o,s} + \lambda_m + \psi_i + \varepsilon_{i,g,t}. \quad (1)$$

where $Y^{\text{Error}}_{i,g,t}$ is a binary variable equal to one if team t, while fielding, committed at least one defensive error in inning i of game g, and zero otherwise. $\text{Travel}_{g,t}$ indicates whether team t played in a different ballpark on the previous day. $\text{Westward}_{g,t}$ and $\text{Eastward}_{g,t}$ are indicators for travel across time zones to the west and east, respectively. The vector $\mathbf{X}_{i,g,t}$ includes game-specific controls, such as indicators for whether the current game and the previous game were day games, as well as an indicator for whether the fielding team is the home team. We include team-season fixed effects $\mu_{t,s}$, opponent-season fixed effects $\nu_{o,s}$, month fixed effects λ_m, and inning fixed effects ψ_i. In alternative specifications, we additionally include ballpark fixed effects given that teams occasionally change ballparks. Standard errors are clustered at the team-game level.

In this specification, β captures the effect of back-to-back travel within the same time zone relative to the no-travel control group. The coefficients δ_E and δ_W capture the additional effects of eastward and westward time-zone crossings, respectively, beyond the effect of travel itself. Thus, δ_E is the coefficient of primary interest, as eastward travel implies a one-hour time loss and therefore proxies travel-induced sleep loss. The control group consists of games played in the same ballpark after at least one intervening rest day and not immediately following a recent travel sequence. To ease interpretation, our preferred specification restricts the sample to time-zone differences of at most one hour in either direction. We also estimate a range of additional specifications to assess the robustness of our main results.

3. Results

3.1. Basic results

Table 1 presents our main results. Across specifications (columns (1)–(4)), the coefficient on the 'Eastwards' indicator is consistently positive and statistically significant. For example, in column (2), the coefficient is 0.0046 and significant at the 1% level. Since the specification also includes a general travel indicator, this coefficient captures the additional effect of eastward time-zone crossings beyond back-to-back travel without a time-zone change. The total effect of eastward travel relative to the no-travel control group is therefore given by the sum of the travel coefficient and the eastward coefficient, which in column (2) amounts to approximately 0.0053, or 0.53 percentage points. Evaluated at the sample mean of 0.0695, this corresponds to an increase of about 7.6% in the probability of a mental error. These findings support the hypothesis that circadian disruption caused by time-zone-induced sleep loss impairs cognitive performance.

In contrast, the 'Westwards' indicator is not statistically significant across the specifications. This provides no evidence that westward travel, which typically implies a gain in time, impairs performance. The asymmetry between eastward and westward travel effects highlights the importance of sleep loss rather than travel per se. This interpretation is reinforced by the fact that the general travel indicator is not statistically significant in the specifications in which it is included, suggesting that travel alone, without a time-zone change, is not sufficient to reduce

mental performance. In column (4), we introduce quartiles of travel distance, none of which is statistically significant. This suggests that physical travel distance alone does not explain the observed variation in errors.

Column (5) refines the analysis by distinguishing travel distance, measured in thousands of miles, by the type and direction of the time-zone transition. The results show that, for a given travel distance, direction matters: while travel within the same time zone and westward travel have no statistically significant effect, eastward travel across one time zone increases the probability of a mental error by 0.53 percentage points per 1,000 miles travelled. For an eastward trip of 1,000 miles, this corresponds to an increase of about 7.6% relative to the sample mean. This specification most closely mirrors the natural-experiment intuition in Figure 1, as it compares trips of similar length that differ primarily in whether they induce time-zone-related sleep loss.

Finally, column (6) presents a placebo test using a different treatment group, namely the second game after a back-to-back road trip. The precisely estimated zero effect for eastward travel in this specification supports the validity of our identification strategy. Because the placebo games are played by the same teams at the same destinations as the treated games, any time-invariant feature of travelling teams or of the destination, such as stronger opponents, ballpark characteristics, or local conditions in the East, would also show up in the placebo estimates. The absence of such an effect therefore suggests that the main results are driven by the timing of the time-zone shift rather than by characteristics of the teams or destinations involved.

TABLE 1 — Basic results

	(1) **Basic**	(2) **Preferred**	(3) **Ballpark-FEs**	(4) **Distance-I**	(5) **Distance-II**	(6) **Placebo**
Travel between games	0.0010	0.0007	0.0007			0.0013
(1 = yes, 0 = no)	(0.0013)	(0.0015)	(0.0015)			(0.0014)
Eastward travel across TZ	0.0032**	0.0046***	0.0041**	0.0045***		−0.0001
(1 = yes, 0 = no)	(0.0015)	(0.0016)	(0.0016)	(0.0017)		(0.0016)
Westward travel across TZ	−0.0001	0.0004	0.0008	0.0006		−0.0003
(1 = yes, 0 = no)	(0.0014)	(0.0016)	(0.0017)	(0.0017)		(0.0016)
TD Q_1 [a]				−0.0009		
				(0.0020)		
TD Q_2 [a]				0.0000		
				(0.0018)		
TD Q_3 [a]				−0.0002		
				(0.0018)		
TD Q_4 [a]				−0.0012		
				(0.0017)		
Distance - same TZ [b]					0.0003	
					(0.0020)	
Distance - eastward TZ [b]					0.0053***	
					(0.0019)	
Distance - westward TZ [b]					0.0017	
					(0.0019)	
Full controls	*no*	*yes*	*yes*	*yes*	*yes*	*yes*
Ballpark FE	*no*	*no*	*yes*	*no*	*no*	*no*
Observations (N)	264,215	264,215	264,215	264,690		
R^2	0.000	0.011	0.012	0.011	0.011	0.011
Mean dep. var.	0.0695	0.0695	0.0695	0.0695	0.0695	0.0701

Notes: The dependent variable is an indicator equal to one if the fielding team committed at least one error in the inning. The sample is restricted to time-zone differences of at most one hour in either direction to facilitate interpretation. Standard errors, clustered at the team-game level, are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Full controls include team-season fixed effects, opponent-season fixed effects, month fixed effects, inning fixed effects, an indicator for whether the fielding team is the home team, and indicators for whether the current and previous games were day games. [a] Indicators equal to one if the observed travel distance falls within the corresponding quartile of the travel-distance distribution. Non-travel observations form the reference category. [b] Travel distance is measured in thousands of miles and entered separately for travel within the same time zone, eastward time-zone crossings, and westward time-zone crossings; the respective variables are zero for observations outside the corresponding category. Columns (1)–(5) include games played on consecutive days with overnight travel either within the same time zone or across a single time-zone boundary, along with a control group of games played in the same ballpark after at least one intervening rest day. Column (6) reports a placebo test in which the treatment indicators identify the second game following a back-to-back trip rather than the first. The placebo test assumes that the additional recovery time is sufficient for the effects of sleep disruption associated with a time-zone shift of at most one hour to dissipate.

3.2. Within-route comparisons

In a next step, we exploit the fact that many routes between two ballparks are observed in both directions. This allows us to estimate a specification with route fixed effects, thereby comparing eastward and westward travel along the same ballpark pair. The results in Table 2 confirm our main findings: holding the route fixed, eastward travel increases the probability of a mental error by about 0.37 percentage points, or 5.2% relative to the sample mean, compared with westward travel.

While the baseline estimates compare journeys that may differ in their origin and destination, we next exploit routes that are observed in both directions to compare eastward and westward travel between the same two ballparks. Journeys from A to B and from B to A share the same route fixed effect, so geographic distance is held fixed while the direction of the time-zone shift changes. This comparison closely implements the natural-experiment intuition outlined in Section 2.1. For identification, the key advantage is that the estimated east-west difference is based on comparisons *within* routes rather than *between* routes of different lengths. The comparison therefore strengthens our ability to distinguish the consequences of time-zone transitions from the burden of travel distance itself.

Table 2 presents the estimates without and with route fixed effects. The estimated difference between eastward and westward travel changes little, from 0.39 to 0.37 percentage points. The latter estimate corresponds to 5.2% of the sample mean and is statistically significant at the 5% level. Thus, the higher error probability after eastward travel is not explained by differences in geographic route length.

TABLE 2 — Eastward versus westward travel: Within-route estimates

	(1)	**(2)**
Eastwards	0.0039**	0.0037**
	(0.0018)	(0.0019)
Full set of controls	*yes*	*yes*
Route fixed effects	*no*	*yes*
Observations (N)	126,165	126,165
Mean dep. var.	0.0709	0.0709
R^2	0.021	0.024

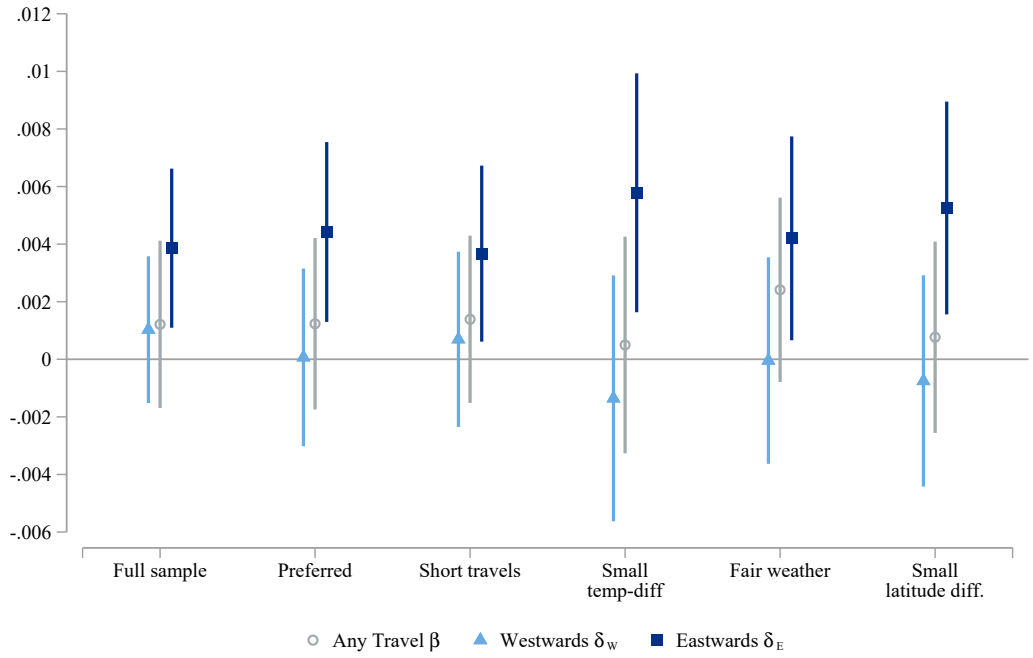
Notes: Estimation samples consist of all back-to-back games as used for column (2) of Table 1 where a team travelled overnight across exactly one time zone. Standard errors are clustered at the team-game level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

3.3. Robustness

We conducted additional analyses to verify the robustness of our results. Figure 4 indicates that our main result based on a sample restricted to time-zone differences of at most one hour ('Preferred') also holds without restrictions on time zones ('Full sample') and for a sample

restricted to trips of at most 1,500 miles ('Short travels'). We further examine whether the result is sensitive to weather-related confounders by restricting the sample to games with small temperature differences between game g and game $g-1$ of at most 10 °F in absolute value ('Small temp-diff'), to games played in favourable weather conditions ('Fair weather'), and to trips with latitude differences of at most 5 degrees between origin and destination ('Small latitude diff.'). Across these specifications, the coefficient on eastward travel remains positive, while the coefficients on westward travel and travel without a time-zone change remain small and statistically insignificant. Additional results (not reported) show that the negative effects of travelling eastwards across time zones cannot be attributed to travelling to well-known nightlife destinations such as Los Angeles, Las Vegas, or Miami.

FIGURE 4 — Sensitivity analysis



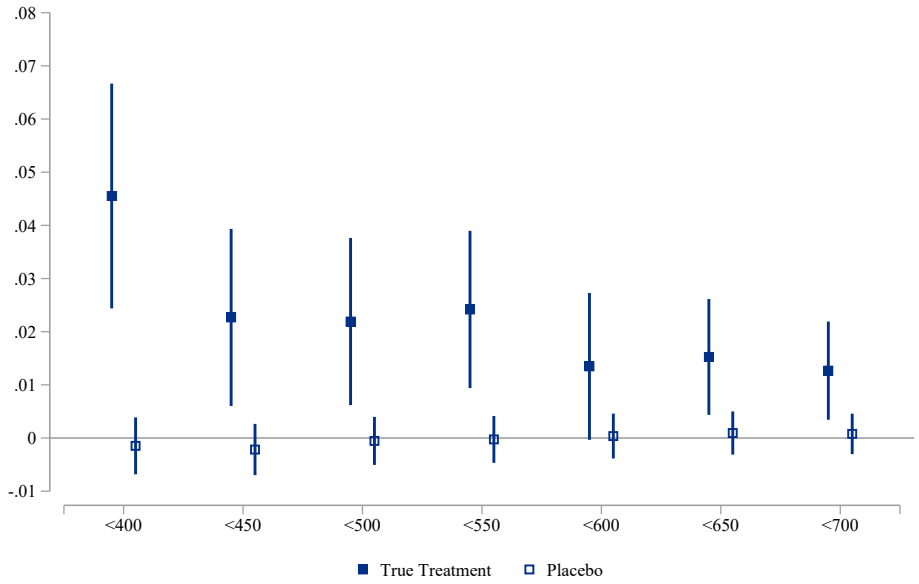
Notes: Estimates of model (1) for different samples. 'Full sample': All time zones; 'Preferred': Sample restricted to ±1 hour time difference; 'Short travels': ≤ 1,500 miles; 'Small temp-diff': +/- 10°F; 'Fair weather': Domes or fair weather (wind speed, dry, no rain, mild temperature); 'Small latitude diff.': +/- 5°.

To strengthen identification further, we focus on short-distance trips that cross exactly one time-zone boundary. This comparison is useful because it limits differences in travel distance while retaining variation in whether teams lose or gain time. Figure 5 presents estimates for samples defined by maximum travel-distance cut-offs ranging from 400 to 700 miles. We also implement a placebo test using short within-time-zone trips classified as pseudo eastward or westward movements. This placebo exercise helps distinguish the effect of crossing a time-zone boundary from the effect of geographic travel direction alone. The estimates show a positive effect of true eastward time-zone crossings, whereas the placebo estimates are close to zero.

These results reinforce our main finding that lost local time, and the associated sleep disruption, is the primary driver of the observed increase in mental errors.

Finally, we address the concern that teams based in the Eastern region may be systematically stronger. If this were the case, our main result could be mechanically driven by teams facing stronger opponents after eastward travel. Such matchups could lead to longer or more demanding defensive innings and, consequently, to a higher probability of errors. While the placebo test in Table 1 already casts doubt on this explanation, we further examine team strength using Elo ratings. Figure A.1 in Appendix A shows the distribution of Elo-based win probabilities, while Figure A.2 plots average Elo ratings by time zone and decade. The latter shows no systematic advantage for Eastern teams, suggesting that regional differences in team strength are unlikely to explain our main findings.

FIGURE 5 — Short-distance travel across time zones



Notes: Each estimate is derived from estimating an alternative version of model (1). The estimation sample consists of short-distance trips as indicated by the distance intervals on the x-axis. Placebo time-zone crossings are defined as geographic east- or westwards trips without crossing a time-zone border. Standard errors are clustered at the team-game level.

4. Mechanisms

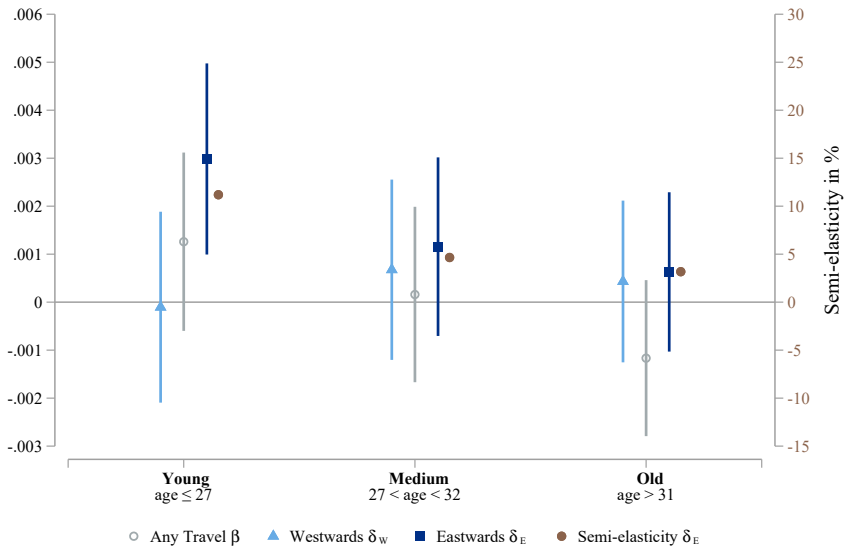
In this section, we conduct heterogeneity analyses to examine how the main effect of eastward travel varies across different subgroups and conditions. Our main interest lies in the role of age and experience, and in particular in the potential to adapt to sleep loss over time.

4.1. *Age and Tenure*

Motivated by research in medicine and psychology (e.g., Philip et al. 2004, Adam et al. 2006, Pasula et al. 2018), we first examine whether younger individuals experience a greater decline in cognitive performance following travel-induced sleep loss than older individuals. This question is challenging to address in field settings, as age is typically correlated with tenure and experience. In our context, the key issue is whether older players are less affected due to biological resilience or because they have developed coping strategies for eastward travel.

Our sample features an unusually broad age distribution for professional sports, ranging from 18 to 52 years. For the analysis, we divide players into age terciles (see Figure A.3 in Appendix A). We then construct age-group-specific outcome variables indicating whether at least one error in an inning was committed by a player in the respective age group, and estimate model (1) separately for these outcomes. The resulting groups are young players (≤ 27 years), the middle age group (28–31 years), and older players (≥ 32 years).

FIGURE 6 — Effect heterogeneity: Age



Notes: Estimates of model (1) for different samples and 95% confidence intervals (left axis). Semi-elasticities (right axis) are the eastward coefficients δ_E divided by the group-specific mean of the dependent variable, in percent. Standard errors are clustered at the team-game level.

Figure 6 shows that the adverse effect of eastward travel is concentrated among the youngest group. For this group, eastward travel significantly increases the probability of an error, whereas the corresponding coefficients for the middle and older age groups are statistically indistinguishable from zero. This finding is robust to a cumulative exclusion exercise: Figure A.4 in Appendix A shows that the effect disappears once errors committed by players aged 27 and below are excluded from the outcome.

A key interpretational challenge is that age is typically correlated with experience, so it is not obvious whether the pattern reflects biological vulnerability among younger individuals or

differential ability to cope with sleep disruption. Related evidence from financial forecasting by Bazley et al. (2025) shows larger performance declines after sleep loss among less experienced and non-professional forecasters, but little effect among professionals, a gradient that could reflect experience, age, or both.

In contrast to much of the existing literature, our setting allows us to observe both age and tenure, measured as years since entry into the big leagues. Although age and tenure are naturally correlated, there is sufficient variation because players enter the league at different ages, which enables us to separate these dimensions empirically. We therefore replicate the previous analysis using tenure terciles (see Figure A.5 in Appendix A).

Figure 7 presents estimates from an exclusion exercise in which the dependent variable is redefined to omit errors committed by players in specific age or tenure groups. The baseline effect remains stable when errors committed by short-tenured, long-tenured, or older players are excluded from the outcome. By contrast, the effect disappears when errors committed by younger players are excluded. We interpret this as evidence that age, rather than accumulated tenure, is the key moderator of the adverse effect of sleep deprivation on cognitive performance.

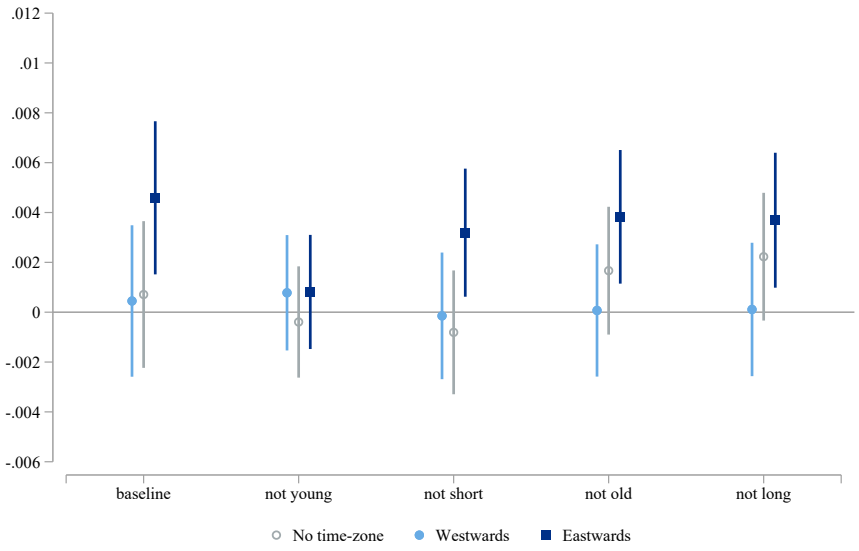
Our findings also help reconcile related results for financial analysts. Song (2023) classifies analysts as *junior* or *senior* and finds that senior analysts are less affected by sleep loss, but seniority conflates age and experience and therefore does not allow the two channels to be separated. Similarly, the experience gradient documented by Bazley et al. (2025) may, at least in part, reflect underlying age-related heterogeneity that cannot be isolated in settings without individual-level age information. Consistent with this interpretation, our results show that variation along the tenure dimension alone does not account for the observed differences in susceptibility. Taken together, our estimates point to age-related factors, rather than accumulated experience, as the primary source of heterogeneity in performance responses to sleep loss. A precise understanding of this distinction is important for translating these findings into organisational practice, particularly in roles where frequent travel is a regular feature of the job.

4.2. Player Origin and Frequency of Treatment

We extend our heterogeneity analysis by examining two additional dimensions: player origin, measured by country of birth, and team exposure to eastward travel. First, we distinguish errors committed by U.S.-born players from errors committed by internationally born players. The rationale is that U.S.-born players may have had greater prior exposure to domestic cross-time-zone travel routines before entering MLB and may therefore be more familiar with the logistical and behavioural adjustments required to cope with travel-induced sleep loss.

Columns (1) and (2) of Table 3, based on model (1), use outcome variables indicating whether at least one error in the inning was committed by a U.S.-born or internationally born player, respectively. The point estimate for the *eastward* indicator is larger in absolute terms for U.S.-born players, but the relative effect is more pronounced for internationally born players

FIGURE 7 — Age, not experience



Notes: Estimates based on model (1). The dependent variables are redefined to indicate whether at least one error in the inning was committed by players outside the excluded age or tenure group. *Young* refers to players in the first age tercile, as illustrated in Figure A.3; *not young* excludes errors committed by players in this group. *Short tenure* refers to players in the first tenure tercile, as illustrated in Figure A.5; *not short* excludes errors committed by players in this group. Analogously, *not old* and *not long* exclude errors committed by players in the oldest age group and longest-tenured group, respectively. Standard errors are clustered at the team-game level.

because their baseline error rate is lower. Specifically, the implied relative effect is 5.0% for U.S.-born players and 9.7% for internationally born players. This pattern is consistent with the idea that prior exposure to domestic cross-time-zone travel may matter, although the evidence should be interpreted cautiously because the absolute effect is larger for U.S.-born players.

Second, we examine whether teams frequently exposed to eastward travel adapt over time or instead experience cumulative fatigue. To do so, we split the sample at the median of the cumulative frequency of eastward travel up to game g. Columns (3) and (4) of Table 3 show that observations with below-median eastward exposure exhibit a modest and statistically insignificant effect of eastward travel, whereas observations with above-median exposure show a larger and highly significant increase in the probability of an error. The coefficient of 0.0065 in column (4) corresponds to a 9.4% increase relative to the sample mean. This pattern provides no evidence of adaptation in the high-exposure group; if anything, it is more consistent with cumulative fatigue or persistent circadian strain.

Across all specifications, the general travel and westward travel indicators remain statistically insignificant. This reinforces the interpretation that the relevant margin is not travel per se, but the direction of the time-zone transition, especially eastward travel.

4.3. Ability/Task Difficulty

Next, we examine whether the relative quality of the opponent moderates the effect of sleep loss. Teams may enter a game as favourites, underdogs, or face opponents of comparable strength.

TABLE 3 — Effect Heterogeneity by Player Origin and Eastward Travel Frequency

	(1) **US Players**	(2) **INT Players**	(3) **Low Eastward Exposure**	(4) **High Eastward Exposure**
Travel	0.0000	0.0009	0.0011	−0.0001
	(0.0014)	(0.0007)	(0.0021)	(0.0023)
Eastwards	0.0028**	0.0015*	0.0022	0.0065***
	(0.0014)	(0.0008)	(0.0022)	(0.0024)
Westwards	0.0010	−0.0004	−0.0034	0.0030
	(0.0014)	(0.0008)	(0.0025)	(0.0021)
Full set of controls	*yes*	*yes*	*yes*	*yes*
Observations (N)	264,212	264,212	139,843	124,369
R^2	0.014	0.014	0.019	0.020
Mean dep. var.	0.0555	0.0155	0.0699	0.0689

Notes: Columns (1) and (2) use outcome variables indicating whether at least one error in the inning was committed by a U.S.-born or internationally born player, respectively. Player origin is defined according to biographical information on players' country of birth, as provided by `Retrosheet.org`. Columns (3) and (4) split the sample by the cumulative frequency of eastward travel up to game g, using the sample median as the threshold. Standard errors are clustered at the team-game level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

The cognitive demands of competition are likely to vary depending on whether a team faces a stronger, similarly strong, or weaker opponent.

As outlined in Section 3.3, we proxy team strength using *Elo ratings*, which estimate team quality based on game outcomes and are updated after each match depending on the result and its ex ante likelihood. We use these ratings to compute ex ante win probabilities and divide their distribution into terciles (see Figure A.1 in Appendix A). We then re-estimate model (1) separately for each tercile of the focal team's win probability.

Table 4 presents the results. The adverse effect of eastward travel is most pronounced when teams face opponents of similar strength or when they are favourites (columns (2) and (3)). By contrast, the coefficient is smaller and statistically insignificant when the team is the underdog (column (1)). One possible interpretation is that, in games in which teams are underdogs, baseline task difficulty is already high, leaving less scope for an additional marginal effect of sleep disruption. In contrast, balanced or favourable matchups may require sustained concentration because small mistakes are more likely to be pivotal, making sleep-related impairments more visible.

5. The role of sleep loss

In this section, we further investigate whether the adverse effect of eastward travel is consistent with a sleep-loss mechanism. The previous analyses suggest that mental errors are not driven by travel per se, but by eastward transitions into later local time zones. A natural explanation is that

these transitions shift the next morning's schedule forward in body-clock terms and thus shorten the time available for sleep. However, sleep duration is shaped not only by wake-up time, but also by bedtime. If sleep loss is an important mechanism, then factors that compress recovery time after the previous game should also matter.

Building on this idea, we examine whether the duration of the previous game, $g-1$, moderates the effect of time-zone transitions. For teams playing on consecutive days, longer previous games reduce the time available for post-game routines, travel, rest, and recovery before the next game. This may amplify the performance consequences of eastward time-zone transitions.

Figure 8 presents estimates from our preferred specification of model (1) for samples restricted by increasingly high thresholds for the duration of game $g-1$. The first estimate includes observations for which the previous team game lasted more than 110 minutes, while the final estimate restricts the sample to observations for which the previous game lasted more than 190 minutes. The results show that the adverse effect of eastward travel remains positive across these increasingly restrictive samples, although the estimates become less precise as the sample of very long previous games becomes smaller.

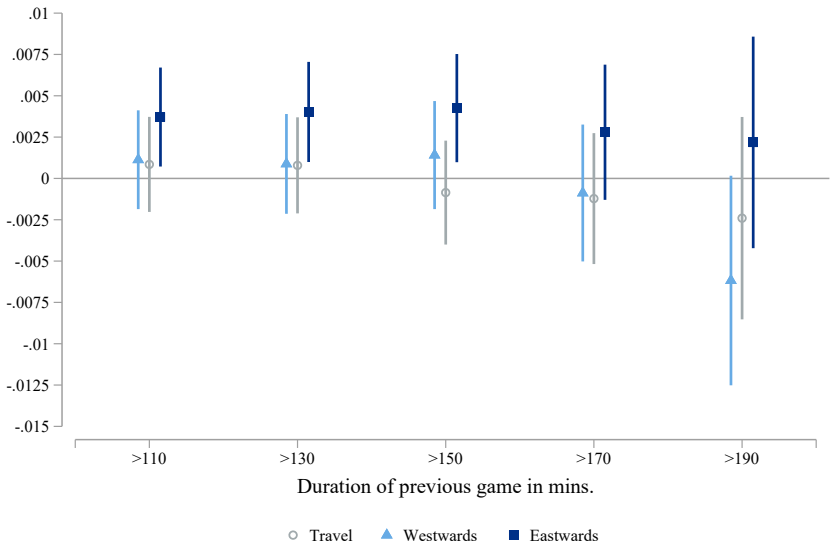
Interestingly, the point estimates for westward travel become negative when the previous game was particularly long, although they are imprecisely estimated. This pattern is consistent with the idea that gaining time is especially beneficial when recovery time is compressed by a late or long previous game. Although we do not observe sleep duration directly, these results provide additional evidence that the main eastward-travel effect operates through reduced recovery and sleep opportunities.

TABLE 4 — Effect Heterogeneity by Ability/Task Difficulty

	(1) T1 [0.24–0.47]	**(2) T2** [0.47–0.53]	**(3) T3** [0.53–0.76]
Travel	0.0023	−0.0013	0.0001
	(0.0033)	(0.0027)	(0.0025)
Eastwards	0.0037	0.0091***	0.0069**
	(0.0027)	(0.0029)	(0.0033)
Westwards	0.0022	0.0017	0.0020
	(0.0029)	(0.0028)	(0.0033)
Win prob.	0.0489	0.0477	0.0845
	(0.0597)	(0.0721)	(0.0638)
Elo	0.0000	0.0001	0.0000
	(0.0001)	(0.0001)	(0.0001)
Full set of controls	*yes*	*yes*	*yes*
Observations (N)	90,119	81,549	71,243
R^2	0.025	0.031	0.031
Mean dep. var.	0.0735	0.0701	0.0678

Notes: T1–T3 refer to the terciles of the team's ex ante win probability based on Elo ratings (see Figure A.1). Elo ratings are available for the seasons 1983–2021. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Standard errors in parentheses are clustered at the team-game level.

FIGURE 8 — Effect of prior game duration on error probability in back-to-back games



Notes: Estimates of model (1) and 95% confidence intervals. The estimation samples are restricted by increasingly high thresholds for the duration of the previous team game, $g - 1$, as indicated on the x-axis. The dependent variable is an indicator equal to one if the fielding team committed at least one error in the inning. Standard errors are clustered at the team-game level.

6. Conclusions

This study provides evidence that eastward time-zone transitions impair cognitive performance by reducing recovery and sleep opportunities. Using detailed Major League Baseball data spanning 1983–2024, we leverage schedule-driven variation in travel direction to isolate the role of circadian disruption in generating mental errors. The identifying intuition is that teams may travel comparable distances but face different local-time shifts: they may remain within the same time zone, lose an hour after travelling east, or gain an hour after travelling west. We find that eastward travel increases the probability of a mental error by about 0.53 percentage points, corresponding to 7.6% evaluated at the sample mean. With route fixed effects, eastward travel increases the probability of a defensive error by 0.37 percentage points relative to westward travel, equivalent to 5.2% of the sample mean. By contrast, westward travel and travel within the same time zone do not exhibit comparable effects. These results are robust across specifications and checks, including placebo tests, route fixed effects, and subsample restrictions.

A central contribution of our analysis is to disentangle age from experience as moderators of susceptibility to sleep-related performance declines. The adverse effect of eastward travel is concentrated among younger players and disappears when errors committed by this group are excluded, whereas analogous exercises based on tenure do not eliminate the effect. This suggests that age-related vulnerability, rather than accumulated experience alone, is the primary source of heterogeneity. We also find larger relative effects for internationally born players and stronger performance losses among teams with more frequent prior exposure to eastward travel, providing

no evidence of adaptation in these high-exposure settings. Further evidence is consistent with a sleep-loss mechanism: the eastward effect persists after long previous games, which compress recovery time before the next game, while the point estimates for westward travel suggest that gaining an hour may be beneficial when recovery time is especially constrained.

Beyond the sports domain, our findings have implications for organisations that rely on cross-time-zone coordination and frequent travel. In such settings, critical tasks, including high-stakes meetings, negotiations, or complex decision-making, may benefit from being scheduled with sufficient recovery time after eastward travel. Scheduling therefore represents a relatively low-cost organisational tool: avoiding cognitively demanding tasks immediately after eastward travel, or allowing an additional recovery window, may reduce preventable performance losses. The implications are particularly relevant for safety-critical and knowledge-intensive occupations, where small cognitive lapses can have disproportionate consequences. More broadly, sleep should be treated as a productivity-relevant input, and mitigation policies may be more effective when they account for age-related vulnerability rather than relying on experience alone. Organisations may also benefit from evaluating when physical travel is necessary and when high-stakes interactions can instead be shifted to virtual formats or scheduled after adequate recovery. At the same time, our setting does not allow us to observe sleep duration directly, so the sleep-loss mechanism should be interpreted as suggested by the pattern of results rather than directly measured. Finally, because MLB is a high-performance environment with strong incentives, extensive monitoring, and professional support, the estimated effects may represent a lower bound for performance impacts in less supported workplaces.

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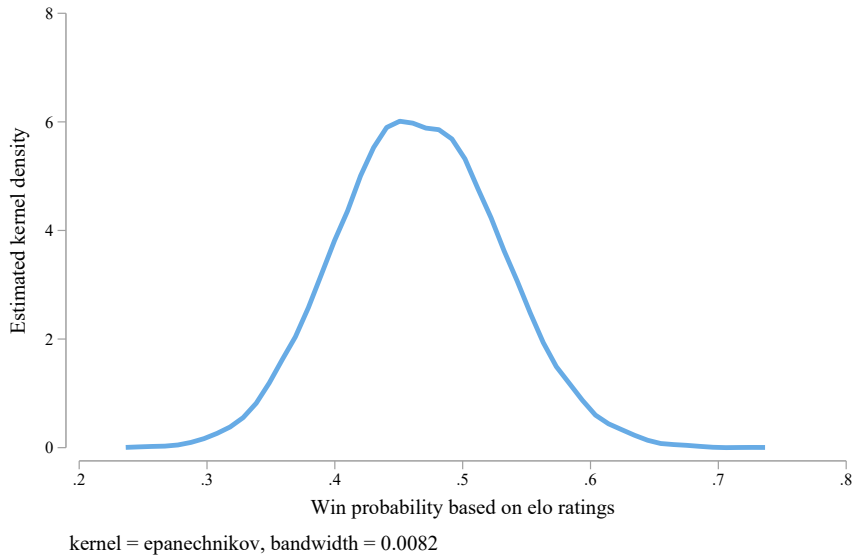
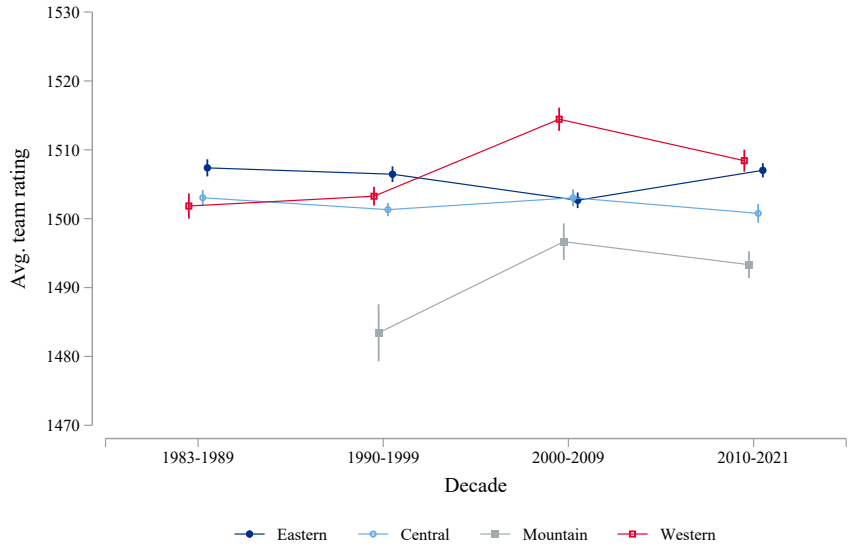
A. Additional Figures

FIGURE A.1 — Win probability based on the Elo rating system



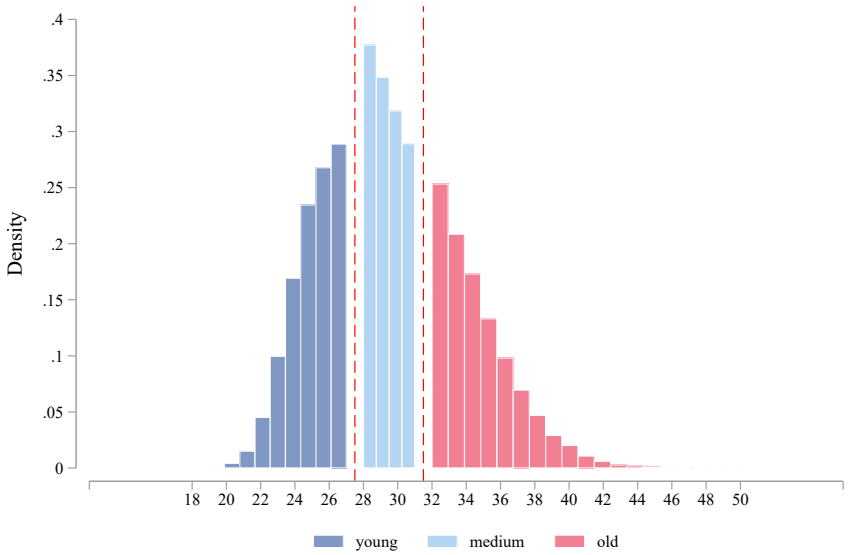
Notes: Distribution of ex ante win probabilities based on Elo ratings for all teams in games 1983–2021 in our data.

FIGURE A.2 — Team ratings grouped by time zones and decade



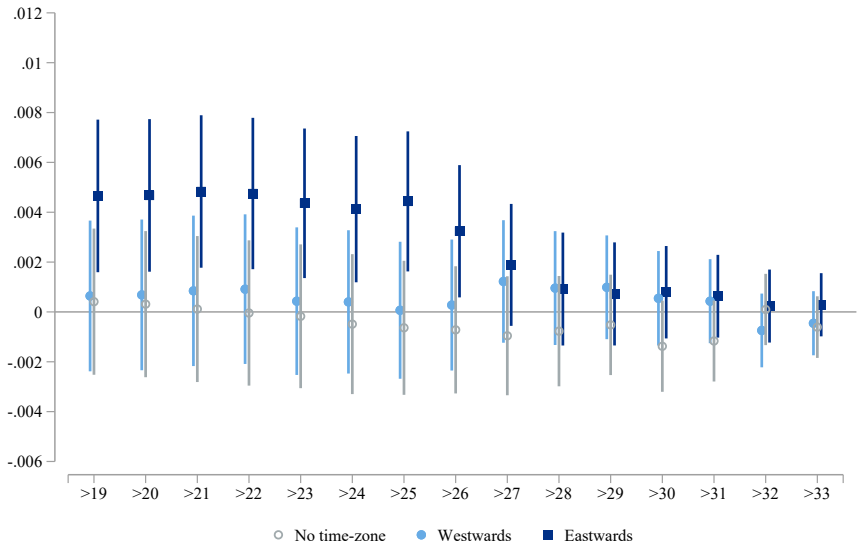
Notes: Average Elo ratings by time-zone region in our data, 1983–2021.

FIGURE A.3 — Age distribution



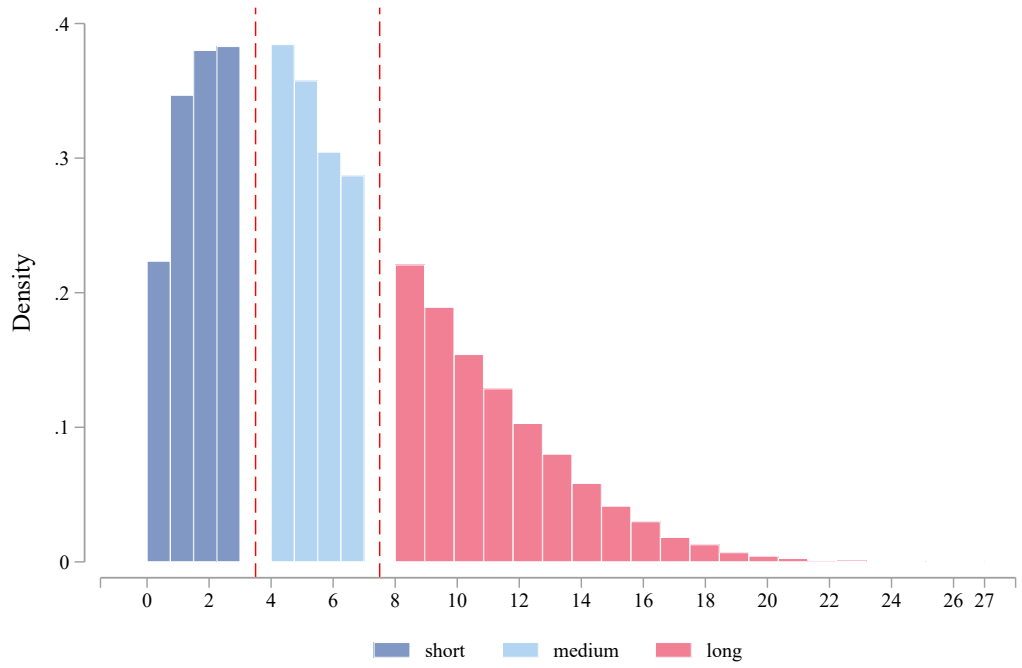
Notes: Age distribution of all players observed active during games in our data.

FIGURE A.4 — Effect heterogeneity: Age (robustness)



Notes: Estimates of model (1) and 95% confidence intervals. For each age threshold indicated on the x-axis, the dependent variable equals one if the fielding team committed at least one error in the inning attributable to a player older than the threshold, and zero otherwise. Standard errors are clustered at the team-game level.

FIGURE A.5 — Distribution of tenures



Notes: Distribution of tenure by all players appearing in the games of our data from 1983–2024. Tenure is measured as years in the big leagues, 0 indicating the rookie season.

B. Additional Tables

TABLE B.1 — Time-zone transitions and error rates

Panel A: Time gain/loss due to time-zone transitions

	P	**M**	**C**	**E**
P	0	-1	-2	-3
M	+1	0	-1	-2
C	+2	+1	0	-1
E	+3	+2	+1	0

Panel B: Mean error rates by time-zone transition

	P	**M**	**C**	**E**
P	0.074	0.075	0.077	0.088
M	0.068	0.063	0.074	0.072
C	0.076	0.071	0.072	0.078
E	0.081	0.074	0.077	0.075

Notes: Panel A shows the time gained or lost when travelling between MLB time zones. Panel B reports the mean error rates observed for each origin–destination time-zone pair. Rows denote origins, columns destinations. P = Pacific, M = Mountain, C = Central, E = Eastern.

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