Effect of Travel Stress and Physiological Training Load on In-Game Performance, Recovery, and Subjective Sleep Quality in NCAA DI Women's Basketball Athletes

by

River VanZant

(Under the direction of Dr. Michael D. Schmidt)

ABSTRACT

Recent NCAA DI conference realignment has created significant change to the geographic footprint of college athletics, with new large mega-conferences spanning multiple time zones, creating a connection of different regions of the country that have not historically been affiliated and creating a novel and impending dilemma of increased travel stress for NCAA DI student-athletes. The overall theme of this dissertation, separated into three studies, was to observe and report on travel-induced changes on items of recovery, sleep quality, and performance in a sample of NCAA DI Women's Basketball athletes. Further, travel stress (TS) was observed along with sport specific training load (TL) to dually report on the independent and combined effects of each independent variable.

The results of this dissertation would suggest a significant, negative association between chronic travel stress and subjective happiness in addition to significant negative associations between TL and subjective soreness and fatigue reported in Study I. Results from Study II suggest a detrimental association between the occurrence of a time zone change for a game and study team performance, such that games in a different time zone were more likely to be lost than games in their local time zone regardless of opponent quality. Study II also reported a significant negative association between accumulated TL on the day prior to a game and team free throw percentage. However, no significant interactions between TS and TL were observed on any measures of in-game performance in Study II. Finally, Study III also demonstrated that games played in a different time zone were significantly more likely to be lost over five seasons, supporting the results provided in Study II across a larger sample of games.

The combined results from each study would suggest that TS, specifically the occurrence of a time zone change for competition, is negatively associated with specific measures of recovery and performance in this sample of NCAA DI Women's Basketball athletes. In light of recent conference realignment, future research on the topic is warranted to better understand the effects of TS on measures of performance and recovery in NCAA student-athletes.

INDEX WORDS: Travel Stress, Performance, Recovery, Basketball, Training Load, Conference Realignment, Athletic Development, Sleep Quality

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DEDICATION

The work presented in this study is dedicated first to my family. Without your unrelenting support, I would not be the person I am today, let alone capable of pursuing and completing my Doctorate at such a prestigious university. I would also like to dedicate this dissertation to Joshua Rucci, who provided me the opportunity to work with UGA Athletics and provided immeasurable professional and moral support throughout the duration of my time as an intern for UGA Athletics. Your passion for advancing the field of sports science to better service not just your own athletes, but also those around the country, was the inspiration for this dissertation and all future work I do in the sports science field. Finally, I would be remiss to not dedicate this work to Josh Wildeman, who pushed me and encouraged me to pursue a doctorate in Kinesiology and believed in me at a time in which I certainly did not believe in myself. Your influence on my professional and personal development cannot be overstated.

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Chapter I

Introduction

1.1 Significance

The phenomenon of conference realignment in NCAA collegiate athletics is not a novelty, as major power players in NCAA Division I sports have decided to either forfeit their conference independence in the case of Penn State University joining the Big East Conference in 1990, or leave a longstanding conference affiliation to join a more financially lucrative and stable conference as the University of Arkansas did in joining the Southeastern Conference in 1991 (Havard, et al. 2023). In fact, in just the three-year period of 2010-2013, over 40 NCAA Division I schools changed conference affiliation (Havard, Wann, and Ryan, 2013). However, no prior shift in conference affiliation can rival the paradigm shift in the geographical footprint of NCAA Division I athletics set to begin in August of 2024. What was once five "power conferences" has been cut to four, with each of those four conferences acquiring new member institutions from regions outside of the longstanding geographical footprint of prior iterations of each conference. Further, three power conferences (the Big 10, Atlantic Coast Conference, and the Big 12) currently have member institutions that stretch from the Eastern time zone and the Atlantic Coast to the Pacific time zone and Pacific Coast (Havard, et al. 2023). While universities leaving their current conferences for the sake of greater annual revenue are in line for, reportedly, tens of millions of dollars more each year (Berkowitz, 2023), the effect of the newly imposed travel demands on the performance, well-being, and athletic development of NCAA Division I student-athletes has seemingly become an afterthought for those deciding which conference those student-athletes will be competing in, particularly for non-football sports that require more frequent travel over the course of their competitive season (Havard, et al. 2023).

Prior research has demonstrated the significant effects of frequent long-haul travel due to sport competition on sport-specific performance (Cook, et al. 2022, Charest, et al. 2021; Huyghe, et al. 2018; Pradhan & Alton, et al., 2021; Roy and Forrest, 2018; Staunton, et al. 2017; Thornton, et al. 2018; & Waterhouse, et al. 2004), injury risk (Teramoto, et al. 2017 & Von Rosen, et al. 2017), sleep quality and well-being (Fox, et al. 2021; Gupta, et al. 2016; Mah, et al. 2011; Ochoa-Lacar, et al. 2022; & Singh, et al. 2021), and athletic development (Abbott, et al. 2022; Chapman, et al. 2011; Murr, et al. 2023; Petway, et al. 2020; & Senbel, et al. 2022). More specifically, prior research on the effect of frequent, long-distance travel has demonstrated a significant challenge to maintain a synchronized circadian rhythm to the local 24-hour environment. This circadian challenge can present itself as either jet lag, when travel involves a change of one or more time zones, or travel fatigue, which is defined as the summation of physiologic, psychologic, and environmental factors that accrue during a single instance of travel, with travel fatigue accumulating as travel frequency increases over a competitive season (Samuels, et al. 2012; Waterhouse, et al. 2004). Athletes experiencing jet lag have reported symptoms that range from episodic disturbances in gastrointestinal health, sleep disturbance, intermittent fatigue, and impaired cognitive function as a result of circadian desynchronization, with symptoms tending to be resolved with circadian resynchronization at a rate of one day per time zone traveled. On the other hand, travel fatigue accumulates over longer periods of time, and has been characterized by persistent fatigue, onset or recurrence of illness, changes in mood state and behavior, and loss of motivation (Samuels, et al. 2012).

Despite differences in the onset and symptomology of travel-induced jet lag or travel fatigue, prior research indicates that both jet lag and travel fatigue have the potential to affect various aspects of exercise performance, including but not limited to dynamic strength (Edwards, et al. 2000; Leatherwood & Dragoo, 2012; Wright, et al. 1983), anaerobic capacity (Fowler, et al. 2014b), grip strength (Reilly, et al. 2000; Edwards, et al. 2000; Lemmer, et al. 2002), countermovement vertical jump (CMJ), (Atlag & Gotshalk, et al. 2023; Chapman, et al. 2011; Fowler, et al. 2017; Kraemer, et al. 2016), agility and maximal speed (Kraemer, et al. 2016; Leatherwood & Dragoo, 2012), and aerobic performance (Leatherwood & Dragoo, 2012). Additionally, prior research suggests a consistent, detrimental effect of frequent, long-distance travel on sport-specific in-game performance, sleep quality, and indicators of recovery for athletes competing in the professional sports of American football (Taylor, et al. 2016), hockey (Roy & Forest, 2018), basketball (Charest, et al. 2021; Glinski & Chandy, 2022; Leota, et al. 2022; Roy & Forest, 2018; Staunton, et al. 2017), soccer (Fowler, at al. 2014a; Hands, et al. 2023), rugby (McGuckin, et al. 2014) and Australian Rules Football (Richmond et al, 2007). Inversely, there is significantly less research available on how travel stress might affect NCAA student-athletes, particularly women's basketball athletes, with the available evidence supporting a negative association between increased travel stress and winning percentage, total points scored, and shooting efficiency in NAIA women's basketball athletes (Pradhan & Alton, 2021) and reductions in health markers such as resting heart rate, blood pressure, and salivary cortisol in addition to reductions in isokinetic leg strength and countermovement jump performance during phases of the season in which frequent travel occurs in NCAA DI women's basketball athletes (Atalag & Gotshalk, 2023).

While prior research suggests a consistent, negative effect of travel on performance and recovery in elite athletes, significant gaps in the current literature exist on how travel demands might affect NCAA student-athletes, particularly NCAA Division I Women's

Basketball student-athletes. These gaps include the effect of travel stress on in-game statistical efficiency, GPS-measured movement quality, sleep quality, recovery, and subjective wellness. In addition, very little research has been conducted on how travel stress might interact with, or exacerbate, detrimental effects of sport-specific training load, which is customary to student-athletes participating in NCAA DI Women's Basketball. The focus of this dissertation is to assess the effect of travel on measures of in-game performance, movement quality, physical readiness, and subjective recovery in this population, and to quantify the potential moderating effect of cumulative physiological load on the effect of travel stress in a population of NCAA DI Women's Basketball athletes competing in the Southeastern Conference during the 2023-2024 competitive season.

1.2 Primary Aims

Study 1. Assessing the Effect of Travel Stress and External Training Load on Sleep Quality, Mood States, and Physical Readiness in NCAA Division I Women's Basketball Athletes over the course of a Competitive Season.

Aim 1. To observe the independent effects of travel stress and external training load on changes in subjective sleep quality that occur among student-athletes over the course of their competitive season. Specific questions include 1) whether increases in travel-related stress results in adverse changes in sleep quality, and 2) whether elevations in GPS-measured external training load exacerbate travel-related changes in subjective sleep quality.

Aim 2. To observe the independent effects of travel stress and external training load on changes in physical soreness and fatigue and/or mood states over the course of the competitive season.

Aim 3. To observe the independent effects of travel stress and external training load on changes in vertical jump performance over the course of the competitive season. In particular, how specific indices of jump performance, such as peak power relative to body mass, the ratio of flight time to contraction time, and concentric peak force relative to body mass, might be affected by the independent or combined effects of travel stress and external training load.

Study 2. Investigating the Effect of Travel Stress and Cumulative External Training Load on Basketball Performance and GPS-measured Performance Quality in NCAA DI Women's Basketball Athletes.

Aim 1. To observe the independent and combined effects of travel stress and external training load on changes in basketball-related performance, via the Player Efficiency Rating (PER), end-game scoring margin, and team field goal, three-point, and free throw percentage over the course of the season.

Aim 2. To observe the independent and combined effects of travel stress and external training load on changes in GPS-measured performance quality, via Catapult's proprietary "Performance Quality Metric" (PQM).

Study 3. Assessment of the association between travel stress and basketball-specific statistical performance over a five-year period in NCAA DI Women's Basketball Athletes.

Aim 1. To describe the association between travel stress and team efficiency statistics and end-game scoring margin throughout over the course of five competitive seasons.

Aim 2. To describe the association between travel stress and shooting-specific basketball statistics (e.g., field goal percentage, three-point percentage, and free throw percentage) over the course of five competitive seasons.

1.3 Sports Science Significance

There is currently a lack of research on the independent and combined effects of travel stress and sport-related training load on the performance, recovery, and well-being of elite, female athletes competing in NCAA DI athletics. Additionally, the topic is of current interest as the landscape of collegiate athletics begins to come into form following a large shift in conference affiliation through the most recent phase of conference realignment. This lack of research could be due to either a lack of access for researchers to the student-athlete population or a lack of research interest with this particular population of student-athletes at the NCAA DI level of athletics. An additional reason might also be that researchers who are interested in the topic might be lacking the validated, objective measures of performance, recovery, or training strain that might make research in this area more feasible. Regardless of the cause for the lack of quantity of research on the topic, this dissertation will seek to fill the current knowledge gaps by combining multiple measures of performance and recovery to understand the influence of travel stress and physiological training load on NCAA Women's Basketball athletes competing in the Southeastern Conference. More importantly, perhaps, this study hopes to provide evidence to guide sport coaches and performance personnel on how to best approach upcoming in-season travel to maximize the performance and recovery of athletes under their direction. For example, practitioners could modify their travel plans to minimize travel-related jet lag by arriving at their destination early enough for circadian resynchronization to begin in their new local environment. Further, if time-zone travel is eminent, practitioners could begin to schedule practice and training sessions that align more with the time zone of the competition site to begin the process of circadian phase advance or delay. In sum, research in this area will help guide sport coaches or performance personnel to make informed decisions to offset any potential performance decrements associated with either acute or chronic travel stress.

1.4 Limitations

A primary limitation of this study is its observational design, with the inability to control for confounding variables that could influence changes in any of the primary outcomes observed, such as nutritional status, body composition, or inter-personal factors that could affect individual or team performance. Additionally, data collection for most measures did not follow a consistent schedule, with all subjective assessments and some objective measures dictated by the weekly schedule of the women's basketball program. Another noted limitation of this study is the small sample size; therefore, findings from this study should be replicated on a larger scale to confirm their generalizability. Further, this study utilized a subjective questionnaire to assess several outcome measures related to recovery, mood states, and sleep which requires honesty and consistency on behalf of the participant for data analyses to carry any practical significance. This study was also conducted on a group of women's basketball athletes competing for a "Power Conference" university, which undoubtedly provides resources related to performance, recovery, and travel accommodations that do not exist at universities that may not operate on the same platform financially. Finally, this study only included subjective measures and countermovement jump performance over the course of one competitive season whereas other measures in the study, such as team efficiency rating, end game scoring margin, and shooting percentages, were extended to look at trends over the past five competitive seasons. Therefore, subjective measures of recovery and mood state and countermovement jump performance might lack external validity because they reflect only this small subset of the NCAA DI Women's Basketball population.

1.5 Delimitations

This study was delimited to NCAA Women's Basketball student-athletes competing for the University of Georgia over the course of the 2023-2024 season for all subjective measures related to sleep, mood states, measures of subjective recovery, and countermovement jump performance. Non student-athletes were not included in this study as well as student-athletes participating in other sports at the university.

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Chapter 2

The Effect of Travel and Sport-Specific Training Load on Items of Recovery and Performance in Athletes: A Review of Literature

2.1 Introduction

The following section of this dissertation involves a review of literature of the various subtopics addressed or measured within each study. For each subtopic, an emphasis will be placed on the two main variables of travel stress and sport-specific training load on outcome measures of performance, recovery, and health on athletes. Subtopics addressed in this review of literature include the effect of travel on exercise, sports, and basketball-specific performance, as well as the effect of travel and sports participation on items of sleep quality and psychometric properties in athletes. Further, this review will also address the concept of using countermovement jump (CMJ) performance to monitor fatigue and adaptation in athletes and how travel and sports-specific training stress might influence CMJ performance. Finally, this review will address the two items of sports-specific training load (TL) on sleep, psychometric properties, physical readiness, and performance and the effect of circadian rhythm or chronotype on sports-specific performance. Upon conclusion, this review will address gaps in the current literature and provide suggestions for future research on the topic of travel stress and sport-specific TL on performance and recovery in NCAA DI Women's College Basketball athletes and address ways in which this dissertation will seek to address current knowledge gaps in this field of research.

2.2 NCAA DI Conference Re-Alignment: Justification and Implications

NCAA Division I (DI) collegiate athletics will enter a new era beginning in the fall of 2024, as recent conference expansion and realignment will shift the geographic landscape of collegiate athletics from a collection of regionally similar conferences a collection of "power" and "non-power" conferences who's borders stretch further than once thought possible (Russo, 2023). And while the concept of a university changing its conference affiliation is not a novel one (Havard, et al. 2023), it's rather the sheer magnitude of the total number of universities changing conference allegiance over the past decade, with over 40 NCAA DI institutions changing conference affiliation over just the three-year period of 2010-2013 (Havard, Wann, and Ryan, 2013) and over two dozen schools set to change conferences from the '23-'24 to '24-'25 academic years alone (Hawkins, 2023).

On a macro, fiscal-level, the justification for conference realignment for universities either moving into a major conference or moving from a smaller tier major conference into a financially more lucrative conference is clearly understood, with member institutions of the Big Ten and Southeastern (SEC) Conferences expecting annual payouts potentially exceeding $70 million in the coming years. Further, new and current member schools of the other two current power conferences, the Big 12 and Atlantic Coast Conference (ACC), hope to build on the $42-45 million and $37-$41 million, respectively, reportedly distributed in the 2022 fiscal year (Russo, et al. 2023). However, while revenue appears to be the sole, driving factor for the paradigm shift in Division I collegiate athletics, this shift has created an ensuing novel challenge for NCAA DI student-athletes competing within these redesigned power conferences as it relates to the frequency and magnitude of travel to be expected during the in-season phase of all sports teams representing universities at this level. To underscore this point, the four new members of the Big Ten Conference, each residing on the west coast of the United States and in the Pacific Time Zone, are collectively no closer than 1,500 miles to any of their new conference opponents residing mostly in the Great Lakes and northeastern regions of the United States (Russo, 2023), with similar changes made to the structures of both the Atlantic Coast Conference and the Big 12 Conference. Thus, at the power-conference level, the regional aspect of collegiate athletics has been replaced by a more national, bi-coastal nature of the North American professional sports model seen in the NFL, NBA, MLB, and NHL. And while the intent of increasing annual revenue per school has been met for many relocating institutions, the sheer size of the footprint of the new NCAA DI "power" conferences would highlight the impending increase in travel-related stress as it relates to the magnitude of travel for many NCAA DI student-athletes competing away from their home location within their own conference.

2.3 Effects of Travel on Exercise, Sports, and Basketball-Specific Performance

Effect of Travel on Exercise Performance

While a feature of elite sport participation, especially within the realm of NCAA collegiate athletics, long-distance travel has demonstrated to contribute to ensuing symptoms that can be broadly defined as "travel fatigue" or "jet lag" if the travel consists of crossing several time zones (Waterhouse, et al. 2004). Further, the concept of travel fatigue can be viewed though the lens of the summation of physiologic, psychologic, and environmental factors that accrue during a single instance of travel, accumulating over a larger period of time such as a competitive season in the sports context (Samuels, et al. 2012). Jet lag has shown to manifest as episodic disturbances in gastrointestinal health, sleep disturbance, intermittent fatigue, and impaired cognitive function as a result of circadian desynchronization and symptoms tend to resolve with circadian resynchronization at a rate of one day per time zone traveled. On the other hand, travel fatigue accumulates over longer periods of time, and has been characterized by persistent fatigue, onset or recurrence of illness, changes in mood state and behavior, and loss of motivation (Samuels, et al. 2012). Despite differences in the onset and symptomology of each, prior research would demonstrate that both jet lag and travel fatigue have the potential to affect various aspects of exercise performance (Atlag & Gotshalk, et al. 2023; Chapman, et al. 2011; Edwards, et al.

2000; Fowler, et al. 2014; Fowler, et al. 2017; Kraemer, et al. 2016; Leatherwood & Dragoo, 2012; Lemmer, et al. 2002; Reilly, et al. 2000; Wright, et al. 1983).

As it relates to jet lag, prior research has demonstrated the effect of acute, long-haul travel on dynamic strength (Edwards, et al. 2000; Leatherwood & Dragoo, 2012; Wright, et al. 1983), anaerobic capacity (Fowler, et al. 2014), grip strength (Reilly, et al. 2000; Edwards, et al. 2000; Lemmer, et al. 2002), countermovement vertical jump, or CMJ, (Atlag & Gotshalk, et al. 2023; Chapman, et al. 2011; Fowler, et al. 2017; Kraemer, et al. 2016), agility and maximal speed (Kraemer, et al. 2016; Leatherwood & Dragoo, 2012), and aerobic performance (Leatherwood & Dragoo, 2012). In more detail, a study conducted with healthy, male soldiers aged 18-34 (n = 81), demonstrated significant reductions in dynamic knee extensor and elbow flexor strength and endurance following travel across multiple time zones, while cardiorespiratory function remained unaffected (Wright, et al. 1983). A more recent review on air-travel and performance highlighted the post-travel acute effect on circadian synchronization, characterized by reductions in leg strength, back strength, and elbow flexor strength among other items of aerobic and anaerobic performance (Leatherwood and Dragoo, 2012). Fowler, et al. 2017 also demonstrated a significant effect of travel, particularly eastward travel, on maximal and intermittent sprint performance and peak force during CMJ assessment (Fowler, et al. 2017). This collection of research would point to a fairly consistent negative effect of acute travel demands on ensuing performance until circadian resynchronization can occur, often within a few to several days after the travel occurs (Samuels, et al. 2012), which could significantly affect performance in NCAA DI student-athletes, particularly with the future changes to travel demands in-season due to pending conference realignment.

Effect of Travel on Sports Performance

Research on how travel might affect sport-specific performance largely resembles that of the aforementioned studies on travel and exercise performance, with perhaps the latter association between travel and negative effects on exercise performance contributing to similar associations between travel and sports performance. Early attempts to quantify the effects of travel on sports performance observed the direction of travel and number of time zone changes in NCAA College Football teams, and found that teams traveling across one or more time zones, particularly if traveling eastward, scored less points, allowed more points, and had a worse margin of end game score than teams not traveling or teams traveling westward (Worthen & Wade, 1999). Contrary to collegiate football, a similar attempt to assess performance in response to travel in professional sports found that time zone change, particularly with westward travel, led to significantly lower winning percentages over five years of games in the NBA and NHL, with trends also observed in the NFL (Roy & Forest, 2018). These contradicting results might be due to differences in the scheduling of games at the collegiate and professional level, with more frequent night competitions in professional sports causing a circadian phase delay when athletes compete one or more time zones westward from their home location (Roy & Forest, 2018). Taylor, et al. (2016) used a 4-component model labeled as an "aggregate stress model" to try to delineate the combined effect of distance traveled, direction of travel, frequency of consecutive away trips, and frequency of away trips over a month on the constructs of team task performance (concentration-based penalties) and counterproductive work behavior (aggression-based penalties) over five years of NFL games between 2009-2014. Results demonstrated that all components of aggregate travel stress were negatively and significantly associated with team task performance, with total distance traveled for away games having the largest statistical relationship among the 4-component model (Taylor, et al. 2016). This collective literature on thousands of sporting contests across multiple leagues and different levels of sports participation would indicate a consistent, negative relationship between travel and sport-specific performance, with distance traveled, direction of travel, and timing of competition all listed as potential contributing factors.

To further highlight this association, other attempts to measure or observe the effects of travel on sport-specific performance include several case studies across various sports, with results supporting the association between travel and reduced in-game performance. Research on professional soccer athletes has shown that short-haul domestic air travel for away matches has a significant negative effect on competition points accumulated and goals conceded in away v. home matches (Fowler, at al. 2014a) and greater high speed and very high speed running activity in home v. away short-haul or long-haul matches (Hands, et al. 2023) while research with rugby athletes (McGuckin, et al. 2014) demonstrated reduced cognitive performance and increased perceived stress following air travel for professional competitions. Another study on travel and sports performance observed the effect of interstate domestic travel on the performance of elite Australian Rules Football athletes, and demonstrated a reduced rating of performance by coaches and lower "impact ranking" in away matches v. home matches, which was partially explained by reduced perceived sleep rating on nights prior to away matches compared to nights prior to home matches (Richmond et al, 2007). One interesting observation for each of these studies with elite, professional athletes is the absence of time zone change or direction of travel discussion on their findings, perhaps supporting the fact that sports performance can be impaired by travel in the absence of time zone change and regardless of travel direction.

Effect of Travel on Basketball Performance

While research on the effect of travel and sports performance consists of a wide variety of sports observed, basketball performance has received a lot of research attention; however, this attention exists almost exclusively at the professional level of the sport. An early attempt to measure the effect of travel on NBA teams from 1987-1995 reported few consistent effects between in-game performance by NBA athletes and either the distance traveled by a team or the direction of travel, but did note the potential for a circadian disadvantage for away teams traveling eastward one or more time zones as teams traveling under these conditions scored fewer points per game than the home team or teams traveling westward (Steenland & Deddens, 1997). A more recent review on the effect of travel distance and direction on NBA game outcomes from 2013-2020 disputed this finding, reporting that distance traveled did play a significant role in game outcome (win/loss), with each additional 300 miles of travel, or 500 kilometers, significantly reducing the likelihood of winning by 4% ($p = .038$) for teams traveling back home for a second game of a back-to-back game sequence while also reporting that eastward travel significantly increases chance of winning ($p = .024$) compared to westward travel when teams competed in an away game in a different time zone (Charest, et al. 2021).

A retrospective review on NBA performance from 2011-2021 by Leota, et al. 2022 supported the findings of Charest, et al. 2021 by demonstrating a reduced winning percentage ($p = .051$) for NBA teams and athletes experiencing eastward (but not westward) jet lag, in addition to worse point differential ($p = .015$), rebound differential ($p < .0001$), and effective field goal percentage differential ($p < .01$), with negative effects on point differential directly associated with the magnitude of eastward jet lag (Leota, et al. 2022). A similar retrospective analysis attempted to measure the effect of jet lag on free throw shooting percentage in NBA athletes over 48,309 games, with over 675 of those games meeting the condition of jet lag, with results demonstrating a slight, significant decrease in free throw shooting percentage ($p = .02$) when conditions of jet lag were met for teams traveling from west to east but not the inverse (Glinski & Chandy, 2022). Staunton, et al. 2017 provided insight as to why the association between reduced statistical performance in basketball athletes under conditions of high travel stress might exist, demonstrating a positive relationship between total sleep time and player efficiency rating (PER), with total sleep time reduced during congested match play during a competitive season for elite Australian female basketball athletes (Staunton, et al. 2017). Finally, the current literature on travel stress in professional basketball athletes also included two attempts to quantify risk for injury in NBA athletes. Teramoto, et al. 2017 observed injury risk and frequency over three seasons of NBA games, and reported that a congested competition schedule alone, such as playing games on back to back days or playing four games over five days, was not associated with increased risk of injury whereas playing games away from home presented a stronger risk factor for injury, particularly if multiple away games occur over a condensed time period (Teramoto, et al. 2017). A similar review on the effect of air travel and health and performance in NBA athletes underscored the association between injury risk and away games, with short-haul travel across time zones, which is inherent to the travel schedule of NBA teams, demonstrating a consistent increase in injury risk and performance reduction with travel fatigue, with mild hypoxia during flights, prolonged sitting in cramped space, and disruption of normal sleeping and eating routines all listed as potential contributing factors to exacerbate accumulated travel fatigue (Huyghe, et al. 2018).

The collection of literature on how travel stress during a competitive season might influence performance and health of NBA athletes would indicate a consistent, negative association between travel and performance in this population of athletes. However, similar attempts to assess performance or health under conditions of increased travel stress have not been performed at the same volume at the collegiate level, particularly with NCAA Women's College Basketball athletes. A review on the scheduling model of NCAA DI basketball programs by Watkins, 2013 provided descriptive data on the distribution of away games, and subsequent travel demands, reporting that 75-80% of non-conference games at the beginning of the season were played at home for NCAA DI teams competing in the Big 12 conference, while only 50% of games are played at home during the back half of the season during inter-conference play. The review of game performance for home v. away games over two seasons of teams competing in the Big 12 went on to report that home teams won, on average, 86% of games during the non-conference portion of the season and 67% of games during the conference portion of the season, indicating the presence of a noticeable home-court advantage despite a greater level of competition and travel stress during conference play. Further analysis was performed and reported on the effect on the number of miles traveled and game outcome (win/loss) with no significant effect of total miles traveled on game outcome, and no differences found between short, moderate, or long-haul trips by number of miles traveled to compete on game outcome (Watkins, 2013). One potential limitation to these results and how they might apply to the current NCAA DI college basketball landscape is the fact that the study observed two seasons of data for the Big 12 Conference prior to any sizable conference realignment over the course of the past decade (2013-2024), with all but one school located in the central to south central United States and within the same time zone (U.S. Central), with the one outlier residing in the Mountain Time zone (Sports Reference, 2023). Therefore, these findings might understate the new travel demands on college basketball athletes and have less external validity to the current status of NCAA DI conference geography, as that same conference (Big 12) has seen up to six schools leave over the last decade and have added eight new member institutions from 2023-2024 alone, with current members stretching from Morgantown, WV (West Virginia University) to Phoenix, AZ (Arizona State University) and including all four time zones in the continental U.S. (Bender, 2023).

With that said, one item of the study from Watkins, 2013 that still remains in the present state of college basketball is the scheduling structure, with teams in power conferences still playing a large percentage of games in the first half of the season at home and backloading a lot of the in-season travel in the conference portion of the season. In light of changes to the structure of all NCAA DI conferences with conference realignment, a follow-up on how the new travel demands of college basketball might affect items of performance and recovery is warranted, but few attempts to do so exist. A more recent retrospective study performed on ten years of National Association of Intercollegiate Athletics (NAIA) Women's Basketball performance found that teams scored significantly more points ($p = .03$) and won more games ($p = .04$) when traveling fewer miles away from their home city, as well as having better field goal shooting percentages with more days in between games (Pradhan & Alton, 2021). Additionally, a study with NCAA DI Women's Basketball athletes ($n = 51$) observed the effects of in-season travel and competition on performance and health, and demonstrated significant, negative changes in resting salivary cortisol, heart rate, blood pressure, and visceral trunk fat compared to a group of controls, while also showing a reduction in isokinetic force of leg muscles and CMJ performance during periods of the season in which there was a congested travel schedule and an increase in frequency and magnitude of air travel (Atalag & Gotshalk, 2023). While each study with women's basketball athletes provide support on the effect of travel on performance and health of this population, there exists a gap in the current literature on whether or not this association exists at the NCAA DI level of women's basketball.

2.4 Effect of Elite Sports Participation on Sleep Quality and Relationship Between Sports-Specific Travel and Sleep, and Effect of Sleep on Sports Performance

Sleep Quality Assessment and Review in Elite Athletes

The current literature on sleep quality assessment in athletes and how it might affect performance would indicate that sleep quality, as a construct, is poorly defined and lacking a consistent criterion measure. In a meta-analysis of sleep quality assessment in athletes, Claudino, et al. 2018 reviewed over seventy studies regarding sleep quality assessment in athletes from 1994-2017, and reported over thirty different assessment tools, consisting of actigraphy, insomnia-based subjective questionnaires, custom questionnaires, and polysomnography. The meta-analysis also sought to understand the sensitivity, level of instability, reliability and efficacy of tools for monitoring sleep quality in team sport athletes, with results demonstrating that four objective measures of actigraphy, including sleep efficiency, sleep onset latency (SOL), wakeful bouts after sleep onset (WASO), and total time of waking bouts, all demonstrating validity of sleep assessment with moderate effect sizes and low coefficient of variation (CV). Further, six subjective items of sleep quality assessment demonstrated moderate to large effect sizes with low CV, including items from the Pittsburg Sleep Quality Index (PSQI), RESTQ-Sport, Liverpool Jet Lag Questionnaire (LJLQ), and Likert Scales based on the Hooper Index (Claudino, et al. 2018). Results from this comprehensive review of the literature as it relates to sleep quality assessment in athletes would indicate a need for future attempts to better understand the construct of sleep quality and to assess the components of sleep quality, either objectively or subjectively, with evidence-based tools to better describe the nature of sleep quality in this population.

In an attempt to describe the presence of insomnia symptomology in elite sport athletes, Gupta, et al. 2016 conducted a systematic review of thirty-seven studies with the purpose of better understanding whether participating in elite sport might lead to reduced sleep quality. Among the main findings, as addressed by Claudino, et al. 2018, was that the evidence-base addressing sleep quality in athletes is low, with "poor operationalization of sleep quality constructs and few controlled comparisons of athlete and non-athlete sleep" (Gupta, et al. 2016). However, even while acknowledging the limited number of high-quality evidence available in the literature, results of the systematic review would indicate that elite athletes demonstrate a high prevalence of insomnia symptoms, characterized by longer sleep latencies, greater sleep fragmentation, lack of restorative feeling upon waking, and excessive daytime fatigue. Further, sub-groups among the population of elite athletes seem to present worse sleep quality, with women's sports, compared to male sport equivalents, solo sports, compared to team sports, and aesthetic sports, such as ballet and gymnastics, more susceptible to insomnia-like symptoms. Finally, the review highlighted in-season competitions, particularly night competitions, congested travel schedules, and early morning training sessions as the most significant contributing factors to reducing sleep quality in elite sport athletes (Gupta, et al. 2016). With that said, two notable limitations to the review of literature by Gupta, et al. 2016 include a lack of discussion regarding athlete chronotype, which was summarily addressed as a limitation by the authors, and the lack of differentiation of NCAA student-athletes from other elite sport athletes, who experience the added scholastic responsibilities for sport participation. These noted gaps in the literature, in addition to the excessive travel stress caused by recent conference realignment, would highlight the need for future research to feature the NCAA student-athlete population to better understand how sleep quality is affected by participation in NCAA collegiate athletics.

In a cross-sectional study of more than 600 student-athletes at Stanford University, Mah, et al. 2018 added some insight as to how sleep quality can be generally described in elite level NCAA DI athletes. Using a modified Pittsburgh Sleep Quality Index (PSQI) questionnaire to provide a global score for sleep quality and Epworth Sleepiness Scale (EPS) to measure daytime sleepiness and dysfunction, student-athletes in this study reported on sleep items such as sleep duration, sleep onset latency, sleep disturbances, and subjective sleep experience. Responses to each questionnaire contributed to a global PSQI score that created a dichotomous variable to distinguish poor sleepers (PSQI Score > 5) from good sleepers and a continuous variable score from the EPS, with higher scores indicating more daytime sleepiness. Additionally, Mah, et al. 2018 assessed for sleep quality differences at home or on-campus v. during travel for away competitions using custom Likert-based questions regarding overall fatigue, difficulty waking up, routines and napping habits, and sleep environment disturbances. Results were pooled for analysis by sex, age, and sport affiliation, with results demonstrating that, on the whole, student-athletes in this study were classified as poor sleepers (PSQI Mean = 5.38), reported inadequate sleep duration (<7 hours), and that over half of student-athletes surveyed reported excessive daytime sleepiness with EPS Scores greater than 10 (Mah, et al. 2018).

Interestingly, and perhaps contrary to prior expectations, student-athletes in the Mah, et al. 2018 study reported significantly better sleep quality ($p<.001$) away from home when traveling for competition than they experienced at home, with potential contributing factors reported as environmental noise and disturbances by roommate(s). Additionally, the two sports reporting the worst sleep quality, on average, were the sports of women's lacrosse and men's wrestling, somewhat contradicting the summary from Gupta, et al. 2016 which highlighted female, aesthetic, solo sports as the most likely to suffer from poor sleep quality (Gupta, et al.

2016; Mah, et al. 2018). While Mah, et al. 2018 provides much needed insight as to the nature of sleep quality of NCAA DI student-athletes, there are potential gaps in this study that could be addressed with future research. First, as opposed to a one-time questionnaire, a longitudinal assessment of sleep quality during a competitive season to better parse out how sleep quality might be sensitive to acute travel demand or accumulated travel load is warranted, as results from Mah, et al. 2018 might be more of a reflection of one's perception of sleep quality during travel with only one assessment when travel wasn't taking place. Further, the study reported that sleep quality assessments took place during the 2011-2012 academic year which, while not a limitation, was before the notable shifts in conference affiliation could influence the nature of travel in this population. Finally, one notable limitation is the lack of assessment of athlete chronotype to better describe how diurnal rhythms or preference might influence the sleep experience in NCAA DI student-athletes. This dissertation, while smaller in sample size and sample diversity by sport, will look to identify the acute and chronic effects of congested travel while also addressing athlete chronotype as a potential moderating factor to sleep quality in NCAA DI student-athletes.

Effect of Sports-Specific Travel on Sleep

The effect of travel related to sport competition on items of sleep has been thoroughly reviewed, with potential explanations on how travel might affect performance by means of disrupted sleep and circadian desynchronization (Samuels, et al. 2012; Waterhouse, et al. 2004; Youngstedt & O'Connor, 1999). In a review of literature and discussion on the impact of air travel on athletic performance through the lens of the jet lag performance hypothesis, Youngstedt & O'Connor, 1999 described potential changes in sleep quality and circadian rhythm synchronization that could occur with rapid transmeridian air travel. While the review described the lack of quality evidence to support the jet lag performance hypothesis, the authors noted the definitive evidence on the effect of extensive travel on sleep quality and mood following transmeridian flight, citing the clear circadian desynchronization between the circadian system and the sleep-wake cycle resulting in impaired sleep. One noted limitation to the review of prior literature on sleep quality was the lack of practical application to many sleep deprivation studies conducted, often consisting of 24-72 hours of sleep deprivation, and actual sleep disturbances experienced by athletes which do not resemble that of true sleep deprivation (Youngstedt & O'Connor, 1999), which, therefore, would suggest the need for research to more closely observe the sleep disruption potentially encountered by athletes to better understand how travel then might affect athletic performance by means of sleep degradation in this population.

Two more recent reviews (Waterhouse, et al. 2004) on the effect of travel on items of sleep and subsequent performance would support the physiological rationale provided by Youngstedt & O'Connor, 1999. Waterhouse, et al. 2004 described the general symptoms of both travel fatigue and jet lag due to transmeridian travel across time zones, and documented the disturbance to the sleep-wake cycle causing excessive fatigue during the day and inability to sleep at the local nighttime associated with circadian desynchronization. These symptoms are noted in the review of literature in addition to, or directly leading to, less concentration and motivation, decreased mental and physical performance, and increased headaches and irritability (Waterhouse, et al. 2004). Further, Samuels, et al. 2012 provided a review of travel fatigue and jet lag literature for the purpose of creating a travel management plan, and also noted the marked sleep disturbance associated with multiple time zone travel, as well as other physiological and psychological parameters that require circadian re-entrainment at the rate of one day per time zone to resolve (Samuels, et al. 2012). This collective review of literature would emphasize the effect of travel-related stress and jet lag on items of sleep quality by means of circadian desynchronization and travel fatigue which, in turn, could potentially reduce sports-specific performance.

Several case studies have observed changes in sleep parameters due to in-season sports competition travel, with most demonstrating a change in sleep behavior due to travel. One such study used both objective measures of actigraphy and subjective scoring (sleep rating scale) to describe the effect of interstate travel on sleep patterns in elite Australian Rules Football athletes, with total sleep duration demonstrating an increase on nights prior to competitions regardless of location ($p< .05$) and subjective sleep rating being poorer during away games compared to that of home games ($p< .05$) (Richmond, et al. 2007). Further, Fowler, et al. 2014 conducted a randomized crossover trial to simulate the effect of travel of both domestic and international air travel with a normobaric, hypoxic altitude room and observed changes in sleep, performance, and recovery. As it pertains to sleep, both quality and quantity measured via sleep actigraphy were significantly less during the simulated international air travel condition compared to the domestic air travel and control conditions ($p < .001$), which authors explained as a potential contributing factor to subsequent changes observed in physical performance ($p < .01$) and subjective exertion and mood states ($p < .05$) during the simulated international travel (Fowler, et al. 2014b).

Therefore, results of this study would indicate that travel magnitude and duration would be the largest contributing factor to subsequent changes in sleep quality, which was supported by Fowler et al. 2017, which demonstrated sleep disruption caused by reduced sleep duration and excessive jet lag following northbound, long-haul, international travel in elite Australian soccer athletes (Fowler, et al. 2017). Inversely, two studies have reported findings that refute the effect of travel on items of sleep quality, as Fowler et al. 2014 found no change in objective measures of sleep quantity or quality in response to domestic travel of male, professional Australian soccer athletes despite long flights and time zone change. With that said, authors of the study also noted the limitations of sample size (n = 6) and number of away trips that were observed during the season (n = 6), as well as the professional-level of athletes observed, who could be more adapted to travel demands and travel schedule, as potential reasons for no differences in the outcome measures of sleep and perceived recovery (Fowler et al. 2014a). Additionally, a study on elite, wheelchair basketball athletes (n = 11) found that long-haul, transmeridian travel had no effect on objective or subjective measures of sleep quality following travel to the International World Championships. One explanation provided as to the lack of effect of long-haul travel on this population was the fact that baseline sleep duration already fell below National Sleep Foundation guidelines, creating a scenario of little margin for potential change to occur in response to long-haul, time zone travel in this population (Fowler, et al. 2017).

The collection of literature on the association between sports-related travel for competition and items of sleep quality would indicate a potential association between the two variables, but considerable gaps exist to guide further research on the topic. While results presented in this review are conflicting, potential limiting factors to prior research is the lack of sample over time to assess the cumulative effect of travel demand on sleep, as opposed to a one-time assessment before and after long or short-haul travel. Further, few studies exist to observe the acute and chronic effects of sport-related travel on NCAA DI student-athletes in particular, which might be paramount following recent conference realignment causing greater frequency of long-haul air travel for many student-athletes belonging to this population. Attempts have been made, however, to describe the general sleep patterns and habits of NCAA DI student-athletes

(Brauer, et al. 2019; Mah, et al. 2018), but future research is warranted in light of the drastic, impending change in conference affiliations. Additionally, one noticeable omission in the current literature is the lack of studies that include assessment of individual athlete chronotype and/or distribution of chronotype among a team/group of NCAA DI student-athletes to observe the effect of diurnal rhythm on sleep quality or other outcome variables. Future attempts to describe general sleep habits or sleep quality in this population, including attempts to observe the effect of in-season competition travel, should include chronotype assessment to avoid presenting results that could be better explained through the lens of individual athlete chronotype.

Association between Sleep and Sports Performance and Injury Risk in Athletes

The available literature on the independent effects of sleep on sport-specific performance would warrant the need to include items of sleep quality or quantity as an outcome measure or confounding variable to any performance-based study in athletes due to the consistency of the positive relationship demonstrated between sleep and athletic performance. Recent case studies or reviews using sleep quality or quantity as an independent variable in athletes have demonstrated an effect of poor sleep on sport-specific performance (Clemente, et al. 2021; Fox, et al. 2021a; Jones, et al. 2018; Mah, et al. 2011; Ochoa-Lacar, et al. 2022; Singh, et al. 2021). countermovement jump (CMJ) performance (Mah, et al. 2019), injury risk (Milewski,, et al. 2014; Senbel, et al. 2022; Von Rosen, 2017a; Von Rosen, et al. 2017b; Watson, et al. 2020), and well-being or recovery (Angus, et al. 1985; Brauer, et al. 2019; Cohen, et al. 2009; Clemente, et al. 2019; Fowler, et al. 2015; Fietze, et al. 2009; Fullagar, et al. 2016; Lund, et al. 2010; Riegler, et al. 2021; Van Dongen, et al. 2003).

The two sports most represented in the current literature by frequency of available publications regarding observational studies or reviews of the association between sleep and performance appear to be soccer and basketball. Clemente, et al. 2021 conducted a META analysis on the associations between sleep, athletic and match performance, injury rates, and training load in soccer players. A systematic review of over 30 studies (n = 32) suggested that while inconsistent, pooled results would suggest that poor sleep appears to affect soccer performance and increase the frequency and severity of musculoskeletal injuries (Clemente, et al. 2021). As it relates to basketball-specific performance, prior research on the association of sleep and in-game performance would indicate a consistent, positive relationship between the two variables, with individual points and rebounds accumulated (Jones, et al. 2018), blocks, assists, rebounds, steals, and free-throw accuracy (Fox, et al. 2021), winning percentage and point differential (Cook, et al. 2022), sprint and CMJ performance, reaction time, and shooting accuracy (Mah, et al. 2018), and injury rate (Ochoa-Lacar, et al. 2022, Watson, et al. 2020) all demonstrating a sensitivity to measures of sleep quality or quantity. With that said, while multi-year narrative reviews on basketball-specific performance are prevalent, the current literature would suggest a lack in quantity of longitudinal case studies in basketball athletes to better understand how the sleep profile of basketball athletes might be influenced during in-season competition and how changes in sleep might then translate to better or worse in-game basketball performance.

Of the available case studies that do exist in the current literature with sleep assessment in basketball athletes, Mah, et al. 2011 provided insight as to how extending nightly total sleep time (TST) over 5-7 weeks might improve measures of physical and basketball performance in collegiate men's basketball athletes. Results of the study would indicate that increasing the total amount of nightly sleep by almost two hours (mean increase of approximately 110 minutes per subject above normal sleep; $p < 0.001$) led to faster sprint times, increases in shooting accuracy for FT% (9% increase) and 3-point shooting accuracy (9.2% increase; $p < 0.001$ for both), as well as improvements in reaction time, reduced daytime fatigue, and improved mental well-being through assessment of Profile of Mood States (Mah, et al. 2011). Further, Fox, et al. 2021 aimed to assess the association between sleep quality and quantity in basketball performance and male, semi-professional basketball athletes (n = 7), with results demonstrating a positive association between sleep efficiency and subjective sleep quality on nights prior to competition and free throw accuracy, rebounds, assists, steals, offensive rating, and player efficiency ($p < .05$). Results also demonstrated the effect of sleep items such as subjective sleep quality, movement index, and wake time for up to 4 nights leading into competition on performance items such as free throw accuracy, assists, steals, and player efficiency ($p < .05$) (Fox, et al. 2021a).

Other available research studies on the sport of basketball have taken the approach of quantifying injury risk in relation to items of sleep quality (Von Rosen, et al. 2017a; Von Rosen, et al. 2017b; Watson, et al. 2020). In a cohort of male NCAA DI basketball athletes (n = 19), Watson, et al. 2020 observed the independent effect of sleep duration on subsequent injury risk over two years of basketball seasons, and found that sleep duration demonstrated independent predictive potential on in-season injury risk ($p < 0.001$), and remained a significant predictor even when multivariate models included separate risk factors of fatigue, soreness, mood, and stress. In fact, in this study, sleep duration had a strong enough association with injury risk that authors concluded that even a one hour increase in sleep duration contributed to a 43% reduction in injury risk the following day (Watson, et al. 2020). Other, larger reviews on sleep and injury risk that include basketball athletes in their cohort would support these findings, with sleep above eight hours per night associated with a 61% injury risk reduction in adolescent athletes (Von Rosen, et al. 2017b). More specifically, Milewski, et al. 2014 supported the positive association between sleep duration and injury risk, demonstrating sleep duration of less than 8 hours per night being the strongest predictor of injury in adolescent athletes, whose injury risk was 1.7 times higher than that of those sleeping 8 hours or more per night (Milewski, et al. 2014). Finally, one longitudinal study with NCAA DI Women's Basketball athletes measured the impact of sleep and training stress on game performance and injury over 25 weeks, with results demonstrating a significant effect of sleep, specifically sleep duration and REM sleep, and training stress on injury rate in this population (Senbel, et al. 2022).

While the aforementioned reviews and case studies would indicate a consistent trend of how aspects of sleep might affect basketball-specific performance and injury rate within the sport, clear gaps exist in the current literature that can guide further research. First, many of the available research studies on sleep and aspects of athletic performance focus exclusively on male, professional athletes for observation. Further, there appears to be little attempt to also assess athlete chronotype as a moderating factor or confounding variable between the association of sleep and performance or injury rates in athletes. Finally, most studies reviewed used either a low sample size (less than 10) or short study duration (less than a full season) as their means to measure sleep effects, thereby limiting external validity and requiring future research to repeat the same findings to validate past results on the topic.

2.5. Countermovement Jump Assessment to Monitor Fatigue and Performance Adaptation in Athletes

Methods to Assess CMJ in Athletes and Primary Outcomes

Of particular importance in the field of sports performance and performance science is the ability to objectively measure performance adaptation to monitor aspects of sport or training-induced fatigue or to observe physiological adaptation, or maladaptation, as an athlete or group of athletes develop over time. One particular method to achieve this goal that is often cited in the sports performance literature is the use of countermovement jump (CMJ) performance metrics in athletes. However, considerable variation exists between the mode in which CMJ performance is assessed and the specific CMJ performance metrics used to describe CMJ performance. One particular method used to assess CMJ performance is the use of an electronic timing jump mat system, that measures flight time following the takeoff phase of a CMJ until landing back on the jump mat, which is then converted into jump height using the following equation: 1/8 (g X t2); where g = the acceleration due to gravity and t = airtime (Vescovi & Mcguigan, 2008). The jump mat system and method has been reported as a method of CMJ performance for studies involving athletes participating in soccer and lacrosse (Vescovi & Mcguigan, 2008), men's and women's basketball (Heishman, et al. 2017; Sanders, et al. 2019), and Winter Olympic skeleton (Chapman et al. 2011). The most often cited metric for CMJ assessment using a jump mat system was CMJ height (inches or centimeters), and the current literature demonstrated attempts to correlate CMJ height with sprint performance (Vescovi & Mcguigan, 2008), describe sport-related factors that contribute to change in CMJ performance (Sanders, et al. 2019), to observe the effect of long-haul travel on CMJ performance (Chapman, et al. 2011), and to observe any time of day effects of CMJ performance (Heishman, et al. 2017). Other less cited methods to measure CMJ performance in athletes involve the use of a visual-motion capture CMJ system (Optojump, Bolzano, Italy), used in two case studies to assess the effect of sleep restriction on explosive power of CMJ in elite soccer players (Abbott, et al. 2022) and to assess the relationship between training load and sleep on CMJ height in youth athletes (Sawczuk, et al. 2018). Additionally, one study reported the use of a linear transducer (GymAware, Kinetic Performance Technologies, Canberra, Australia) to measure the effect of simulated domestic and international air travel on

CMJ measures of jump height, peak power, and peak velocity in male athletes (Fowler, et al. 2014).

As opposed to the aforementioned methods used to measure CMJ performance in athletes, the current literature would suggest that the use of force plate technology and software is the most often cited CMJ assessment tool used in the sports performance setting. However, considerable variation exists among the different force plate systems used and cited in the literature on performance-based research with athletes. While not exclusive, force plate systems used to assess CMJ performance in athletes in this review of current literature include an AMTI (AMTI, Accupower, Watertown, MA, USA) portable force platform (Donahue, et al. 2023; Jaitner, et al. 2015; Mah, Cheri D., et al. 2019), the Ballistic Measurement System (BMS; Fitness Technology, Australia; Version 2012.3.7) (Gathercole, et al. 2009, Spiteri, et al. 2013), VALD Performance (Vald Performance, Brisbane, Australia) ForceDecks Software (Heishman, et al. 2020b; Jiang, et al. 2023; Minahan, et al. 2021; Petway, et al. 2020; Wrona, et al. 2023), and the Hawkins Dynamics (Hawkins Dynamics, Westbrook, Maine) portable force platform (Murr, et al. 2023). In addition to the considerable variation to force plate systems used, the current literature would also suggest considerable variation in the outcomes observed through CMJ force plate testing. Prior research includes, but is not limited to, observing the effect of sleep restriction on maximal CMJ performance via force plate (Mah, et al. 2019), attempts to measure the relationship between CMJ metrics from a force plate to sprint and agility performance (Vescovi & Mcguigan, 2008), creating a position-specific jump profile in elite, female rugby athletes (Minahan, et al. 2021), to investigate the presence and effect of bilateral asymmetry during the CMJ and potential effects on performance (Jiang, et al. 2023; Wrona, et al. 2023), as a criterion measure for injury progress assessment (Collings, et al. 2021), and for the purpose of validating jumping methods (Heishman, et al. 2020b) or other jump-measurement technology (Jaitner, et al. 2015). Despite the noted variation in primary outcomes, the current literature would suggest that the majority of force plate studies have a primary outcome of using CMJ metrics to assess sport-induced fatigue (Donahue, et al. 2023; Gathercole, et al. 2009; Heishman, et al. 2020a; Murr, et al. 2023; Petway, et al. 2020; Spiteri, et al. 2013).

Use of Force Plate CMJ to Monitor Fatigue and Performance in Basketball Athletes

The use of CMJ as an instrument to assess or monitor fatigue status and performance development in athletes was reviewed and found to be one of the most commonly used tests in individual and team sport athletes, as well as military personnel in a meta-analysis performed by Claudino, et al. 2016, in which the authors attempted to explain potential variance in outcome measures particular to CMJ assessment and provide guidance on best practice for practitioners using CMJ as an assessment tool. Interestingly, authors of the review highlighted the mixed results in the literature regarding the efficacy of CMJ assessment to monitor fatigue or performance, with some studies indicating CMJ as a valid objective marker of fatigue or supercompensation (Basolabre-Fernandez, et al. 2014; Cormie, et al. 2009; Coutts, et al. 2007a; Jimenez-Reyes, et al. 2011) while others reporting lower efficacy of CMJ metrics for the intent of fatigue and performance monitoring (Coutts, et al. 2007b; Freitas, et al. 2014; Gathercole, et al. 2009; Malone, et al. 2015). Claudino, et al. 2016 provided both general and specific potential contributing factors to the lack of unanimity regarding the use of CMJ to monitor fatigue and performance in athletes, with possible explanations including the population used, the duration and frequency of testing, and the use of a large number of different CMJ performance metrics reported in the literature that may or may not be valid or sensitive to change with concurrent changes in neuromuscular fatigue status (McLean, et al. 2010; Mooney, et al. 2013). However, overall results from the meta-analysis from Claudino et al. 2016 on over 151 articles and 531 effect sizes would indicate that data from CMJ performance, particularly the average CMJ height over time, peak power, mean power, peak velocity, peak force, and mean impulse all demonstrated sensitivity to monitor either athlete fatigue or supercompensation in athletes (Claudino, et al. 2016). Further, an additional recent review of literature by Bishop, et al. 2023 provided evidence to support the need for specificity when selecting outcome measures of fatigue and performance monitoring in athletes to better improve the quality of analyses for the performance parameters of athletic development, fatigue monitoring, and injury rehabilitation. More specifically, the review of literature provided support for jump height, peak power, mean propulsive force and propulsive impulse as metrics to be used for performance profiling; reactive strength index, time to take-off, propulsive phase duration, and time to peak power are recommended for neuromuscular fatigue; and peak propulsive force, peak landing force, landing impulse, and asymmetry are recommended for injury rehabilitation (Bishop, et al. 2023).

As it relates to case studies taking a longitudinal, observational approach to assess changes in CMJ indices as a method to observe fatigue or performance in basketball athletes, prior research indicates that different methods of CMJ assessment have been cited, including a jump mat timing system in women's collegiate basketball athletes (Sanders, et al. 2019) and force plate technology and software in both the collegiate (Heishman, et al. 2017; Heishman, et al. 2020a; Heishman, et al. 2020b; Murr, et al. 2023; Petway, et al. 2020) and the professional basketball athlete population (Spiteri, et al. 2013). Specific to the use of force plate technology, prior research with basketball athletes have used CMJ metrics derived from force plates as a way to monitor neuromuscular fatigue during a competitive season (Heishman, et al. 2020a; Murr, et al. 2023; Petway, et al. 2020; Spiteri, et al. 2013), time of day effects on CMJ performance in collegiate men's basketball athletes (Heishman, et al. 2017), and to assess differences in CMJ performance measures with and without an arm swing during the CMJ (Heishman, et al. 2020b). Focusing solely on the effect of sport-specific training and/or in-season competition on CMJ metrics to assess fatigue and performance, the literature suggests mixed results, with some studies demonstrating the sensitivity to CMJ measures of jump height and power to internal TL (Sanders, et al. 2019), flight time:contraction time sensitivity to training intensity (Spiteri, et al. 2013), jump height and peak force sensitivity to conference play sport demands v. non-conference demands (Petway, et al. 2020), and flight time:contraction time and modified reactive strength index sensitivity to weekly training demands (Heishman, et al. 2020a), while one study demonstrated no significant, negative effect of in-season competition on CMJ measures of jump height, peak power, or reactive strength index (Murr, et al. 2023). One potential explanation for this contradicting finding by Murr, et al. 2023, is the use of a different force plate device and software during testing (Hawkins Dynamics, Westbrook, Maine) than all other studies using CMJ as an outcome measure in basketball athletes.

This current review of literature would indicate a fair number of prior research and reviews on CMJ performance and how it might reflect fatigue and performance adaptation caused by sport-specific training or competition demands. However, future research on CMJ performance in athletes could seek to fill in the current gaps that exist in the literature, such as a lack of research on sport-specific travel stress as an independent variable on CMJ performance, no attempts to assess the interaction effect of sport-specific travel and training stress on CMJ performance, and a lack of longitudinal case studies on NCAA DI Women's basketball athletes as it relates to CMJ performance over the course of a competitive season.

2.6. Sport-Specific Training Load (TL) Effects on Sleep, Psychometric Properties, Physical Readiness, and Performance

Sport-Specific TL Effects on Injury Rate/Illness, Sleep, and Psychometric Properties

Sports participation, particularly at the elite level, requires an inherent level of acute and chronic physiological training stress that requires an equivalent need for recovery to occur to offset training-associated decrements in performance to promote long-tern performance adaptation and supercompensation. With that said, the impact of sports-specific training load (TL) from all forms has been extensively studied and found to potentially have detrimental effects on items of sleep, mood state, stress levels, and well-being if that sports-specific training stress/load exceeds the individual or group recovery capacity of an athlete or group of athletes. The current literature on the matter would indicate a wide swath of case studies working with athletes across a variety of sports and using a variety of outcome measures regarding sleep, stress, and mood state responses to sport-specific TL, in addition to formal reviews that focus on larger associations between sports-specific TL and items of recovery and performance, including but not limited to, injury/illness (Jones, et al. 2017), sleep, performance, and injuries in soccer players (Clemente, et al. 2021), and the independent effect of training and competitions on sleep in elite athletes (Haines-Roberts, et al. 2018). These combined attempts to review the current literature as it relates to sports-specific TL to the aforementioned outcome measures would suggest a consistent, linear relationship between increasing acute or chronic TL and negative recovery outcomes of injury rate (Jones, et al. 2017), sleep (Clemente, et al. 2021; Haines Roberts, et al. 2018), and mood states.

In more detail, Jones, et al. 2017 performed a meta-analysis on the association between acute and chronic sport-specific TL on injury rate and illness, reviewing over sixty studies (n = 68) that represented athletes from fourteen different sports, with soccer (n = 21), rugby (n = 18), and Australian Rules Football (n = 6) being the most represented sports in the review. While the review's primary outcome was to assess the consistency of reported associations between sport-specific TL and injury/illness risk in elite athletes, authors did point out the lack of consistency in terminology related to TL, with terms representing different constructs, such as TL and fatigue, being mistakenly used interchangeably as if they represent the same construct, which can make the current literature on the topic confusing or misleading. However, despite inconsistent terminology, the review of literature as it relates to the association between TL and injury risk/illness would indicate that increases in the magnitude of acute TL beyond what is customary or sustained increases in TL over longer periods of time would both contribute to a heightened risk for injury and illness in elite athletes. Furthermore, the review highlighted the potential for extended competitive seasons, such as in World Cup years in professional soccer players, and intensified training following a period of time off are two scheduling factors that have demonstrated an increased risk for injury in elite athletes (Jones, et al. 2017). A more recent meta-analysis on the relationship between TL on sleep and injury risk in soccer players reported inconsistent findings in the literature but did suggest that poor sleep was reported in this population of athletes, which demonstrated negative effects on injury rate and in-game performance, with increases in TL at different phases of the year listed as a potential contributing factor (Clemente, et al. 2021). However, other reviews on injury risk in athlete populations have highlighted the independent effect of sleep duration and quality as the primary risk factor when assessing for injury risk, potentially highlighting a complex, multidimensional relationship that exists between TL, sleep, and injury (Senbel, et al. 2022; Von Rosen, et al. 2017a; Von Rosen, et al. 2017b; Watson, et al. 2020). To better elucidate the framework and progression of the multi-factor model of training demands, in-season competitions, sleep, and injury risk, Gupta et al.

2016 provided a review of factors contributing to reduced sleep quality and quantity in elite sport athletes, with night competitions, early morning sports training, and travel for competitions all listed as potential contributors (Gupta, et al., 2016). Results presented by Gupta, et al. 2016 would support the notion that elite sports participation alone negatively influences sleep quality in athletes, potentially regardless of training stress, thereby increasing the risk for athletes to sustain injuries or illness with or without excessive training stress.

A more recent meta-analysis (n = 54) to review the effects of elite sports training and competition provided further insight on the multi-dimensional relationship that exists between training and sport demands and sleep. The systematic review would indicate that studies on sleep profiles in athletes would demonstrate a propensity for elite athletes to achieve a total sleep time (< 7 hours) and sleep efficiency (< 85%) that is below the sleep recommendations when measured objectively through actigraphy or polysomnography, with factors such as night competitions and early morning training listed as potential contributing factors (Haines Roberts, et al. 2018). Interestingly, several studies (n = 11) included in this meta-analysis also observed the effect of increased TL on both total sleep time and sleep efficiency and reported a consistent reduction in both items of sleep following large increases in TL (> 25%), with potential explanations for this finding focusing on the effect of excessive training demand on the autonomic nervous system, particularly an over-expression of the sympathetic nervous system, and dysregulation of the HPA-axis required for healthy sleep. Further, Haines Roberts, et al. 2018 commented that studies that reported no effect of increased TL on sleep did not demonstrate a significantly increased TL, thereby lessening the effect observed (Haines Roberts, et al. 2018). In summary, this review would support the findings of previously mentioned meta-analyses (Clemente, et al. 2021; Gupta, et al. 2017; Jones, et al. 2017) by demonstrating a consistent effect of elite sports participation on items of sleep quality, potentially leading to detrimental effects to overall performance and increased risk of injury, with acute or chronic excessive sport-related TL documented as a strong contributing factor in the multi-dimensional relationship that exists between sleep, recovery, and performance.

In a narrative review involving a joint effort and consensus statement by the European College of Sports Science (ECSS) and American College of Sports Medicine (ACSM) on the prevention, diagnosis, and treatment of sport-related maladaptation, which could potentially lead to the occurrence of the overtraining syndrome (OTS), Meeusen, et al. 2013 provided ample evidence in the current literature to support the relationship between altered psychology and psychometric properties when an imbalance exists between training stress and recovery capacity (Meeusen, et al. 2013). This evidence would date back to the 1980's where research using the Profile of Mood States (POMS) questionnaire with NCAA collegiate swimming athletes consistently reported elevations in negative moods such as tension, depression, anger, fatigue, and confusion and reductions in the positive mood of vigor during periods of rigorous training, with negative moods receding upon training tapers back to levels observed prior to increases in TL (Morgan, et al. 1987). Further, a dose-response relationship between rigorous sports TL and increases in negative mood states was documented in a review of literature involving over 1000 athletes from a variety of endurance and non-endurance sports (Raglin & Wilson, 2000). Further evidence would support the notion that mood state changes in response to training stress are a more sensitive measure for monitoring training adaptations than oft-cited biomarkers of training stress such as cortisol (Coutts, et al. 2007b), with one study in particular demonstrating significant changes on items of the POMS following only two days of intensified training (O'Connor, 1997). The combined joint statement from the ECSS and ACSM summarizes the efficacy of monitoring changes in psychometric properties by providing general support for the use of psychological assessments in both basic and applied research with athletes, with negative changes in mood states or other psychological items serving as a consistent and valid measure of maladaptation when TL outpaces the recovery capacity of an athlete or group of athletes (Meeusen, et al. 2013).

Several case studies within the last ten years have taken the findings from earlier literature on the association between sports-specific TL and aspects of psychological health or well-being and looked to add to the literature with elite level athletes from a variety of sports including, but not limited to, soccer (Clemente, et al. 2017; Moalla, et al. 2016), basketball (Clemente, et al. 2019), and youth athletes (Sawczuk, et al. 2018a; Sawczuk, et al. 2018b; Watson, et al. 2018). However, despite earlier case studies indicating the usefulness of the POMS to document changes in psychometric properties in elite athletes (Morgan, et al. 1987; O'Connor, et al. 1997), more recent attempts have opted for different assessment tools to measure items of psychological status, including the Hooper Index Questionnaire (Clemente, et al. 2017; Clemente, et al. 2019; Moalla, et al. 2016), a daily custom, subjective well-being questionnaire (Sawczuk, et al. 2018a; Sawczuk, et al. 2018b), and a daily, custom Likert scale (Watson, et al. 2018). Of the individual case studies included in this review of literature, presented results would indicate a consistent, negative relationship between daily TL and weekly TL and total scores on the Hooper Index, which includes subject ratings of sleep, stress, fatigue, and soreness (Short, et al. 2023), in both soccer and basketball athletes (Clemente, et al. 2017; Clemente, et al. 2019; Moalla, et al. 2016). Further, in youth athletes, two case studies would indicate a tendency for increases in TL to negatively impact both sleep quality and, subsequently, daily scores on a subjective well-being questionnaire (Sawczuk, et al. 2018a; Sawczuk, et al. 2018b) while another study with female youth athletes demonstrated a significant ($p < .001$) negative effect of daily TL on subjective stress scores from a custom Likert-scale assessment tool (Watson, et al. 2018). Despite the consistency of findings, one might question the repeatability of the results presented in the aforementioned case studies that assessed stress as an outcome measure using methods that have not previously been validated as a construct of psychological health in the athlete population. With that said, the current foundation of literature would indicate a consistent, detrimental effect of increased TL on items of injury risk, sleep, and psychometric properties in the athlete population.

Sport-Specific TL Effects on Physical Readiness and In-Game Performance in Athletes

Recent attempts to quantify the effect of sport-specific TL on physical readiness largely focuses on using baseline and follow-up field tests of performance such as CMJ (Donahue, et al. 2023; Gathercole, et al. 2009; Heishman, et al. 2020a; Murr, et al. 2023; Petway, et al. 2020; Sanders, et al. 2019; Spiteri, et al. 2013), change of direction ability and peak torque of the knee extensors (Ferioli, et al. 2018), strength, endurance, agility, and power (Nunes, et al. 2014), and anaerobic capacity and submaximal heart rate responses to exercise (Aoki, et al. 2017). The review of collective studies using CMJ as an outcome measure to monitor changes in physical readiness in response to sport-specific TL would indicate mixed results, with several observational case studies reporting CMJ metrics that are sensitive to increases in physical TL in athletes, such as significantly lowered jump height in the conference v. non-conference portion of the season in NCAA DI men's basketball athletes (Petway, et al. 2020) and also as TL increased in elite female rugby athletes (Gathercole, et al. 2015), significantly lower flight time:contraction time (FT:CT), relative power, and jump height following basketball games in professional women's basketball athletes (Spiteri, et al. 2013), significantly lower CMJ height following a higher internal TL for the three days prior to testing in NCAA DI women's basketball athletes (Sanders, et al. 2019), and changes in both FT:CT and modified reactive strength index (mRSI) when external TL was high in men's NCAA DI basketball athletes (Heishman, et al. 2020a). However, in contrast, several observational case studies reported little to no change in CMJ metrics in regards to changes in TL, including studies involving CMJ testing in NCAA Men's DI basketball athletes (Murr, et al. 2023), NCAA DI Female Volleyball athletes (Donahue, et al. 2023), and youth athletes (Sawczuk, et al. 2018b). One potential explanation for these mixed results could be explained by the results from the meta-analysis on TL and sleep by Haines Roberts, et al. 2018, which reported that TL must increase by greater than 25% to consistently worsen items of sleep in athletes (Haines Roberts, et al. 2018). As each study using CMJ as a measure to quantify physical readiness was an observational study, the research team likely could not influence daily TL; therefore, large increases in TL (such as greater than 25%) may not have been observed in the studies reporting no change in CMJ because the TL was fixed throughout the duration of the study by sport coaches or performance staff personnel.

Other observational case studies have used baseline and follow-up performance testing measures other than CMJ to monitor the effects of sports-specific TL, with results largely demonstrating a sensitivity of performance testing to increases in TL. One such study observed changes in repeated change of direction ability and peak torque of the knee extensors in professional and semi-professional basketball athletes, with results demonstrating a moderate to large inverse relationship between external TL and performance during a change of direction test and peak torque of the knee extensors (Ferioli, et al. 2018). Nunes, et al. 2014 reported a full battery of performance tests in elite, female Brazilian national basketball athletes and how performance might change before and after a highly stressful 12-week training period in preparation for an international championship event, including an 8-repitition max squat and 1-repetition max bench press, 40-meter agility T-test, yo-yo intermittent anaerobic endurance test, and squat jump test. Results demonstrated that, following the 12-week intensified training program and brief tapering period, significant improvement was observed in the bench press 1RM and squat 8RM tests ($p \leq 0.05$), time to complete the agility T-test ($p \leq 0.05$), and distance covered during the Yo-Yo intermittent anaerobic endurance test ($p \leq 0.05$), despite incremental increases in TL throughout the course of the 12-week preparatory phase (Nunes, et al. 2014). Results provided by Nunes, et al. 2014 might indicate that more frequent, weekly testing of performance parameters might be needed to observe signs of fatigue or maladaptation, and also that performance parameters can demonstrate super-compensatory effects if built-in tapering periods are included in an intense training phase of the competitive calendar. Further, these findings were supported by similar research in nine professional male basketball athletes from Brazil, who demonstrated moderate to large improvements in anaerobic capacity, repeat sprint ability, and aerobic fitness over nine weeks of pre-season and in-season phases of the competitive calendar (Aoki, 2016). These collective results might indicate the usefulness of performance-based testing before and after phases of high TL to evaluate training and practice periodization to ensure positive adaptation. However, further research is warranted to determine if performance-based physical testing other than CMJ testing is sensitive to acute daily, or weekly changes in TL to serve as a measure of physical readiness.

Similar to the subjective assessments of psychometric properties listed and described in previous sections of this review, several recent case studies have included the outcome measure of subjective physical assessments of fatigue or soreness as a method to assess physical readiness in response to sport-specific TL in a population of athletes. Drew, et al. 2016 provided insight on this association by performing a systematic review of literature (n = 35) on the relationship between sport-specific TL and injury, illness, and soreness, with the results demonstrating a consistent, dose-response relationship between training load and muscle/joint specific soreness, particularly in repetitive overhand throwing sports like baseball, water polo, and cricket (Drew, et al. 2016). Within the laFst ten years, case studies using this approach include studies with professional soccer athletes (Clemente, et al. 2017; Moalla, et al. 2016), basketball athletes (Clemente, et al. 2019), and youth athletes (Sawczuk, et al. 2018a; Sawczuk, et al. 2018b; Watson, et al. 2018). Further, case studies observing the association between TL and physical states of soreness and/or fatigue would demonstrate a significant, negative effect of internal TL on items of fatigue and muscle soreness (Moalla, et al. 2016) and delayed onset muscle soreness and fatigue (Clemente, et al. 2017) in the professional soccer athlete population. These results were partially supported by a study in female professional basketball athletes (n = 15), which reported little to no change in muscle soreness but moderately greater subjective fatigue ($p = 0.468$) during congested weeks of training and practice in which TL is higher (Clemente, et al. 2019). Finally, in case studies involving youth athletes, studies have reported that an increase in sports TL had a small, negative effect on soreness and perceived recovery in forty-eight youth athletes (Sawczuk, et al. 2018a), a significant negative effect on perceived state of physical recovery in fifty-two youth athletes (Sawczuk, et al. 2018b), and significant negative effects of TL on subjective soreness in sixty-five female youth soccer players (Watson, et al. 2018). This collection of literature on the association between TL and subjective physical readiness would indicate a generally consistent trend of a negative effect of increased sport-specific TL demands on items of such as soreness and fatigue.

Perhaps the most important aspect of understanding the effects of sport-specific TL is how acute or chronic TL might influence in-game sports performance in either direction. To better understand this association, Fox, et al. 2018 performed a systematic review (n = 26) to examine the relationship between TL and performance outcomes in team sports. Results of the systematic review would suggest that aerobic endurance team sports were the only reported sports or athletes affected by TL, with training exposure and high-intensity activity (≥ 90% of maximal heart rate) strongly associated with aerobic performance. Further, the review suggested that there was no clear association between TL and game-related performance or statistics for other sports or performance types, such as anaerobic or intermittent sports (Fox, et al. 2018). However, several sport-specific case studies have further examined the effect of TL on in-game performance, including but not limited to, Australian Rules Football performance (Johnston, et al. 2019), elite female field hockey (McGuinness, et al. 2020), professional rugby union (West, et al. 2020), soccer performance (Coppalle, et al. 2019; Rago, et al. 2021), and basketball performance (Coyne, et al. 2021; Fox, et al. 2021b; Garcia, et al. 2022; Petway, et al. 2022; Sansone, et al. 2020). The results from these individual attempts to quantify the effect of TL on sport-specific performance are inconsistent though, with some studies reporting no effect of pre-season or in-season effect of TL on in-game performance (Coppalle, et al. 2019; Garcia, et al. 2022; Johnston, et al. 2019; West, et al. 2020) while others demonstrated a clear association between TL and in-game performance efficiency (Fox, et al. 2021b; McGuinness, et al. 2020; Sansone, et al. 2020), end-game scoring margin (Petway, et al. 2022) and coach rating of performance (Coyne, et al. 2021).

Focusing specifically on in-game basketball performance and how it might be sensitive to acute or chronic effects of TL, recent case studies within the last ten years would suggest mixed results. Coppalle, et al. 2019 observed the effects of pre-season TL on biological markers of exertion and in-season team performance, and while some associations were reported between TL and biological markers of exertion (lactate dehydrogenase, C-reactive protein: $p < 0.05$), no association was observed between pre-season TL and overall team performance (Coppalle, et al. 2019). A similar study in male Spanish professional basketball players ($n = 15$) supported this results and conclusion of Coppalle, et al. 2019, which reported no association between internal or external TL on different measures of in-game player efficiency or contributions (Garcia, et al. 2022).

Inversely, several recent studies provide evidence to support the association between TL and in-game performance in basketball, with two studies on male semi-professional basketball athletes reporting significant relationships between relative player load and high-intensity bouts per session on player efficiency rating (Fox, et al. 2021b) and prior week TL with in-game performance efficiency quantified by a "performance index rating" ($p = 0.042$) (Sansone, et al. 2020), respectively. Further, both internal and external TL were significantly correlated with a coach rating of performance and distinguished between successful and unsuccessful performances ($p < 0.001$) among a group of women's basketball athletes preparing for an International Basketball Federation Olympic qualifying event (Coyne, et al. 2021). Finally, Petway, et al. 2022 provided the strongest support for the association between acute TL and in-game basketball performance, collecting TL data in an NCAA DI Men's basketball program over the course of three competitive seasons and reporting the effects of high or low TL in the days leading up to competitions on subsequent in-game performance. Significant effects were observed between training duration two days ($p = 0.03$) and one day ($p = 0.01$) on the end-game scoring margin in relation to the closing point spread differential, with authors reporting worse outcomes with point differential as TL increased within the two days leading up to competition (Petway, et al. 2022). The inconsistency as it relates to the current literature on how in-game athletic performance, particularly as it relates to basketball performance, would warrant further research on the topic to provide guidance for practitioners to optimize prescription of sport-specific TL to optimize in-game performance.

Despite a considerable amount of research work on the effects of sport-specific TL on aspects of recovery, such as sleep quality, psychometric properties, and physical readiness, and on sport performance, the current foundation of literature would suggest considerable knowledge gaps to guide future research. First, no study or systematic review described in this review of literature addressed the potential interaction effects of both sport-specific TL and in-season travel stress on any aspect of recovery and performance in any level of athletics. With prior research providing evidence that both TL and travel stress have independent effects on recovery and performance, and in light of new travel demands for many NCAA DI student-athletes through recent conference realignment, research designed to observe the interaction effect of these two independent variables would be valuable to sport performance practitioners at the NCAA DI level. Further, many studies and reviews listed in this review of literature that used sleep quality as an outcome measure did not use assessment methods that meet current guidelines for sleep quality assessment, prompting the need for a more thorough sleep quality assessment approach when trying to measure effects of TL for athletes at all levels. Finally, with most studies reviewed in this literature review occurring before the paradigm shift of recent conference realignment, results of past studies with NCAA DI student-athletes regarding aspects of recovery or performance might lack the external validity that they once had.

2.7 Effect of Chronotype/Circadian Rhythm on Sports Performance

Chronotype/Circadian Rhythm Effects on Exercise and Sports Performance

One particularly overlooked aspect of early sports science research is the potential confounding effect of individual circadian rhythm factors on outcome measures of recovery, adaptation, or performance which could be influenced by the time of day in which these outcome measures were observed or reported. However, more attention has been paid to understand how individual chronotype, an expression of circadian rhythmicity, might influence all aspects of human performance including several systematic reviews on the topic that demonstrate a consistent effect of chronotype on various aspects of performance (Reilly, et al. 2009; Thun, et al. 2015; Vitale, et al. 2017). Reilly, et al. 2009, provided an extensive review of literature on the diurnal nature of exercise performance, noting that athletes are reported to both feel their best and perform their best in the late afternoon and early evening, with world record-type performances almost exclusively occurring in this time window. Furthermore, the review provided evidence in the literature to support this notion, citing studies that have documented diurnal variation in performance for exercise parameters including but not limited to, peak force of leg, back, and arm muscles, maximal anaerobic power, and maximal vertical and broad jump performance. The review went on to state that when studies measured performance over the span of 24-hours with six or more testing intervals spaced evenly throughout the day, that peaks in exercise occurred within the 3:30PM to 8:30PM (1530-2030) time window. However, despite the evidence provided in prior research, authors of the review made the point to note the low quality of studies supporting or refuting the hypothesis of a circadian rhythm to exercise performance at the time, with a collective failure to address other potential confounding variables that could influence the hypothesis testing, such as intrinsic motivation, audience effect, and laboratory v. field-based testing (Reilly, et al. 2009).

More recent reviews have also supported the notion that performance is influenced by circadian factors, with a meta-analysis conducted by Thun, et al. 2015 that reviewed exercise and sports performance research that included an assessment of the effect of circadian rhythm from 1980-2012 (n = 112 studies). Of the main findings of this review was the fact that the most robust result in the literature reviewed is that athletic performance seems to be the best in the evening, which supports the review provided by Reilly, et al. 2009. Thun, et al. 2015 provided additional physiological rationale for this phenomenon by describing the relationship between peak athletic performance and the rise in core body temperature that happens over the course of the day, which also peaks in the late afternoon/early evening (Thun, et al. 2015), perhaps creating a more conducive environment for cellular ATP production to turnover at a higher rate, increases joint mobility, and could lead to a greater potentiating effect of skeletal muscle during exercise or sports competition. Finally, the systematic review provides support of the concept of travel-related circadian desynchronization explaining a large amount of the performance decrement observed with long-haul time zone travel, where an athlete's body clock becomes misaligned with the local 24-hour clock and pushing peak body temperature to a time that doesn't coincide with the timing of a sports event or competition (Thun, et al. 2015).

An additional systematic review of the influence of chronotype on athletic performance reviewed all research on the topic from 1985-2015 (n = 10 studies), with a focus on reviewing both performance and psychophysiological outcome measures in athletes by chronotype. Although a smaller sample than other reviews listed above, the results of this meta-analysis would suggest that athlete chronotype influences feelings of subjective exertion at different times of the day, with "morning-types" (M-types), reporting lower rating of perceived exertion (RPE) and performing better on submaximal and self-paced physical tasks occurring earlier in the day than either "evening-types" (E-types) or "neither-types" (N-types) when athletes are assessed for chronotype with the Horne-Ostberg Morningness-Eveningness Questionnaire (MEQ). The review then highlighted case studies that supported chronotype differences in performance in athletes participating in swimming, rowing, marathon running, and field hockey when participants were assessed for chronotype and performance was measured or observed at different times of the day (Vitale, et al. 2017).

While recent systematic reviews of literature on the topic would indicate that circadian factors do influence exercise and sports performance, recent studies have attempted to add more context to the matter. Studies currently existing in this field of research include attempts to describe chronotype distribution across a large group or team of athletes and how it might affect sleep quality or recovery in athletes (Anderson, et al. 2018; Bender, et al. 2018; Grace, et al. 2023; Kunorozva, et al. 2017; Lastella, et al. 2021; Lim, et al. 2021), while others assessed chronotype effects on specific measures of sports performance at different intervals of time, such as different times of the day or different days of the week (Bruno, et al. 2023; Heishman, et al. 2017; Pengelly, et al. 2021; Pengelly, et al. 2022; Roveda, et al. 2020; Turner, et al. 2022; Turner, et al. 2023). Regarding attempts to describe the distribution of chronotype amongst a group of athletes, Bender, et al. 2018 had Canadian National Team athletes (n = 63) complete a one-time assessment of subjective sleep quality (PSQI) and assessed for chronotype (Athlete MEQ) and compared these results to a control group of good-sleeping, non-athletes. Results from this cross-sectional study would indicate athletes are more skewed towards morningness despite no group differences in wake time or sleep time and that athletes also reported less subjective sleep quality (PSQI Mean = 5.0) than non-athlete controls (PSQI Mean = 2.6) despite no differences in self-reported sleep duration (Bender, et al. 2018). Further, a large cross-sectional study in elite, South

African male rugby athletes (n = 120) would support the tendency for athletes to report a higher prevalence of morningness than a group of non-athlete controls, with athletes demonstrating a higher percentage of morning-types (47%) than the non-athlete control group (23%). However, an additional finding of this study was that the elite rugby athletes did not have a higher prevalence of the morningness-associated PERIOD3 variable number tandem repeat allele, known as PER3 when compared to non-athletes, therefore, suggesting that the diurnal preference for morningness in athletes might be more environmentally or behaviorally driven than any biologically driven factors to prefer morningness (Kunorozva, et al. 2017).

Despite the reported evidence to support a tendency for athletes to skew towards morningness when assessed for chronotype, this notion is not unanimous in the current literature. Another large cross-sectional study that described chronotype distribution in a population of elite Korean athletes (n = 340) reported that none of the athletes who completed the Korean version of the MEQ (MEQ-K) for chronotype assessment were defined as "definite morning-types" (n = 0), with a small number categorized as "moderately morning-type" (n = 13), and all other athletes surveyed being reported as "neither-type" (n = 169), "moderate evening-type" (n = 111), and "definite evening-type" (n = 61) (Lim, et al. 2021). Further, a smaller study with NCAA DI collegiate swimmers (n = 27) reported only three "morning-types" within the sample when assessed for chronotype, with all others categorized as "neither type" (n = 17) or "evening-type" (n = 7), while also demonstrating that "evening-type" swimmers swam 6% slower on average in the morning training sessions and had 50% greater salivary amylase levels, an objective assessment of physiological effort, than "morning-type" teammates. Inversely, during evening training sessions, "morning-type" athletes also required 5-7 times more physiological exertion to match morning training performance (Anderson, et al. 2018). These conflicting findings on athlete chronotype demographics would indicate the potential for high variance in chronotype distribution from one subset of athletes to another, highlighting the need to assess chronotype on an individual by individual or team by team basis due to a lack of consistency in the literature on general trends for athlete chronotype distribution.

As opposed to the cross-sectional design of the aforementioned studies to describe chronotype distribution in athletes, several recent prospective cohort studies have taken an observational approach to measure chronotype effects on specific items of sports performance, including but not limited to research with the sports of lacrosse (Grace, et al. 2023), soccer (Lastella, et al. 2021; Roveda, et al. 2020), tennis (Turner, et al. 2022; Turner, et al. 2023), and basketball (Bruno, et al. 2023; Heishman, et al. 2017; Pengelly, et al. 2021; Pengelly, et al. 2022). In a group of collegiate female lacrosse athletes (n = 14), Grace, et al. 2023 measured chronotype via a reduced MEQ (rMEQ) and assessed for differences in sleep quality, wellness, and training volume and reported that, despite no significant differences between chronotypes for either outcome measure, "neither-types" consistently averaged better sleep quality (PSQI) and had a higher training volume than either the "morning" or "evening" types (Grace, et al. 2023). Similar results were reported in a study with elite women's soccer athletes (n = 36), which found no chronotype differences in items of sleep quality, but did note that "morning-types" had significantly earlier wake up times than other chronotypes but also had a higher average training RPE when training sessions occurred regularly within the 6:00-7:00/7:30PM time window (1800-19/1930 hours), suggesting that chronotype played a role in the perception of difficulty of training sessions in "morning-types" (Lastella, et al. 2021). Further, Roveda, et al. 2020 measured chronotype differences in sleep quality and a battery of performance tests performed either in the morning or in the evening in a group of adolescent soccer athletes (n = 75) that were selected by chronotype and assigned to either a “morning-type”, “neither-type”, or “evening-type” group (n = 25 per group). While no differences were observed in measures of sleep quality by chronotype, statistically significant differences were observed between “morning” and “evening-types” for squat jump, agility, and endurance tests, with “morning-types” performing better during the morning test battery, “evening-types” better in the evening test battery, and “neither-types” demonstrating no difference between the two testing sessions (Roveda, et al. 2020). Finally, a pair of case studies with elite male tennis athletes (n = 12) documented time of day effects on tennis-specific performance, specifically noting that tennis backhand consistency and maximal service velocity was worse in the evening (8:00PM or 2000h) compared to morning (8:00AM or 800h) or afternoon (2:00PM or 1400h), with no differences observed by chronotype (Turner, et al. 2022), and also that unforced error frequency was higher and total distance covered and first serve scores both lower in the evening match time (8:00PM or 20:00h) despite a significantly lower RPE in the evening match time than morning or afternoon match times (Turner, et al. 2023).

Chronotype and Circadian Rhythm Effects on Basketball-Specific Performance

The current literature provides a variety of research studies designed to assess circadian influence on basketball performance, with several studies designed in a way to assess how basketball performance might be negatively influenced by long-haul travel and its ability to cause circadian desynchronization, subsequently affecting performance. Roy & Forest, 2018 reviewed National Basketball Association (NBA) performance through end game results over five years of games played with an emphasis on measuring the distance traveled, direction of travel, and time zone change, with results demonstrating a significant negative association between winning percentage and the number of time zones traveled and time of game start, with a clear disadvantage for NBA teams traveling westward ($p < 0.001$) (Roy & Forest, 2018). Another extensive review on NBA performance from 2011-2021 supported the effect of travel-related jet lag and circadian desynchronization on basketball performance, but provided evidence to suggest that eastward but not westward jet lag reduced winning percentage ($p = .051$), point differential ($p = 0.015$), rebound differential ($p < 0.0001$), and effective field goal percentage differential ($p < 0.01$), and also noted that as the magnitude of eastward jet lag increased, team point differential decreased ($p < 0.05$) (Leota, et al. 2022). Furthermore, an additional retrospective cohort study analyzing game outcomes over five NBA seasons (over 9,000 games) demonstrated that greater circadian misalignment, regardless of travel direction causing a circadian delay or advance, and increasing travel distance negatively influenced NBA game performance (Cook, et al. 2022). At the college level, a study of in-game performance over ten seasons of NAIA Women's Basketball demonstrated that teams traveling fewer miles from their home city scored significantly more points ($p = 0.03$) and won more games ($p = 0.04$), potentially suggesting better performance when circadian rhythm was in synch with the local environment compared to when travel for competition invoked a circadian delay or advance (Pradhan & Alton, 2021). Despite the consistency of the research cited above regarding the potential for circadian rhythm to influence in-game basketball performance, one key limitation to any of the reported findings was the lack of chronotype assessment due to the retrospective nature of many of the studies. Therefore, while circadian or phenotype effects might have contributed to changes with in-game basketball performance at both the professional and collegiate level, the evidence provided can only describe these effects as a potential explanation but not definitively as a causative factor.

As opposed to the larger reviews referenced above, several recent studies have assessed for athlete chronotype with the intent to observe chronotype-based differences in basketball-specific performance. One such study assessed for chronotype using the MEQ in male professional basketball players (n = 11), and measured statistical performance in evening games occurring later than 6:00PM (1800h). Results demonstrated a small, significant effect of chronotype favoring “morning-types” for number of blocks per game compared to “neither-types”, with non-significant, small to large effects favoring “neither-types” for attempted and made 3-point shots, assists, and steals during evening games compared to “morning-types” (Pengelly, et al. 2021). An additional study with male professional basketball players (n = 13) assessed for chronotype via MEQ and observed potential differences in shooting accuracy at two times of the day (8:00-9:30AM v. 3:00-4:30PM; 0800-0930 v. 1500-1630). Results suggested non-significant differences by chronotype or time of day in shooting scores ($p > 0.05$), indicating that shooting performance remained consistent across morning and afternoon sessions regardless of individual chronotype in a group of professional basketball athletes (Pengelly, et al. 2022). One noted limitation of this study is a lack of a true evening testing session to see how shooting performance might differentiate by chronotype or time of day during the evening hours (after 6:00PM or 1800h). Finally, a study in adolescent male basketball athletes (n = 93) assessed for chronotype using the rMEQ and observed the chronotype differences on shooting accuracy and the interaction between chronotype and day of the week on shooting performance, with results demonstrating that chronotype and its interaction with the day of the week significantly predicted shooting accuracy when school was in session but not on holidays. “Evening-types” in the study demonstrated a gradual performance decrease in shooting accuracy from Monday to Friday compared to either “morning-types” or “neither-types”, with authors of the study highlighting the accumulated sleep debt in "evening-types" attending school and subsequent social jet lag as a likely contributor to the performance change throughout the week (Bruno, et al. 2023).

The current literature as it relates to the effect of circadian rhythm or chronotype on basketball-specific performance would indicate the potential for circadian factors to influence performance outcomes over time and in instances in which travel demands are elevated. However, several knowledge gaps exist that future research could address to better describe this effect. First, rather than indirectly assuming that circadian rhythm might play a role in reduced statistical performance in professional or collegiate athletes, future studies could first assess for individual chronotype or assess sleep/wake patterns to better gauge the propensity for sport-related travel to challenge circadian synchronization. Current research on the topic suggests that circadian dysregulation could be a causative factor in reduced performance during heightened travel (Cook, et al. 2022; Leota, et al. 2022; Pradhan & Alton, 2021; Roy & Forest, 2018), but these reviews did not assess individual circadian rhythm profiles or chronotype. Therefore, the reduced performance observed for basketball players in this study could be due to confounding variables such as performance psychology, opponent quality, or lifestyle factors associated with competitions away from home. Further, studies that have assessed chronotype in basketball athletes in the current literature have only described the acute effects of chronotype on shooting performance at different times of the day or different days of the week (Bruno, et al. 2023; Pengelly, et al. 2021; Pengelly, et al. 2022), rather than observing long-term performance differences by chronotype over the course of a competitive season. Finally, there appears to be a lack of literature on circadian or chronotype effects on NCAA DI Women's Basketball athletes in particular, thereby suggesting a potential for future research with this population in particular.

2.8 Summary and Suggestions for Future Research

The current literature reviewed for this dissertation would support the independent effects of both travel stress and TL on aspects of recovery and performance, such that as either travel stress or TL increases beyond the ability of an individual or group of individuals to cope with either form of stress, measures of recovery or performance are suggested to decline. In particular, this review of literature would indicate that travel stress, either acute or accumulated, has a detrimental effect on sleep quality, exercise performance, and in-game sports performance, while excessive sport-specific TL has demonstrated a detrimental effect on injury rate, sleep quality, physical readiness, and in-game sports performance in athletes. Further, this review of literature would support the use of CMJ to monitor fatigue and adaptation in athletes, with research demonstrating a sensitivity of specific CMJ metrics to monitor parameters of performance-related fatigue or adaptation. Finally, the current literature would support the effect of circadian rhythm or chronotype on specific measures of exercise performance, but evidence to support the effect of either on in-game sports performance lacks the same quality or quantity of definitive evidence.

However, despite the evidence provided for each independent variable or outcome measure in isolation, considerable knowledge gaps exist on how specific factors related to sports performance might interact to contribute to positive or negative changes in recovery, physical readiness, athletic development, and in-game/competition athletic performance. Few, if any, studies included within this review of literature attempted to measure or observe the combined effects of travel stress and sport-specific TL on any of the outcome measures observed and reported on in the current literature, such as sleep quality, psychometric properties, CMJ performance to assess for fatigue, or in-game statistical output. With each independent variable demonstrating fairly consistent, detrimental effect on recovery and performance, future research on the potential interaction between the two variables is warranted. Further, relatively few studies currently exist in the literature with NCAA DI athletes, particularly NCAA DI Women's Basketball athletes, which are required to both travel long distances for competitions and endure a high sport-specific TL over large portions of their calendar year, potentially exposing them to the negative effects of both acute and accumulated travel stress and TL. In light of the recent and impending changes to the magnitude of competition-related travel in NCAA DI athletics, future research on associations between travel stress, TL, recovery, physical readiness, and performance would help practitioners in the sport-performance field make informed decisions on how best to approach upcoming in-season travel to mitigate any potential performance loss both before and after travel occurs. Finally, while the evidence-base for chronotype effects on athlete performance is not as strong or conclusive, future attempts to better elucidate the effect of circadian rhythm or chronotype on recovery and performance in NCAA DI athletes could be beneficial for researchers and practitioners alike.

The following chapters of this dissertation seek to add to the current foundation of literature on the potential independent effects of both travel stress and sport-specific TL, and the interaction effect between the two independent variables, on items of recovery such as sleep quality, mood state, and physical readiness via CMJ performance over the course of a competitive season in NCAA DI Women's Basketball athletes. Additionally, analyses will be performed to understand how these two variables independently affect, and combine to effect, elements of in-game statistical performance in this sample of athletes. Finally, a five-year review of performance will be conducted to assess larger trends as it relates to travel demands on performance of an NCAA DI Women's Basketball program competing in the Southeastern Conference.

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Chapter 3

Assessing the Effect of Travel Stress and External Training Load on Sleep Quality, Mood States, and Physical Readiness in NCAA Division I Women's Basketball Athletes over the course of a Competitive Season

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3.1 Abstract

Purpose: This study quantified the effects of travel stress (TS) and training load (TL) on items of recovery and physical performance in NCAA DI women's basketball athletes during a competitive season. **Methods:** Athletes (n=13) completed a weekly questionnaire to assess sleep, mood, and physical readiness while also completing weekly countermovement jump (CMJ) assessments on a force platform. Acute and chronic TS was quantified using an evaluative checklist that considered multiple travel parameters. TL was measured using a GPS monitoring system for all basketball sessions throughout the season. Repeated measures linear mixed models were used to measure effects of TS and TL on outcome measures and to assess significance of linear changes of outcome measures over time. **Results:** Chronic TS was negatively associated with subjective happiness ($ß = -.014$; $p = .036$) while prior week TL was negatively associated with soreness ($ß = -.0005$; $p = .017$) and fatigue ($ß = -.0004$; $p = .031$). No significant effect of TS or TL was observed on any measure of sleep quality or countermovement jump performance ($p > 0.05$). **Conclusions:** Higher chronic TS in NCAA DI Women's basketball athletes was associated with lower ratings of subjective happiness while higher prior week TL was associated with greater subjective soreness and fatigue over the course of one competitive season. Neither TS nor TL were associated with CMJ performance, suggesting a possible lack of sensitivity of CMJ assessments to changes in recovery and performance in this sample of NCAA DI Women's Basketball athletes.

Key Words: NCAA DI Women's Basketball, travel stress, training load, recovery, sleep quality

3.2 Introduction

NCAA Division I (DI) collegiate athletics will enter a new era beginning in the fall of 2024, as recent conference realignment has shifted the landscape of collegiate athletics from a collection of regionally similar conferences to a collection of power and non-power conferences whose borders stretch further than ever before.[1] In fact, three of the new "Power Conferences" will have member institutions on both the U.S. Atlantic and Pacific coasts across three separate time zones. Further, some new additions to the Big 10 conference are no closer than 1500 miles from their closest new conference opponent.[2] Therefore, sport-related travel will be greater in both frequency and magnitude for many NCAA DI student-athletes than ever before.

The effects of frequent, long-distance travel on exercise and sports performance has been well documented as it relates to professional sports performance. One review documented the characteristics of both travel fatigue and jet lag associated with travel across multiple time zones in elite sports athletes, with acute detrimental effects observed for both cognitive and physical performance.[3] Potential negative effects of travel fatigue and/or jet lag include excessive daytime fatigue due to circadian dysregulation and sleep loss, detriments in the performance items of strength, maximal speed, and endurance, and unfavorable changes in the ability to concentrate, motivation, and mood during travel across multiple time zones.[3] Recent reviews on the effect of travel-related circadian desynchronization suggest multiple contributing factors, with travel distance, direction of travel, and time spent on an airplane all demonstrating negative effects on sleep quantity and quality, alertness, subjective stress, perceived fatigue, mood states, and countermovement jump performance (CMJ) in team sports.[4−10]

In particular, the effects of travel stress (TS) on performance and recovery have been documented among basketball players, especially at the professional level. Current research suggests that the travel demands of professional basketball leagues, such as the NBA, unfavorably influence injury risk, game performance, and sleep quality.[11−20] However, less research has been conducted with NCAA basketball athletes to determine if travel has similar effects on recovery and performance, with the sparse current literature demonstrating that box score statistics such as points scored, blocks, and shooting percentage are influenced by the distance away from a team's home location in NAIA women's basketball athletes.[21] One study found that items of CMJ performance, as well as physiological markers of stress and leg muscle strength, were significantly diminished following a travel-heavy portion of in-season competition in NCAA Division II Women's Basketball athletes.[4] Additionally, a few studies have examined changes in CMJ performance in men's and women's NCAA Basketball athletes, with results tending to demonstrate a detrimental effect of in-season travel and sport-specific training load on jump height, peak power, flight:contraction time ratio, and reactive strength index.[22–26]

Increasing in-season TS often coincides with increasing sport-specific TL due to competitions being played, and both variables have demonstrated independent, negative effects on sport performance. Regrading TL, prior studies have reported that large increases in TL during the season can contribute to unfavorable changes in several outcome measures including in-game performance, injury rate, CMJ performance, and items of sleep quality.[23–31] Other reviews have also demonstrated the effect of TL on subjective states of stress, fatigue, mood states, and well-being .[32–35] In sum, prior research suggests a trend for sport-specific TL to negatively impact items of recovery, sleep and mood states in basketball athletes. However, most attempts to document this association have only assessed TL in isolation and not attempted to account for the concurrent influence of TS on recovery and physical readiness in athletes over time.

In summary, there are significant gaps in knowledge on how TS experienced in-season relates to sleep quality, mood states, perceived fatigue and soreness, and CMJ performance in NCAA Women's Basketball athletes. Additionally, few studies have attempted to concurrently assess the independent effects of both TS and sport-specific TL on the recovery and performance of these athletes over time. Therefore, the aim of this study was to quantify the independent effects of TS and sport-specific TL on subjective items of recovery, sleep quality, and CMJ performance in a sample of NCAA DI Women's Basketball athletes over the course of a competitive season. It was hypothesized that both TS and TL would be significantly, negatively associated with the outcome measures.

3.3 Methods

Participants

Thirteen NCAA DI Women's Basketball athletes were recruited to participate in this study (ages 18-23). The study protocol was approved by the university's institutional review board and all athletes provided written informed consent.

Study Design

This study was a prospective observational study that collected data throughout the duration of one competitive NCAA Women's Basketball season spanning approximately four months with the first assessment date on October 23, 2023 and the final assessment date on March 1, 2024. Weekly assessments for all outcome measures of recovery and physical performance were obtained. TS was quantified using a custom, evaluative TS checklist that scored each week of the season based on the travel demands that each week imposed. Subjective measures of recovery and sleep quality were provided to athletes weekly via a digital questionnaire customized by the research team and delivered through a smartphone application (Kitman Labs, USA). Throughout the season, the questionnaire was completed on days that accommodated the athletes' training and competition schedule to maximize athlete response rate and to reduce athlete burden. Further, all subjective measures of recovery and assessments of CMJ performance usually took place during a Saturday, mid-morning scheduled team resistance training session, with CMJ performance measured at the beginning of each session. Measures of external TL were provided during all basketball training sessions and games via the Catapult GPS athlete monitoring system.

Measures

Travel Stress (TS)

TS was assessed for each week of the season using the following travel parameters: occurrence of time zone change, total distance traveled (miles), mode of travel, time of departure from home location and time of arrival back to home location, the number of games played per trip, and the number of days since the last competition when travel took place. The travel parameters of time zone change, total distance of travel, and mode of travel were weighted to emphasize their greater impact on overall TS, as prior research on TS indicates a consistent effect of time zone change and total distance on sports performance and recovery in athletes.[5,10,11,14–18,21] Points accumulated for each parameter each week were summed to create an acute travel stress (ATS) score to reflect all travel that occurred that week. Chronic TS (CTS) was estimated by summing the ATS scores accumulated over the prior month prior and was calculated on a rolling basis for each assessment date. Figure 3.1 provides a detailed description of how ATS and CTS was calculated and the point value assigned to each travel parameter. Additionally, a full list of TS terms, abbreviations, and descriptions can be found in Figure S3.1 in the list of supplementary figures for this study.

External Training Load (ETL)

ETL was estimated for all basketball practice sessions and games throughout the course of the season and was provided by the "accumulated player load" metric from the Catapult GPS monitoring system (Catapult Sports, Melbourne, Australia), which quantifies the total strain of a practice session or game based on distance covered, running speeds attained/maintained, and total duration of the session. Catapult GPS "player load" for the entire team accumulated over the previous week before assessment of outcome measures was termed "prior week training load" (PWETL). Additionally, an average ETL per session was calculated for each week of the season by dividing the team's accumulated "player load" by the number of sessions (practices and games) from the previous week and was labeled "PWTL/session" to provide an indicator of training intensity during the week prior to any assessments of outcome measures.

Sleep Quality (SLQ)

All measures of SLQ were obtained via a weekly, custom questionnaire distributed by a mobile smartphone application (Kitman Labs, USA). The four items pertaining to SLQ were– total sleep time (TST), sleep onset latency (SOL), wakeful bouts following sleep onset (WASO), and overall subjective sleep quality (SLQ). Each item of SLQ was distilled from similar items of the Consensus Sleep Diary,[36] and condensed to four items to reduce participant burden and increase response rate. Figure S3.1 in the supplementary list of figures for this study provides each term, abbreviation, and a description for each SLQ item and Figure S3.2 provides the full list of questions and available answers for the SLQ assessment.

Mood States and Subjective Physical Readiness

All measures of mood state and physical readiness were assessed via the same weekly, custom questionnaire distributed by a smartphone application. Two items of mood state –

happiness and irritability – were adopted from the Profile of Mood States (POMS) questionnaire, which has demonstrated sensitivity to nonfunctional maladaptation in athletes.[37] Athletes in the study were asked to rate their overall level of happiness and irritability over the prior week on a 1-10 scale, with higher scores representing a greater amount of that particular mood state. Further, subjective physical readiness was assessed by a subjective rating of fatigue and soreness on a 1-10 scale over the past week, with lower scores indicating a greater amount of fatigue or soreness. Figure S3.2 provides each question regarding mood state or physical readiness assessment and the available response options.

Countermovement Jump Performance (CMJ)

CMJ performance was assessed weekly via the VALD Forcedecks dual force plate software (VALD Performance, Brisbane, Queensland, Australia). All CMJ testing occurred during a strength training session scheduled during the week around practices and competitions. The time of day in which testing was performed was not consistent across all assessment dates due to the fluctuating nature of the in-season weekly schedule for the athletes observed in this study. Athletes were instructed to stand with their feet on each force plate with hands on hips and to explosively perform a CMJ. Three repetitions were performed with brief rest periods in between each repetition and the best repetition was recorded for analysis. The metrics of peak power relative to body mass (PP/BM), flight time:contraction time ratio (Ft:Ct), concentric peak force relative to body mass (CON PF/BM), and impulse-momentum jump height in centimeters (JH) were selected a priori for measures of power output (PP/BM; JH), neurological readiness (Ft:Ct), and dynamic strength and force output (CON PF/BM).

Statistical Analysis

Descriptive statistics, including means and standard deviations (SD), were obtained for all continuous variables to describe changes in each measure during the season. Histograms were used to assess data normality and to screen for data anomalies. Repeated measures linear mixed models were used to assess potential linear group mean differences over time and to assess the independent effects of TS and ETL on all outcome measures, with all independent effects of TS and ETL modeled separately. The repeated measures linear mixed models used in this study also accommodates missing data, which occurred sporadically for select outcome variables. The AR (1): Heterogeneous method was used for both the repeated covariance type and covariance type for random effects and random slopes were not included within the model. Additionally, random intercepts were used to account for clustering of data by subject and the Restricted Maximum Likelihood (REML) estimation model was used to generate parameter estimates. All Statistical analyses were completed using SPSS version 26.0 (IBM Corp, Somers, NY) with an alpha level <0.05 indicating statistical significance.

3.4 Results

A sample of thirteen NCAA Women's Basketball athletes provided consent to participate in this study. The group mean age was 21.0 years (18-23) with a mean height of 182.4 cm and mean weight of 79.6 kg. Additional tables that demonstrate mean changes in all variables of this study across the non-conference and conference portion of the season (Tables S3.1-S3.3), team mean values across each assessment date throughout the duration of the study with p-values that represent the significance of mean differences across the season using repeated measures linear mixed modeling (Tables S3.4-S3.7) can be found in the list of supplementary tables for this study.

Tables 3.1, 3.2, and 3.3 provide parameter estimates and p-values derived from repeated measures linear mixed modeling to assess the effects of TS and ETL on all outcome measures. As detailed in Table 3.1, measures of TS and ETL were not significantly associated with any measure of SLQ. However, there was a negative association between CTS and SLQ that approached statistical significance ($\beta = -.014$, $p = .080$) and a suggested positive association between PWETL and SOL ($\beta = .001$, $p = .076$). These near-significant associations observed in this dataset would suggest the potential for stronger, more significant associations between CTS and SLQ and PWETL and SOL, respectively, across a larger sample or a greater number of assessments over time.

Table 3.2 demonstrates significant negative effects of CTS on subjective happiness ($\beta = -.014$, $p = .036$), suggesting that higher CTS at points during the season led to significant decreases in the mood state of happiness. Figure 3.2 visually depicts the relationship between CTS and subjective happiness across all assessment dates during the season. Figure 3.2 demonstrates that CTS was at its highest across the 10-12 assessment range with concurrent reductions in team mean subjective happiness below the mean team subjective happiness across the season (season mean happiness = 5.4). Table 3.2 also reports significant negative effects of PWETL on subjective soreness ($\beta = -.001$, $p = .017$) and fatigue symptoms ($\beta = -.0004$, $p = .031$), suggesting an effect of residual physical fatigue from the prior week TL on these subjective measurements of physical readiness. Figure 3.3 visually depicts the relationships between PWETL and the subjective mood states of soreness and fatigue across all assessment dates during the season, with peak PWETL occurring and across assessment dates 1-3 and remaining relatively stable throughout the remainder of the season with more soreness (lower scores) reported during assessment dates 1-3 than the season mean for both fatigue (mean = 6.2) and soreness (mean = 6.3). Finally, there were no significant effects of either TS or TL on any measure of CMJ performance observed in this study (Table 3.3).

3.5 Discussion

The current study aimed to observe the effects of in-season travel and sport-specific TL on subjective measures of sleep quality, mood states, physical readiness, and objectively-measured CMJ performance in NCAA DI Women's College Basketball athletes over the course of a competitive season. Results indicate a significant negative effect of CTS on subjective happiness and significant negative effects of ETL on subjective soreness and fatigue. However, results of this study demonstrated no effect of either TS or ETL on subjective measures of SLQ or CMJ performance, suggesting that these particular outcome measures might be more invariant to changes in either TS or ETL than subjective mood states.

Results from this study also indicate that this sample of women's basketball athletes fell below sleep guidelines for young adults provided by a multidisciplinary expert panel from the National Sleep Foundation in regards to TST, which recommends a minimum of 7 hours of nightly TST for young adults.[38] This finding supports prior research that characterizes the sleep experience in NCAA student-athletes, with similar reports of TST below recommended guidelines for this sample of athletes.[39,40] Despite these low levels of sleep duration, neither TS nor TL were associated with items of SLQ in this sample. These findings contradict past research on the effect of travel on SLQ, with previous studies reporting a consistent pattern of poor sleep in elite athletes due to congested travel schedules, high competition frequency, and early morning training obligations.[7,41,42] As the poor subjective SLQ reported in this study cannot be explained through negative effects of TS or TL, poor SLQ may reflect adverse scheduling, social, or lifestyle factors prevalent in this sample of athletes.

Specific to the effect of TS, results from this study suggest a significant negative relationship between CTS and the mood state of subjective happiness. Results of this study also suggest a significant, negative relationship between PWETL and the physical states of soreness and fatigue, respectively, such that increases in PWETL resulted in more subjective soreness and fatigue reported by the athletes in this study. These findings are in agreement with prior studies in athletes that have demonstrated unfavorable changes in subjective psychological and physical readiness as sport-related demands accumulated in a congested time period.[29,33–35,43,44] A potential explanation for the effect of CTS on subjective happiness is the residual travel fatigue from a congested travel schedule covering large distances and requiring frequent time zone changes, which has been reported to negatively affect subjective mood states in the athlete sample.[3] Further, the observed effect of PWETL on subjective states of soreness and fatigue suggests that elevated, acute sport-specific TL is negatively associated with subjective physical readiness, which has also been reported in previous research with athletes.[32–35]

Despite significant negative changes in subjective mood state and physical readiness, this study found no significant negative effect of TS or ETL on measures of CMJ performance. Primary CMJ outcome measures of power, dynamic strength, and neuromuscular performance were either maintained or improved throughout the duration of the season, as mean values for multiple CMJ metrics increased throughout the season. The absence of negative changes in CMJ performance, despite negative changes in other outcome measures, supports previous findings with basketball athletes that demonstrate that the CMJ may lack efficacy for monitoring performance or fatigue in particular groups of athletes.[45–47] One potential explanation for the null CMJ results observed in this study, despite significant, negative changes observed in other outcome measures, could be the lack of a consistent assessment schedule, as assessments were required to be scheduled around the practice, competition, and academic schedules of the student-athletes. Additionally, the CMJ is a very familiar movement pattern for the athletes who were observed in this study, and significant change in CMJ performance might require substantial increases in either or both TS and TL that were not observed in this study.

This study and its findings contribute to the very limited current literature on NCAA DI student-athletes, particularly NCAA DI Women's Basketball athletes, while also providing a feasible template for future research on how TS or sport-specific TL might affect items of recovery or sleep quality in this sample of collegiate athletes. Further, this study was able to objectively quantify ETL via the use of sport-specific GPS technology, and findings of this study can help guide performance practitioners on how GPS-measured ETL might influence items of subjective and objective recovery and physical readiness when used with elite athletes. Finally, results of this study combine with previous research on the efficacy of mood state assessment in elite athletes, as the mood states observed in this study demonstrated a greater sensitivity to changes in TS or TL than objective measures of physical performance such as the CMJ.[37,48,49]

3.6 Practical Applications

Recent and upcoming changes in NCAA DI conference affiliation for many universities warrants further investigation on the effect of increasing travel demands, either in isolation or combined with sports-specific TL, on subjective measures of SLQ, mood states, physical readiness, and objective measures of performance such as the CMJ assessment in this sample of athletes. While the results of this study largely contradicted the authors' hypothesis by only demonstrating a marginal effect of TS and ETL on the mood states of happiness and soreness and fatigue, respectively, this study can still serve as a feasible template for future research on the topic which could help inform sport performance practitioners, coaches, and athletes alike on the potential detrimental effects of in-season TS and physiological TL on recovery and performance in NCAA DI athletes. In particular, athletes that have been or will be competing in NCAA DI conferences that cover large distances across multiple time zones.

Limitations to this current study include its observational design, with little to no influence on either TS and TL and only being able to assess outcome measures of recovery and performance when it could be scheduled around basketball practice sessions and competitions throughout the season. Another limitation is the low number of athletes on a NCAA Women's Basketball roster compared to other sports, and the fact that the athletes represented just one NCAA DI institution. There were also no corrections for multiple statistical testing within this study, therefore, there is a greater likelihood of observing statistically significant associations by chance alone. These limits combine to reduce the sample size, statistical power, and the generalizability of this study's findings. Finally, the athletes observed in this study also compete in a NCAA power conference that has maintained a semblance of regionality covering only two adjacent time zones, lowering the magnitude of TS compared to athletes who have been or will be competing in conferences spanning multiple time zones across the United States. These limitations could be addressed with similar future research that examines recovery and performance in a different subset of NCAA DI student-athletes who have greater travel demands than the one observed in this study.

3.7 Conclusions

Results of this study suggest that chronic travel stress (TS) had a significant negative association with the subjective mood state of happiness and that sport-specific training load (TL) had a significant negative associations with the subjective physical states of soreness and fatigue. Neither TS nor TL demonstrated any effect on measures of CMJ performance, suggesting that

CMJ performance may be more resilient to effects of TS and/or TL than subjective mood states or subjective physical readiness.

3.8 Acknowledgements

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3.10 Figures

Figure 3.1. Travel stress evaluation to create acute travel stress (ATS) Metric

The following evaluative checklist was used to evaluate the travel stress of each instance of travel throughout the season. Time zone change, distance of travel, and mode of travel were weighted in a way to emphasize their individual effect on overall travel stress, with prior research on travel stress provided in the "methods" section to support these variables being weighted more heavily than others.

I. **Time Zone Change (Y/N)**
   a. 2 points for "yes", 0 points for "no"

II. **Number of games played during trip**
   a. 1 point for each game played during the trip

III. **Mode of transportation (Bus v. Commercial Flight v. Charter Flight)**
   a. 1 point for bus, 2 points for charter flight, 3 points for commercial flight

IV. **Total Distance Traveled (There and Back)**
   a. 0 points if less than 100 miles, 1 point for every 100 miles traveled (i.e. 150 miles = 1 point; 450 miles = 4 points; 1400 miles = 14 points)

V. **Time of Departure from Home Location**
   a. 1 point if 7:00AM or earlier, 0 points for later than 7:00AM

VI. **Time of Arrival back in Home Location**
   a. 1 point if later than 12:00AM, 0 points if earlier than 12:00AM

VII. **Time since last Competition**
   a. 2 points if last game is less than 24 hours between end of game and departure time; 1 point if less than 48 hours between end of game and departure time; 0 points if greater than 48 hours between end of game and departure time

Figure 3.2 Chronic travel stress (CTS) and team mean subjective happiness scores across all assessments throughout the season

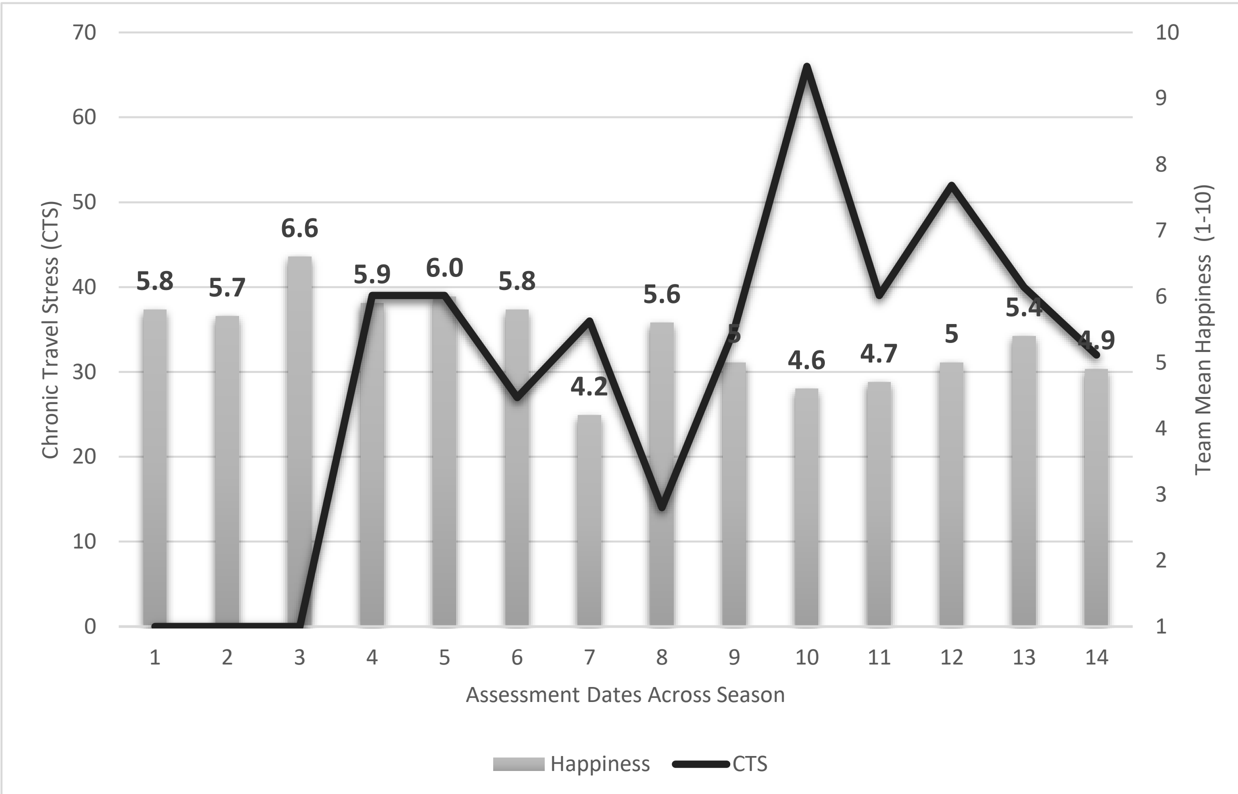
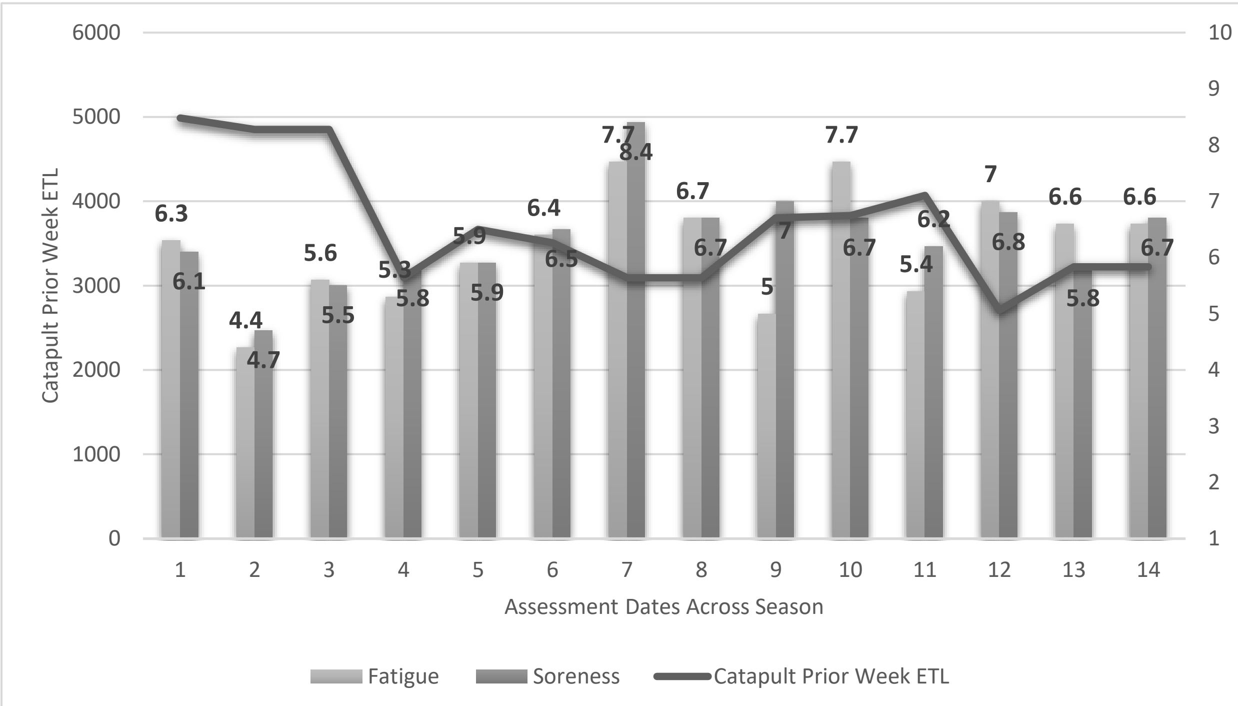


Figure 3.3. Catapult prior week training load (PWETL) and team mean subjective soreness and fatigue across all assessments throughout the season



3.11 Tables

Table 3.1. Repeated measures linear mixed-model parameter estimates of the effects of travel and ETL on measures of subjective sleep quality

Subjective Sleep Quality Measures								
	SLQ - 1-10		WASO – Bouts/Week		TST – Hours		SOL – Mins.	
Travel Stress & Catapult ETL	Parameter Estimate	p-Value	Parameter Estimate	p-Value	Parameter Estimate	p-Value	Parameter Estimate	p-Value
Acute TS	-.016	.283	0.00	.904	-.004	.346	-.046	.515
Chronic TS	-.014	.080	0.00	.833	-.005	.196	-.059	.191
PW ETL	0.00	.771	0.00	.999	0.00	.223	.001	.076
PW ETL/Session	.001	.433	0.00	.998	0.00	.396	-.004	.411

Note: Table data reflect parameter estimates derived from a repeated measures linear mixed model approach to assess the effect of travel stress (TS) and external training load (ETL) on subjective sleep quality metrics. Estimates for TS and TL on each measure of sleep quality were generated in separate models. PW ETL – prior week accumulated training load from Catapult GPS units; PW ETL/Session – Measure of intensity (Accumulated PWETL/Total number of basketball session); SLQ – sleep quality; WASO – wakefulness after sleep onset bouts/week; TST – total sleep time in hours; SOL – sleep onset latency in minutes. *denotes significance at the .05 level; **denotes significance at the .01 level

Table 3.2. Repeated measures linear mixed-model parameter estimates of the effects of travel and ETL on measures of subjective mood state and physical state

Subjective Mood State Scores								
	Soreness		Fatigue		Happiness		Irritability	
Travel Stress & Catapult ETL	**Parameter Estimate**	**p-Value**	**Parameter Estimate**	**p-Value**	**Parameter Estimate**	**p-Value**	**Parameter Estimate**	**p-Value**
Acute TS	.009	.486	-.003	.785	-.018	.178	.001	.929
Chronic TS	.013	.083	.006	.326	-.014	.036*	.012	.148
PWETL	-.001	.017*	-.001	.031*	0.00	.439	0.00	.801
PWETL/Session	-.001	.464	-.001	.567	0.00	.297	0.00	.804

Note: Table data reflect parameter estimates derived from a repeated measures linear mixed model approach to assess the effect of travel stress (TS) and external training load (ETL) on subjective mood state and physical readiness. Estimates for TS and TL on each measure were generated in separate models. PW ETL – prior week accumulated training load from Catapult GPS units; PW ETL/Session – Measure of intensity (Accumulated PWETL/Total number of basketball session). *denotes significance at the .05 level; **denotes significance at the .01 level

Table 3.3. Repeated measures linear mixed-model parameter estimates of the effects of travel and ETL on measures of countermovement jump (CMJ) performance

CMJ Performance Measures								
	Peak Power/BM		Ft:Ct (m/s)		Con. PF/BM		Jump Height (cm)	
Travel Stress & Catapult ETL	Parameter Estimate	p-Value	Parameter Estimate	p-Value	Parameter Estimate	p-Value	Parameter Estimate	p-Value
Acute TS	-.017	.380	0.00	.952	.001	.999	.003	.820
Chronic TS	.010	.292	0.00	.552	0.00	.999	0.00	.999
PWETL	0.00	.701	0.00	.999	0.00	.999	0.00	.999
PWETL/Session	-.001	.474	0.00	.825	0.00	.275	0.00	.827

Note: Table data reflect parameter estimates derived from a repeated measures linear mixed model approach to assess the effect of travel stress (TS) and external training load (ETL) on measures of CMJ performance. Estimates for TS and TL on each CMJ measure were generated in separate models. PW ETL – prior week accumulated training load from Catapult GPS units; PW ETL/Session – Measure of intensity (Accumulated PWETL/Total number of basketball session); Peak Power/BM – Peak power output relative to body mass (watts); Ft:Ct – Flight:Contraction Time (m/s); Con. PF/BM – Concentric Peak Force relative to body mass (newtons); *denotes significance at the .05 level; **denotes significance at the .01 level

3.12 Chapter III Supplementary Materials

Figure S3.1. List of study terms with abbreviations and descriptions

Travel Stress Metrics		
Term	**Symbol**	**Description**
Acute Travel Stress	ATS	Composite measure of travel stress for a single bout of travel; sum of several travel parameters such as travel distance, time zone change, etc.
7-Day Travel Stress	7DTS	Sum of all ATS points accumulated over the course of 7 days prior to a game
Chronic Travel Stress	CTS	Sum of all ATS points accumulated over the course of 1 month prior to a game
Catapult GPS Metrics		
Accumulated Prior Week ETL	PWETL	Accumulated ETL for the week prior to the current week of games
Prior Week ETL/Session	PWETL /session	Accumulated PWETL divided by the number of sessions (practices and games) from the previous week
Subjective Sleep Quality Metrics		
Total Sleep Time	TST	Measure of approximate hours of sleep obtained on average over prior 7 days
Wakefulness After Sleep Onset	WASO	Measure of how often an athlete woke up early from sleep and needed more than 20 minutes to fall back asleep over prior 7 days. Responses were on 0-7 scale (0 = Never; 7 = Every Night)
Sleep Onset Latency	SOL	Measure of approximate minutes needed to fall asleep on average over prior 7 days
Sleep Quality	SLQ	Subjective rating of overall sleep experience on 1-10 scale based off of subjective feeling of restoration upon waking on average over prior 7 days
Countermovement Jump (CMJ) Metrics		
Peak Power/Body Mass	PP/BM	Measure of explosive power during CMJ by multiplying force (N) applied to force plate by velocity (m/s) of the CMJ
Flight:Contraction Time	Ft:Ct	Measure of the amount of time spent in the air following a CMJ divided by the time needed to complete all phases of the CMJ prior to leaving the force plate
Concentric Peak Force/Body Mass	CON PF/BM	Measure of dynamic strength during CMJ by dividing the force exerted (N) during the concentric phase of the CMJ by the athlete’s measured body mass (kg)
Jump Height	JH	Approximate measure of jump height after a CMJ in centimeters (cm)

Figure S3.2 List of questions used to assess subjective sleep quality, mood states, and physical readiness.

1. Rate your OVERALL FATIGUE over the course of the last week (1- As fatigues as possible; 10 – No fatigue)
    a. 1-10 scale for fatigue
2. Rate your level of PHYSICAL SORENESS over the course of the last week (1- As sore as possible; 10 – No soreness)
    a. 1-10 scale for soreness
3. Rate of level of HAPPINESS as it relates to all aspects of your life as a student-athlete (1- Not happy at all; 10 – As happy as possible)
    a. 1-10 scale for happiness
4. Rate your level of IRRITABILITY over the course of the past week (1- None at all; 10- as irritable as possible)
    a. 1-10 scale for irritability
5. Rate your level of ACADEMIC stress over the course of the past week (1- No stress; 10- As stressed as possible)
    a. 1-10 scale for academic stress
6. Rate your level of SLEEP QUALITY as it relates to how REFRESHED AND RESTORED YOU FEEL UPON WAKING (1- Not refreshed at all; 10- Completely Refreshed)
    a. 1-10 scale for happiness
7. Over the last week, how many NIGHTS DID YOU WAKE UP during sleep and it takes you MORE THAN 20 MINUTES TO FALL BACK ASLEEP?
    a. 0-7 SCALE TO INDICATE NUMBER OF NIGHTS
8. Indicate your AVERAGE SLEEP DURATION in hours over the course of the last week to the nearest half hour (i.e. 7.5 or 8).
    a. Text box entry to indicate number of hours
9. Indicate the AVERAGE AMOUNT OF TIME IT TAKES TO FALL ASLEEP to the nearest 5 minutes (i.e. “15” or “30”)
    a. Text box entry to indicate number of minutes

Figure S3.3 Full text of rMEQ chronotype assessment

1. Considering only what you would prefer, at what time would you get up if you were entirely free to plan your day?
    a. 5:00-6:30AM
    b. 6:31-7:30AM
    c. 7:31-9:30AM
    d. 9:31-11:00AM
    e. After 11:00AM
2. After the first half hour after having woken in the morning on a week day, how tired do you feel?
    a. Very tired
    b. Fairly tired
    c. Fairly awake
    d. Completely awake
3. At what time in the evening do you feel tired and as a result in need of sleep?
    a. 8:00-9:00PM
    b. 9:01-10:00PM
    c. 10:01PM-12:30AM
    d. 12:31AM-2:00AM
    e. After 2:00AM
4. At what time of the day do you think that you reach your "feeling best" or "feeling most awake" peak?
    a. Early Morning – 6:00-8:00AM
    b. Later Morning – 9:00-11:00AM
    c. Mid-day – 12:00PM-4:00PM
    d. Late Afternoon/Evening – 5:00 – 10:00PM
    e. Late Evening – After 10:00PM
5. One hears about morning and evening types of people. Which one of these types do you consider yourself to be on most days?
    a. Definitely a "morning" type
    b. More "morning" than "evening" type

c. Neither “Morning” nor “Evening”
d. More “evening” than “morning” type
e. Definitely an “evening” type

Table S3.1. Mean (SD) travel stress and external training load by phase of the season

Phase of Season	Acute TS	Chronic TS	Prior Week ETL	Prior Week ETL per session
Non-Conference	5.1 (9.1)	20.1 (19.3)	4008.3 (858.4)	760.0 (133.3)
Conference	10.8 (8.9)	40.5 (17.7)	3358 (502.3)	622.3 (104.8)
Season	7.8 (9.1)	29.5 (20.7)	3708.2 (766.4)	696.4 (136.3)

Note: Table reflects team mean (standard deviation) values for travel stress and Catapult external training load metrics at different times of the season. TS = Travel Stress; ETL – External Training Load

Table S3.2. Mean (SD) countermovement jump values by phase of the season

Phase of Season	Peak Power/Body Mass	Flight:Contraction Time	Concentric Peak Force/Body Mass	Jump Height (Impulse Momentum – cm)
Non-Conference	50.3 (0.8)	0.67 (0.02)	25.2 (0.4)	30.7 (1.2)
Conference	53.2 (4.8)	0.67 (0.03)	26.1 (1.3)	32.4 (4.0)
Season	51.6 (3.5)	0.67 (0.02)	25.6 (1.0)	31.5 (2.9)

Note: Table reflects team mean (standard deviation) values for CMJ measures at different phases of the season

Table S3.3. Mean (SD) values for subjective measures of physical State, mood state, and sleep quality by phase of Season

Phase of Season	Fatigue (1-10)	Soreness (1-10)	Happiness (1-10)	Irritability (1-10)	Sleep Quality (1-10)	WASO (0-7)	Total Sleep Time (Hours)	SOL (min)
Non-Conference	5.9 (1.0)	6.1 (1.1)	5.7 (0.7)	5.6 (0.8)	5.8 (0.5)	2.4 (0.3)	7.1 (0.2)	15.4 (1.7)
Conference	6.5 (0.5)	6.4 (0.4)	5.0 (0.5)	5.9 (0.4)	5.2 (0.8)	1.9 (0.3)	6.7 (0.3)	17.7 (3.9)
Season	6.2 (0.9)	6.3 (0.9)	5.4 (0.7)	5.8 (0.7)	5.5 (0.7)	2.2 (0.4)	6.9 (0.3)	16.5 (3.0)

Note: Table reflects team mean (standard deviation) subjective scores for mood state, physical state, and sleep quality measures during different phases of the season. WASO = Wakefulness After Sleep Onset; SOL = Sleep Onset Latency

Table S3.4. Mean acute and chronic travel stress and team mean catapult ETL over the course of the season

Team Travel Stress and ETL Over the Course of the Season					
	Travel Stress Means		Catapult ETL Means		
Week	**Acute TS**	**Chronic TS**	**Prior Week ETL**	**Prior Week ETL/Session**	**Prior Week Games Played**
1	0	0	4987	997.4	0
2	0	0	4853	808.8	0
3	0	0	4853	808.8	1
4	22	39	3097	619.4	2
5	0	39	3668	611.3	2
6	0	27	3508	701.2	1
7	14	36	3092	773.0	2
8	0	14	3092	773.0	1
9	21	35	3804	760.8	2
10	20	66	3832	638.7	2
11	13	39	4070	581.4	2
12	13	52	2708	451.3	2
13	19	40	3223	644.6	2

Note: Table data reflects travel stress metrics and Catapult GPS external training load data over the course of the season for each testing week. ETL = External Training Load; TS = Travel Stress; ETL = External Training Load

Table S3.5. Weekly subjective mood state and physical state over course of the season

Subjective Mood State and Physical State Means (SD)					
Week	N	Soreness	Fatigue	Happiness	Irritability
1	12	6.3 (1.6)	6.1 (2.3)	5.8 (2.7)	6.2 (2.8)
2	11	4.4 (1.8)	4.7 (1.7)	5.7 (2.0)	4.5 (1.9)
3	12	5.6 (2.1)	5.5 (2.0)	6.6 (2.4)	5.0 (2.6)
4	13	5.3 (1.9)	5.7 (1.9)	5.9 (1.7)	4.8 (2.4)
5	13	5.9 (2.4)	5.9 (2.8)	6.0 (2.4)	6.2 (2.7)
6	12	6.4 (2.3)	6.5 (1.8)	5.8 (2.4)	5.9 (2.7)
7	11	7.7 (2.8)	8.4 (2.0)	4.2 (2.2)	6.8 (3.0)
8	13	6.7 (2.2)	6.7 (2.1)	5.6 (2.0)	5.7 (2.4)
9	9	6.2 (2.2)	6.1 (2.9)	4.3 (2.2)	6.1 (2.4)
10	9	5.4 (2.7)	6.2 (2.9)	4.7 (2.4)	6.1 (2.8)
11	9	7.0 (1.9)	6.8 (2.3)	5.0 (2.2)	5.9 (2.4)
12	10	6.6 (1.6)	5.8 (1.6)	5.4 (2.6)	6.2 (2.3)
13	10	6.6 (1.9)	6.7 (1.3)	4.9 (2.1)	5.4 (2.2)
P-Value		.079	.342	.281	.450

Note: Table reflects mean team scores for subjective items of mood state and physical state over the course of the season. SD = Standard Deviation; N = Sample; P-values represent the statistical significance of linear changes in values over the course of the season

Table S3.6. Weekly mean (SD) subjective sleep quality over course of the season

Subjective Sleep Quality Means (SD)					
Week	N	SLQ - 1-10	WASO – Bouts/Week	TST – Hours	SOL – Mins.
1	12	6.3 (1.9)	3.1 (1.9)	6.9 (1.0)	15.2 (11.4)
2	12	5.7 (1.6)	2.8 (1.8)	7.1 (1.3)	12.9 (14.0)
3	13	6.1 (1.9)	2.3 (2.3)	6.8 (1.3)	18.3 (13.5)
4	12	6.1 (1.7)	2.3 (2.0)	7.2 (1.1)	16.1 (12.5)
5	13	5.8 (2.1)	2.3 (2.3)	7.0 (1.5)	15.5 (13.1)
6	12	5.8 (2.5)	2.3 (3.0)	7.2 (1.0)	16.2 (10.8)
7	11	4.7 (2.1)	2.1 (3.2)	7.3 (1.3)	13.9 (10.2)
8	11	6.0 (1.6)	2.2 (2.7)	7.0 (1.2)	19.7 (15.9)
9	9	3.8 (2.5)	1.9 (1.8)	6.2 (1.3)	19.6 (16.7)
10	9	5.0 (2.2)	1.7 (1.7)	6.9 (1.1)	16.9 (12.2)
11	9	5.9 (1.7)	1.6 (1.6)	6.9 (1.4)	10.1 (6.8)
12	10	5.1 (1.7)	2.3 (2.3)	6.7 (1.3)	20.0 (13.3)
13	10	5.4 (1.6)	1.8 (1.8)	6.7 (1.0)	18.9 (10.8)
P-Value		.198	.185	.644	.731

Note: Table reflects mean team scores for subjective items of sleep quality over the course of the season. N = Sample size; SLQ = Subjective Sleep Quality; WASO = Mean Wakefulness after Sleep Onset bouts per week; TST = Total Sleep Time; SOL = Sleep Onset Latency; P-values represent the statistical significance of linear changes in values over the course of the season

Table S3.7. Weekly mean (SD) countermovement jump performance over the course of the season

Countermovement Jump Performance Means (SD)					
Week	N	PP/BM Watts	Ft:Ct	CON PF/BM (Newtons)	Jump Height (cm)
1	11	49.1 (5.4)	0.66 (0.12)	24.7 (2.6)	30.1 (4.6)
2	13	50.1 (6.8)	0.67 (0.12)	24.7 (2.4)	31.5 (5.9)
3	13	50.9 (7.7)	0.68 (0.16)	25.2 (2.7)	31.4 (6.5)
4	12	50.2 (7.4)	0.69 (0.17)	25.5 (2.9)	31.2 (6.3)
5	13	51.3 (7.2)	0.66 (0.12)	24.9 (3.0)	31.7 (6.5)
6	13	51.2 (8.8)	0.67 (0.18)	25.1 (3.0)	30.3 (7.8)
7	12	49.7 (6.4)	0.64 (0.11)	25.9 (4.0)	28.4 (6.2)
8	13	51.2 (6.4)	0.67 (0.16)	25.2 (2.6)	31.5 (5.9)
9	9	51.4 (9.7)	0.69 (0.26)	25.1 (2.7)	31.3 (7.8)
10	10	62.2 (11.2)	0.72 (0.24)	28.3 (3.1)	40.1 (12.3)
11	9	54.2 (8.0)	0.69 (0.13)	27.1 (3.6)	32.2 (7.7)
12	5	51.6 (11.2)	0.65 (0.16)	25.6 (3.3)	28.2 (7.4)
13	9	48.5 (8.3)	0.63 (0.19)	25.1 (2.6)	31.5 (7.1)
P-Value		.280	.203	.804	.216

Note: Table data reflects mean CMJ performance metrics over the course of one competitive season. N = Sample Size; PP/BM = Peak Power relative to Body Mass; Ft:Ct = Flight time divided by contraction time; CON PF/BM = Concentric Peak Force relative to Body Mass; cm = Jump Height in centimeters; P-values represent the statistical significance of linear changes in values over the course of the season

Chapter 4

Assessment of the Effect of Travel Stress and External Training Load on Basketball Performance and GPS-measured Performance Quality in NCAA DI Women's Basketball Athletes

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4.1 Abstract

Purpose: In light of recent NCAA DI conference realignment, the aim of this study was to assess the independent and combined effects of travel stress (TS) and training load (TL) on measures of in-game basketball performance and GPS-measured performance in NCAA DI Women's Basketball athletes over one competitive season. **Methods**: An NCAA DI Women's Basketball team (n=13) was assessed via measures of in-game performance and GPS-measured performance quality for each game of a competitive season. TS was quantified by creating an evaluative checklist using specific travel parameters and was measured at the acute and chronic level. TL and performance were measured using the Catapult GPS monitoring system (Catapult Sports, Melbourne, Australia). Associations between TS and TL with in-game performance were measured using correlations adjusted for opponent quality. Linear regression was used to assess potential interaction effects of TS and ETL on in-game performance. **Results:** Significant negative correlations were observed between time zone change and team performance efficiency rating ($r = -.505$; $p < 0.01$) and end-game scoring margin ($r = -.596$; $p < 0.01$). TL demonstrated a significant, negative association on FT% ($r = -.410$; $p < 0.05$). No significant interaction effects between TS and TL were observed. **Conclusions:** Undergoing a time zone change during travel and a high TL the day prior to a game were negatively associated with measures of in-game performance in NCAA DI Women's Basketball athletes. Further, no significant interactions were observed between TS and TL, suggesting that each acts independently to potentially reduce in-game performance in this sample.

Key Words: NCAA DI Women's Basketball, travel stress, training load, in-game performance, scoring margin

4.2 Introduction

The physiological and psychological effects of jet lag and travel fatigue associated with sport-specific travel on exercise performance has been well documented. Travel fatigue and/or jet lag have been characterized by excessive daytime fatigue due to circadian dysregulation and sleep loss, reduced strength, maximal speed, and endurance, and unfavorable changes in the ability to concentrate, motivation, and mood states of anger and irritability during travel across multiple time zones.[1] Reviews focused on the effects of travel-related circadian desynchronization suggest that total travel distance, direction of travel, and time spent on an airplane contribute to reduce sleep quantity and quality, cognitive alertness, subjective stress, perceived fatigue, mood states, and countermovement jump performance in team sport athletes.[2−8]

Specific to professional athletes, long-distance travel has been reported to negatively affect in-game performance across a wide range of sports.[2,4,9−21] Potential explanations for this include travel-induced circadian rhythm desynchronization, slow rate of resynchronization, and performance tasks being performed hours outside of a "peak circadian window" combining to demonstrate a negative relationship between travel stress and peak athletic performance.[6] Basketball athletes competing in the national basketball association (NBA), have been reported to be particularly affected by sport-related travel stress with significant differences in team winning percentage after repeated travel across time zones, evening games, and westward travel reported as contributing factors.[17] Further, a retrospective analysis that observed five years of NBA game data reported that both long-distance travel and repeatedly traveling across multiple time zones reduced in-game statistical performance and reduced winning percentage.[10] This finding has been supported by several similar reviews on NBA performance, with consistent evidence to suggest that travel stress negatively influences in-game performance and end-game outcomes in this sample of professional athletes .[9,11,13,14] On the contrary, research on the effect of travel on collegiate basketball performance, particularly women's basketball performance, is much less robust in the current literature, with two studies reporting negative effects of travel distance on team points scored and winning percentage over ten years of games played at the National Association of Intercollegiate Athletes (NAIA) level of college basketball,[15] and negative effects of travel on markers of health status, dynamic strength, and countermovement jump performance.[2]

In a similar fashion, sport-specific training load (TL) can increase throughout a competitive season as competition frequency increases. Past research on the independent effects of TL on sport performance have reported that increases in TL during the season can contribute to potential adverse changes to in-game performance and injury rate in DI Women's basketball athletes, negative changes in CMJ performance in athletes, negative changes to measures of sleep quality, and unfavorable changes to subjective states of stress, fatigue, mood states, and well-being.[22−36] However, most attempts to document these associations have only assessed TL in isolation and not how TL might interact with existing travel stress during a sports season to influence in-game performance.

The collective literature on the effects of travel stress and TL on performance in athletes, particularly women's basketball athletes at the NCAA DI level, indicate significant gaps in knowledge on how the travel stress and TL experienced in-season affect in-game basketball performance. Filling this knowledge gap could be of interest for NCAA DI athletes who might soon encounter a greater frequency and magnitude of travel due to the recent shift in conference affiliation for many universities. Therefore, this study assessed the independent and combined effects of travel stress and sport-specific TL on in-game basketball performance and GPS-measured movement quality in NCAA DI Women's Basketball athletes over one competitive season. It was hypothesized that there would be significant main effects of both travel and TL on both in-game statistical performance and GPS-measured movement. The presence of a significant interaction between travel stress and TL on each outcome measure of basketball performance was also hypothesized.

4.3 Methods

Participants

Thirteen female NCAA DI Women's Basketball athletes were recruited to participate in this study (ages 18-23) that was conducted during the 2023-2024 competitive season. The study protocol and use of collected data was approved by the university's institutional review board and all athletes provided written informed consent.

Design

This study was a prospective observational study that was conducted throughout the 2023-2024 competitive NCAA Women's Basketball which included 30 games, with the first and last game of the season occurring on November 6, 2023 and March 1, 2024, respectively (https://georgiadogs.com/sports/womens-basketball/schedule). In total, 15 games were either played at the opposing team's arena or at a neutral site (n=4) allowing for an even split between home games (n=15) and games played away from the athletes' home location.

Travel stress (TS) was measured for each game throughout the season using a custom travel stress checklist that evaluated the stress of travel using parameters such as occurrence of time zone change, distance traveled, and modality of travel. External training load (ETL) was provided via a sports-specific GPS monitoring system that was employed by the team for all basketball practice sessions and games throughout the season. Basketball-specific in-game performance was measured using composite and individual box score statistics for each game. Physical performance was also measured using a proprietary algorithm from the Catapult GPS monitoring platform which quantifies the performance of an athlete solely based off of the movement profile (speeds attained, distance covered, high speed acceleration frequency) for a given session, and averages for the team were computed for each game played over the duration of the study.

Measures

Travel Stress (TS)

TS was quantified for each game of the season, through the use of three different composite TS metrics. These included metrics of Acute TS (ATS), which was the sum of all TS points for a single trip, a 7-Day TS (7DTS) score and Chronic TS (CTS) score, which reflect the rolling sum of all ATS over the past seven days (7DTS) and the rolling sum of all ATS over the prior month (CTS), respectively. Individual travel parameters such as travel distance and instance of time zone change were also assessed independently, as prior research would support an independent effect of travel distance and time zone change on sports performance and recovery in athletes.[3,10,11,14,16,19] ATS was quantified using a checklist of travel parameters including the following; occurrence of time zone change, total distance traveled (miles), mode of travel, time of departure from home location and time of arrival back to home location, the number of games played per trip, and the number of days since the last competition when travel took place. The travel parameters of time zone change, total distance of travel, and mode of travel were weighted in a way to emphasize their impact on overall TS more so than other parameters, due to the significance of these particular parameters in the current literature. Finally, points accumulated from each travel parameter for each game were summed to create an ATS. After ATS was calculated, 7DTS and CTS could be calculated for each game by calculating the sum of all ATS for the week prior and month prior to each game of the season. A full description of the evaluative checklist used to calculate ATS can be found in Figure 4.1 of this study and a full list of travel variables used in this study, including abbreviations and descriptions, can be found in Figure S4.1 in the list of supplementary figures for this study.

External Training Load (ETL)

ETL was provided in this study for all basketball practice sessions and games throughout the course of the season via the Catapult GPS monitoring system and its "accumulated player load" metric which quantifies the total strain of a practice session or game based off of distance covered, running speeds attained/maintained, etc. to provide an estimation of ETL for practice session and games. To avoid confusion, authors of this study chose to use the term "ETL" instead of "player load" because "player load" is specific to Catapult whereas ETL can be applied to any form of sport-specific physical stress. Several Catapult ETL metrics were observed in this study to assess the effect of ETL on basketball-performance, with each metric representing ETL accumulated over different time points, such as all ETL from the previous week (PWETL), ETL from two days before a game (GD-2 ETL), and ETL from the day prior to a game (GD-1 ETL). Supplemental Figure S4.1 contains a list of all Catapult ETL variables used in this study with their abbreviations and a brief description of each.

In-Game Basketball Performance

In-game performance was measured with a combination of in-game basketball statistics to assess team performance throughout the duration of the season. Player efficiency rating (PER) was calculated for each athlete during each game, and the sum of all athletes' individual PER was used to represent the "team PER" for each game of the season. End-game scoring margin (EGSM) was obtained from publicly available box score statistics, with positive values reflecting a win from the team being observed in this study and negative values reflecting a loss. Team shooting efficiency was separated into three categories, with team field goal percentage (FG%) representing the total number of shots made divided by the total number of shots taken, multiplied by 100. The same method was used to calculate team 3-point shooting percentage (3P%) and team free throw percentage (FT%). All measures of in-game performance were provided by the publicly-available end-game box score statistics for each game. All basketball performance measures are listed in supplemental Figure S4.1, including calculations for team PER, FG%, 3P%, FT%, with abbreviations and descriptions for each.

In-game GPS-Measured Performance

In-game physical performance was also measured for each game with a proprietary algorithm provided by the Catapult GPS system (Catapult Sports, Melbourne, Australia), which is worn with an upper-body harness that situates the GPS sensor in the middle section of the upper-back of an athlete. The performance quality metric (PQM) factors in multiple variables of movement performance over the course of a game such as total distance covered, movement speeds attained, and movement speeds maintained. This custom statistic is an objective measure of performance based off of the movement profile of an athlete and not their statistical output. The PQM was provided by each athlete that accumulated a minimum of 12 minutes of gameplay (a threshold used previously by the team staff) to filter out low PQM scores from athletes with limited game action. A team average PQM was calculated for each game of the season.

Opponent Quality

To adjust for the confounding influence of opponent strength on the observed relationships between TS and ETL with in-game performance, each team played during the competitive season was assigned an "Opponent Quality Score". Opponent quality scores were extracted from the "Massey Ratings for NCAA DI Women's College Basketball" database, which quantifies the quality of a team using measures such as offensive efficiency, defensive efficiency, and strength of schedule (https://masseyratings.com). Opponent quality via Massey Ratings were on an ordinal scale with lower ratings reflecting a stronger opponent, such that a rating of "1" represented the best team in NCAA DI Women's basketball according to the Massey Rating database. Finally, opponent quality ratings were extracted upon the completion of the season observed so that the rating for each team was finalized. Table S4.7 provides correlation values between Massey Rating Opponent Quality and in-game performance measures for the study team.

Statistical Analysis

Descriptive statistics were obtained for all continuous variables to assess normality and to screen for data anomalies and histograms were created to visually assess data normality. Independent samples t-tests were performed to assess mean differences between travel parameters with dichotomous categories. Due to the strength of the correlations between opponent quality and the dependent variables of performance observed in this study, all statistical analyses except for analysis of FT% were adjusted for opponent quality. Correlations between

Massey Rating opponent quality and items of in-game performance for the study sample can be found in supplemental Table S4.7. Independent effects of travel and TL on performance were assessed through opponent-adjusted bivariate correlations. For independent variables with approximately normal distributions, Pearson partial correlations were generated to quantify the association between independent variables of travel or ETL and dependent variables of in-game performance, controlling for opponent strength. For independent variables that were not normally distributed (ATS, travel distance, and time zone change), Spearman's rho correlations were used to assess associations between these variables with opponent-adjusted measures of performance. Performance measures adjusted for opponent quality were derived by regressing opponent quality on each performance measure and adding the residual for each participant to the mean performance measure value for all participants. Potential interaction effects between TS and ETL were assessed via linear regression modeling, with nine interaction terms selected a priori for analyses. Further, six measures of in-game performance were selected a priori for assessment of interaction effects with TS and ETL, including team PER, EGSM, Catapult PQM, FG%, 3P%, and FT%. All Statistical analyses were completed using SPSS version 26.0 (IBM Corp, Somers, NY) with an alpha level <0.05 indicating statistical significance.

4.4 Results

The group mean age of the athletes who participated in this study was 21.0 years (18-23) with a mean height of 182.4 cm and mean weight of 79.6 kg. Table 4.1 provides means and standard deviations for each composite TS measure used in this study, separated by the early, non-conference and later, conference portions of the season to describe how TS changed throughout the season observed in this study. Data in Table 4.1 demonstrates no change in ATS across the two phases of the season with a slight increase in 7DTS and a large increase in CTS (nearly doubled) as the season progressed. Further descriptive tables for team performance and ETL metrics separated by phase of the season (Tables S4.1-S4.3) can be found in the appendix of this study under the list of supplementary tables and figures and these tables combine to collectively demonstrate the fact that all performance outcome measures except for FT% (increased 13.2%) and PQM (increased by 0.1 unit) decreased between the non-conference and conference portion of the season, while Table S4.3 demonstrates that all GPS ETL measures decreased between the two phases.

Results on the independent associations of TS variables and ETL on in-game performance are provided in tables 4.2A, 4.2B, and 4.3. As shown in Table 4.2A, the composite measures of TS used in this study (ATS, 7DTS, CTS) were not significantly associated with any measure of in-game performance. However, among individual measures of TS, the occurrence of a time zone change for an away game had a significant, moderate negative correlation with both team PER ($r = -.505$; $p < 0.01$) and EGSM ($r = -.596$; $p < 0.01$) (see Table 4.2B). Figure 4.2 provides a visual depiction of the significant difference in team PER during away games that required a time zone change, with mean team PER for games outside of the study team's home time zone significantly lower (mean PER = 52.6) than games within the study team's home time zone (mean PER = 68.1).

Table 4.3 summarizes the observed correlations between Catapult measures of ETL and measures of game performance. ETL accumulated on the day prior to a game ($r = -.410$; $p < 0.05$) and the intensity of ETL on the day prior to a game (GD-1/min; $r = -.529$; $p < 0.01$) were both negatively correlated with team FT%. Further, while measures of ETL were not significantly associated with in-game PQM, there was a moderate negative correlation ($r = -.311$; $p = .082$) between Prior Week ETL and in-game PQM. Figure 4.3 visually depicts the longitudinal relationship between Catapult GD-1ETL and Team FT% for every game observed in this study, with peak GD-1 ETL observed between games 4-12 and subsequent low team FT% compared to the season mean (mean = 70.2%). Correlation tables that are not adjusted for opponent quality are provided in Tables S4.4.4A-S4.6 to provide the reader context as to the magnitude of the change in associations before and after adjusting for opponent quality.

Table 4.4 shows opponent-adjusted group mean differences across different subcategories of TS parameters. A statistically significant 10.9% decrease in team PER was observed for away games (n = 15 games; p = .048) and statistically significant 15.5% and 15.0 % decreases in team PER (p = .043) and EGSM (p = .014), respectively, when away games involved a change of time zone during travel (n = 7 games). No significant group mean differences in performance measures were observed between any other categorical TS parameters.

No significant interactions were observed in this study between the different TS and ETL measures (interaction p-values shown in Tables 4.5-4.7) Therefore, Tables 4.5, 4.6, and 4.7 provide standardized beta values (ß) and their corresponding statistical significance from linear regression models with each TS and ETL metric entered into the models, respectively. More specifically, Table 4.5 demonstrates that, when jointly entered into linear regression models with Prior Week ETL, having a time zone change was significantly associated with EGSM (β= -.554), and Field Goal % (β= -.462). Similar sized associations were observed for time zone change when jointly modeled with other ETL measures, with the addition of a significant association between time zone change and PER when modeled jointly with either GD-2 ETL (β= -.440) or GD-1 ETL (β= -.471). Among the ETL measures, the only significant association was observed between GD-1 ETL and Free Throw % (β= -.435). Further, Table 4.6 demonstrates that, when jointly entered into linear regression models with ATS, GD-1 ETL was significantly associated with team FT % (β= -.456). No other jointly modeled terms with ATS demonstrated a significant association with outcome measures of performance, and Table 4.7 demonstrates no significant associations of CTS when jointly modeled with measures of ETL.

4.5 Discussion

This study aimed to observe the independent and combined effects of in-season travel stress (TS) and sport-specific training load (TL) on measures of in-game statistical performance and GPS-measured performance in NCAA DI Women's College Basketball athletes over the course of a competitive season. Results indicate that time zone change during travel for away games had a moderate, significant negative association with team PER and EGSM while also suggesting a moderate, significant inverse relationship between the ETL variables of GD-1 ETL and GD-1 ETL/session and team FT%. Linear regression modeling demonstrated no statistically significant interactions between measures of TS and ETL but did demonstrate significant negative main effects of time zone change on team PER, EGSM, and team FG% and a significant, negative main effect of GD-1 ETL on FT%.

Among the opponent-adjusted correlations between TS and ETL and in-game performance, the strongest correlation observed was that between the occurrence of a time zone change and in-game Team PER and the end-game scoring margin. The magnitude of this observed relationship would indicate a strong association between travel-related time zone change on in-game basketball performance. Past research on the effect of acute travel requiring a change of time zone suggests that reductions in physical performance parameters such as dynamic strength, anaerobic capacity, grip strength, agility, maximal speed, and aerobic performance could have contributed to the reduction observed in measures of in-game basketball performance in this study.[4−8; 40−44] These results highlight the need for future research on the effect of time zone change on in-game performance for NCAA DI collegiate athletes, as recent conference realignment likely will require many NCAA DI student-athletes to experience greater levels of TS than before.

Associations between ETL and performance outcome measures were typically attenuated upon adjusting for opponent quality. Only one correlation between ETL and performance met statistical significance, which was that between the ETL from the session on the day immediately prior to a game (GD-1 ETL) and study team FT%, which demonstrated moderate, negative correlations for both GD-1 ETL and GD-1 ETL/min, respectively. This result could be of particular importance since the act of free throw shooting is the skill least influenced by outside factors such as opponent quality, officiating, or tactical adjustments from opposing coaches, which might isolate a less biased effect of travel or ETL on in-game performance. Additionally, the movement pattern needed for successful free throw shooting might be more dependent on fine motor skills than other basketball-related skills, with high levels of cognitive focus and neuromuscular coordination needed for successful execution. Therefore, neural consequences of residual fatigue from high ETL practice sessions on days immediately prior to games might have the potential to reduce free throw shooting performance. While different in their movement patterns, past research on the effect of sport-specific ETL on items of neuromuscular performance measured via countermovement jump (CMJ) would support the negative effect of high ETL on neuromuscular performance.[25,28–30]

Opponent-adjusted correlations between travel stress and Catapult PQM in this study indicate no significant or practical effects of any measure of travel stress on performance quality. Opponent-adjusted correlations between ETL and PQM were also insignificant. However, the relationship between Prior Week ETL and PQM demonstrated a moderate, but insignificant, inverse relationship between the two variables that aligns with prior studies showing negative effects of ETL on physical performance items such as change of direction ability and peak torque of the knee extensors,[45] strength, endurance, agility, and power,[46] anaerobic capacity and submaximal heart rate responses to exercise.[47] As a composite measure of in-game physical performance, results of this study suggest that PQM could be sensitive to high training load accumulated over a short period of time.

A secondary aim of this study was assess for potential interactions between measures of travel stress and training load on in-game basketball performance. Due to the large number of independent variables used in this study, three TS variables (time zone change, ATS, CTS) and three ETL variables (Prior Week ETL, GD-1 ETL, GD-2 ETL) were selected to create a total of nine interaction terms and to observe their association with measures of basketball performance. Linear regression modeling resulted in no statistically significant interaction effects for any of the interaction terms selected for analyses, suggesting that any effect of travel stress on basketball performance was not dependent on the level training load, and vice versa. However, after adjusting for training load, time zone change was significantly and negatively associated with team PER, EGSM, and team FG%. In contrast, after adjusting for time zone changes, the only measure of ETL significantly associated with performance was a significant, negative main effect of ETL on the day immediately prior to a game on FT%.

This study and its findings contribute to the sparse literature on NCAA DI student-athletes, particularly NCAA DI Women's Basketball athletes, while also providing a feasible template for future research on how TS or sport-specific TL might affect in-game performance for this sample of athletes. Further, this study was able to objectively quantify ETL via the use of sport-specific GPS technology, and findings of this study can help guide performance practitioners on how GPS-measured ETL might influence items of in-game basketball performance. Despite the results of this study loosely resembling results from previous literature with professional basketball athletes,[11–13; 20,21] study results do not suggest the same overwhelmingly negative effect of travel on NCAA DI Women's basketball performance. However, the significant, negative effect of time zone change on team PER and EGSM and the relationship observed between GD-1 ETL on FT% warrant future research on how TS and TL might affect performance for NCAA DI athletes who will now be required to experience greater TS than ever before.

4.6 Practical Applications

In light of upcoming changes in NCAA DI conference affiliation for many universities, further investigation is warranted on the potential effects of increasing travel demands, combined with sports-specific ETL, on measures of performance for all athletes competing at this level of American collegiate athletics. This study could provide a feasible template for future research as it relates to quantifying TS and TL to further understand potential detrimental effects of travel and TL on in-game performance for all NCAA DI student-athletes. While results of this study suggested a low to moderate, significant negative effect of specific variables of TS or ETL on in-game performance, these unfavorable changes might be exacerbated commensurate with greater magnitudes of TS for many NCAA DI student-athletes following recent conference realignment.

Potential limiting factors for the results observed in this study include its observational design, small sample size, and focus on a single NCAA women's basketball team over a single season. There were also no corrections for multiple statistical testing within this study, therefore, there is a greater likelihood of observing statistically significant associations by chance alone. These factors limit this study's power to identify statistically significant associations between variables of interest as well as the generalizability of these findings to other sports and leagues. Also, athletes in this study travelled shorter distances than some of their peers at the NCAA DI level, as the conference they compete in is much more regional that other conferences of similar size. Finally, some measures of basketball-specific performance used in this study, such as team total PER and shooting percentages, are mainly offensive statistics that fail to capture either positive or negative defensive contributions to their full extent. These limitations should be addressed in future research that examines performance in NCAA DI student-athletes required to travel greater distances across multiple time zones at a greater frequency than those in this study.

4.7 Conclusions

Results of this study demonstrate small to moderate negative associations of travel on in-game basketball performance. Specifically, the occurrence of a time zone change for an away game demonstrated statistically significant negative associations with both team PER and EGSM. Additionally, increases in ETL on the day prior to a basketball game had a statistically significant negative effect on FT%. No statistically significant interaction effects of TS and ETL were observed for any measures of in-game basketball performance in this study.

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4.10 Figures

Figure 4.1. Travel stress evaluation to create acute travel stress (ATS) Metric

The following evaluative checklist was used to evaluate the travel stress of each instance of travel throughout the season. Time zone change, distance of travel, and mode of travel were weighted in a way to emphasize their individual effect on overall travel stress, with prior research on travel stress provided in the "methods" section to support these variables being weighted more heavily than others.

I. **Time Zone Change (Y/N)**
   a. 2 points for "yes", 0 points for "no"

II. **Number of games played during trip**
   a. 1 point for each game played during the trip

III. **Mode of transportation (Bus v. Commercial Flight v. Charter Flight)**
   a. 1 point for bus, 2 points for charter flight, 3 points for ATL commercial flight

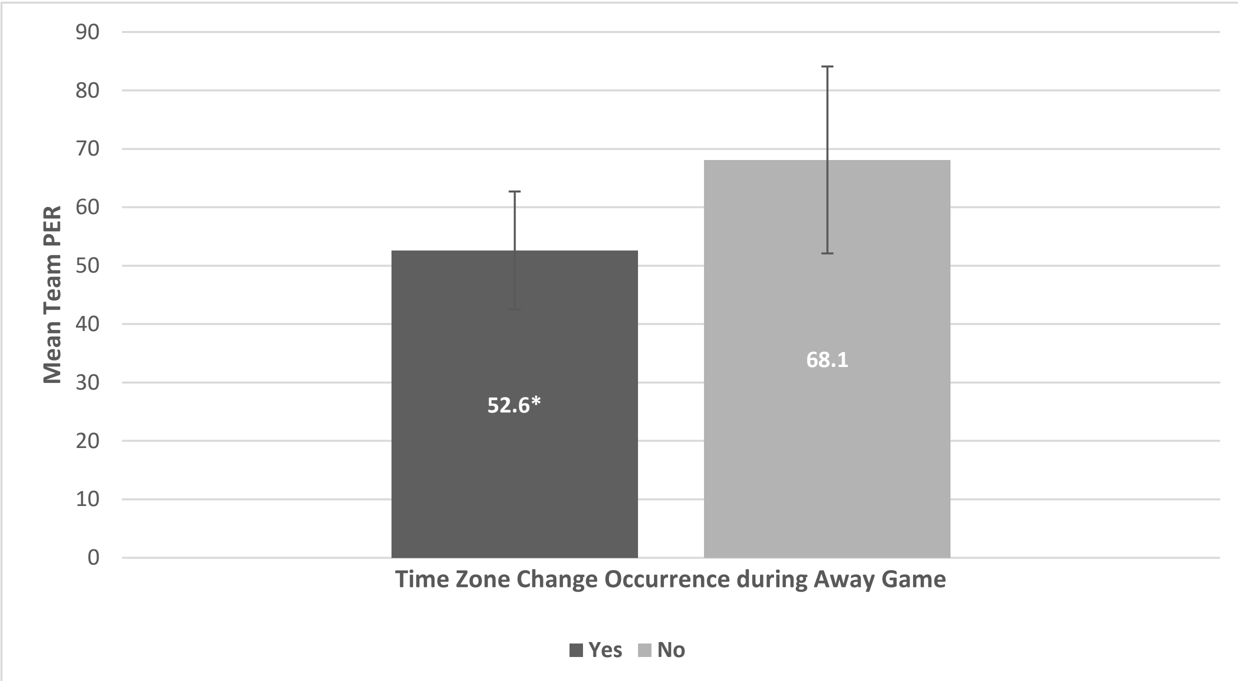
IV. **Total Distance Traveled (There and Back)**
   a. 0 points if less than 100 miles, 1 point for every 100 miles traveled (i.e. 150 miles = 1 point; 450 miles = 4 points; 1400 miles = 14 points)

V. **Time of Departure from Home Location**
   a. 1 point if 7:00AM or earlier, 0 points for later than 7:00AM

VI. **Time of Arrival back in Home Location**
   a. 1 point if later than 12:00AM, 0 points if earlier than 12:00AM

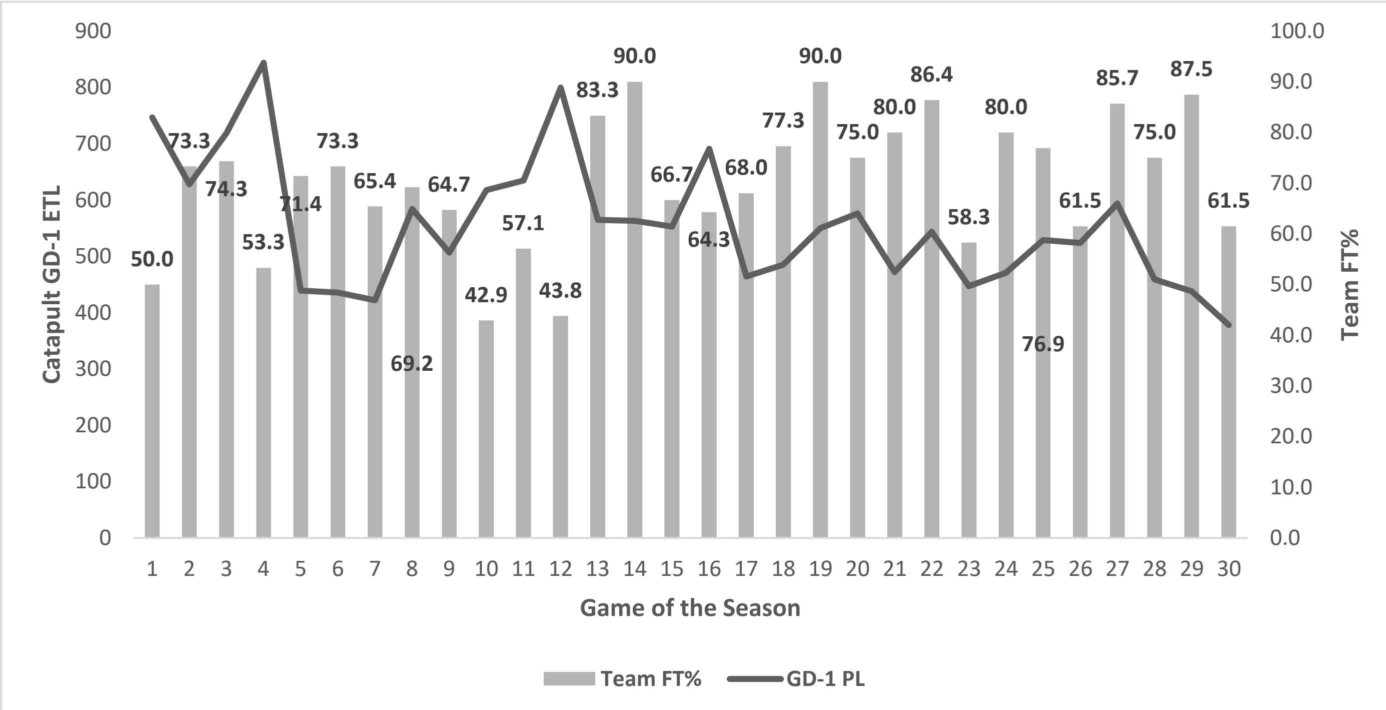
VII. **Time since last Competition**
   a. 2 points if last game is less than 24 hours between end of game and departure time; 1 point if less than 48 hours between end of game and departure time; 0 points if greater than 48 hours between end of game and departure time

Figure 4.2. Mean team PER during away games that required (n=7) or did not require (n=8) a time zone change during travel zone



Note: PER = Team performance efficiency rating; * denotes that away games requiring a time zone change were significantly different at the 0.05 level

Figure 4.3 Changes in mean Catapult GD-1 ETL and team FT% for every game across the season



4.11 Tables

Table 4.1. Travel means across different phases of season

Travel Parameter Means (SD)					
Phase of Season	**% Away Games**	**ATS Score Means**	**7DTS Means**	**CTS Score Means**	**Distance per Away Trip (miles) Means**
Non-Conference	46.1%	6.8 (8.8)	9.4 (10.2)	21.1 (14.0)	800.8 (5.0)
Conference	52.9%	6.5 (7.5)	15.5 (9.90)	39.5 (15.5)	720.2 (4.6)
Entire Season	50.0%	6.6 (7.9)	12.9 (10.3)	31.7 (17.4)	786.7 (4.7)

Note: Table reflects means (standard deviations) at different phases of the season. ATS = Acute Travel Stress; 7DTS = 7-Day Travel Stress; CTS = Chronic Travel Stress

Table 4.2A. Opponent quality adjusted correlations between team performance and composite travel stress parameters

Team Performance Outcome Measures Adjusted for Opponent Quality						
Travel Parameters	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Acute TS	.087	.188	-.044	.105	.066	-.026
7-Day TS	.014	.060	.316	-.045	.059	-.145
Chronic TS	.254	.137	.334	.127	.273	.159

Note: Table correlation values for Acute TS reflect Spearman's rho correlations with Opponent Quality adjusted outcome variables as this variable was not normally distributed; all other correlations reflect Pearson partial correlations with Opponent Quality as the controlled variable. TS = Travel Stress; ATS-Away Games = Acute Travel Stress for away games only (home games filtered out); PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table 4.2B. Opponent quality adjusted correlations between team performance and individual travel stress parameters

Team Performance Outcome Measures Adjusted for Opponent Quality						
Individual TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Travel Distance	-.300	-.197	-.004	-.213	-.264	.103
Time Zone Change	-.505**	-.596**	-.314	-.296	.027	-.005
Time of the Game	-.180	-.346	-.234	-.182	-.037	-.114

Note: Table correlation values for Travel Distance and Time Zone change reflect Spearman's rho correlations with Opponent Quality adjusted outcome variables as these variables were not normally distributed; all other correlations reflect Pearson partial correlations with Opponent Quality as the controlled variable. TS = Travel Stress; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table 4.3. Pearson partial correlations between Catapult GPS parameters and team performance adjusted for opponent quality

Team Performance Measures Adjusted for Opponent Quality						
Catapult GPS Metrics	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Total Prior Week PL	-.180	-.176	-.236	-.086	-.139	-.311
Prior Week PL/Session	-.124	-.133	-.298	-.039	.028	.004
Game Day -2 PL	-.130	-.109	-.279	.026	-.222	.093
Game Day -2 PL/min	-.058	-.151	-.177	.014	-.184	.195
Game Day -1 PL	-.143	-.099	-.056	.129	-.410*	-.134
Game Day -1 PL/min	.053	.166	.160	.292	-.529**	.179

Note: Table reflects Pearson partial correlations between Catapult GPS data and in-game team performance outcome measures with Opponent Quality as the controlled variable. PL = Player Load; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric; GD-2 = Two days before game; GD-1 = One day before game; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table 4.4. Group mean differences between two levels of observed travel parameters and opponent adjusted performance measures

Location	N	PER	EGSM	Catapult PQM	Field Goal %	3-Point %	Free Throw %
Home	**15**	71.71 (13.2)	-0.84 (8.62)	4.12 (0.37)	40.40 (5.17)	29.10 (7.79)	73.41 (14.08)
Away	**15**	60.88 (15.38)	-6.56 (12.66)	4.18 (0.59)	40.59 (5.73)	25.75 (12.52)	66.99 (11.17)
P-value		.048*	.161	.775	.926	.387	.178
Time Zone Change							
No	**8**	68.10 (16.03)	0.47 (11.49)	4.32 (0.62)	43.50 (4.41)	28.16 (15.83)	63.16 (11.30)
Yes	**7**	52.63 (10.13)	-14.59 (8.88)	4.02 (0.56)	37.26 (5.45)	22.99 (7.56)	71.37 (10.02)
P-value		.043*	.014*	.347	.033*	.430	.160
Mode of Transportation							
Bus	**4**	60.09 (20.98)	-7.25 (8.00)	4.20 (0.23)	40.52 (4.73)	24.93 (16.81)	66.67 (11.24)
Plane	**11**	61.17 (14.09)	-6.31 (14.32)	4.17 (0.69)	40.61 (6.26)	26.04 (11.59)	67.12 (11.69)
P-Value		.929	.876	.906	.975	.908	.950
Time since Last Game before Travel							
> 48 hours	**7**	55.49 (14.53)	-10.68 (7.78)	4.11 (0.39)	38.72 (3.72)	20.74 (12.58)	69.11 (8.29)
< 48hours	**8**	65.59 (15.41)	-2.96 (15.39)	4.24 (0.75)	42.23 (6.87)	30.13 (11.44)	65.13 (13.50)
P-Value		.214	.239	.676	.237	.158	.500

Note: Table data reflects group means (standard deviations) between different categories of travel stress parameters with an independent samples T-test performed to observe potential significant differences between groups. PER = Team Performance Efficiency Rating; EGSM = End-Game Scoring Margin; Catapult PQM = Catapult Performance Quality Metric; FG%. *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table 4.5. Interaction effects for time zone change and Catapult GPS ETL metrics on measures of in-game performance

Performance Outcome Measures												
	PER		EGSM		Catapult PQM		Field Goal %		3-Point %		Free Throw %	
Time Zone & ETL	**ß**	**p-Value**	**ß**	**p-Value**	**ß**	**p-Value**	**ß**	**p-Value**	**ß**	**p-Value**	**ß**	**p-Value**
TZ Δ	-.396	.060	-.554	.009**	-.197	.389	-.462	.041*	-.193	.414	.337	.133
PWETL	-.187	.282	-.137	.421	-276	.161	-.160	.390	-.087	.663	-.266	.162
p-Interaction		.678		.612		.460		.235		.158		.600
TZ Δ	-.440	.033*	-.587	.005**	-.264	.257	-.500	.021*	-.214	.357	.274	.206
GD-2 ETL	-.201	.236	-.160	.334	.106	.587	-.284	.111	-.003	.988	-.283	.126
p-Interaction		.697		.715		.937		.856		.722		.807
TZ Δ	-.471	.024*	-.612	.004**	-.284	.224	-.515	.024*	-.202	.385	.210	.299
GD-1 ETL	-.205	.224	-.172	.295	-.142	.464	-.100	.581	.078	.686	-.435	.014*
p-Interaction		.287		.331		.589		.419		.354		.692

Note: Table shows standardized beta values (ß) and their corresponding statistical significance from linear regression models with both time zone and each ETL metric entered into the models. P-interaction indicates the significance level of interaction terms when entered into models along with both independent variables (all p-Interaction > 0.05). ETL – Catapult External Training Load; TZ Δ = Time Zone Change; PWETL = Prior week accumulated ETL; GD-2 ETL = ETL during practice/game sessions two days prior to games; GD-1 ETL = ETL during practice/game sessions one day prior to games. * denotes significance at the .05 level; ** denotes significance at the .01 level

Table 4.6. Interaction effects for acute travel stress (ATS) and Catapult GPS ETL metrics on measures of in-game performance

Performance Outcome Measures												
	PER		EGSM		Catapult PQM		Field Goal %		3-Point %		Free Throw %	
ATS & ETL	ß	p-Value	ß	p-Value	ß	p-Value	ß	p-Value	ß	p-Value	ß	p-Value
ATS	.221	.506	.400	.246	.011	.976	-.036	.921	.227	.533	.207	.555
PWETL	-.269	.144	-.257	.173	-.311	.116	-.238	.234	-.134	.500	-.220	.255
p-Interaction		.309		.079		.407		.078		.137		.635
ATS	.229	.500	.402	.253	-.082	.825	-.005	.990	.206	.577	.247	.474
GD-2 ETL	-.220	.236	-.194	.310	.112	.579	-.285	.153	-.020	.920	-.303	.114
p-Interaction		.798		.585		.059		.868		.857		.531
ATS	.116	.736	.321	.370	-.094	.801	-.104	.783	.244	.508	.003	.993
GD-1 ETL	-.145	.436	-.077	.687	-.123	.542	-.058	.774	.124	.531	-.456	.013*
p-Interaction		.353		.280		.403		.728		.964		.563

Note: Table shows standardized beta values (ß) and their corresponding statistical significance from linear regression models with both acute travel stress (ATS) and each ETL metric entered into the models. P-interaction indicates the significance level of interaction terms when entered into models along with both independent variables (all p-Interaction > 0.05). ETL – Catapult External Training Load; ATS = Acute Travel Stress; PWETL = Prior week accumulated ETL; GD-2 ETL = ETL during practice/game sessions two days prior to games; GD-1 ETL = ETL during practice/game sessions one day prior to games. * denotes significance at the .05 level; ** denotes significance at the .01 level

Table 4.7. Interaction effects for chronic travel stress (CTS) and Catapult GPS ETL metrics on measures of in-game performance

Performance Outcome Measures												
	PER		EGSM		Catapult PQM		Field Goal %		3-Point %		Free Throw %	
CTS & ETL	ß	p-Value	ß	p-Value	ß	p-Value	ß	p-Value	ß	p-Value	ß	p-Value
CTS	-1.88	.175	-1.91	.179	.513	.715	-1.29	.344	-1.95	.176	-.608	.663
PWETL	-.590	.093	-.587	.102	-.206	.558	-.523	.129	-.504	.161	-2.97	.397
p-Interaction		.130		.154		.768		.247		.151		.516
CTS	.050	.917	.238	.625	.345	.475	-.122	.784	-.406	.395	.715	.120
GD-2 ETL	-.231	.570	.015	.970	.267	.518	-.553	.155	-.390	.340	.182	.637
p-Interaction		.694		.775		.690		.341		.224		.291
CTS	-.235	.844	-1.38	.248	-1.33	.264	-.461	.691	-.527	.660	-.280	.798
GD-1 ETL	-.174	.676	-.497	.233	-.512	.219	-.155	.701	-.029	.945	-.500	.195
p-Interaction		.698		.207		.217		.481		.541		.682

Note: Table shows standardized beta values (ß) and their corresponding statistical significance from linear regression models with both acute travel stress (CTS) and each ETL metric entered into the models. P-interaction indicates the significance level of interaction terms when entered into models along with both independent variables (all p-Interaction > 0.05). ETL – Catapult External Training Load; CTS = Chronic Travel Stress; PWETL = Prior week accumulated ETL; GD-2 ETL = ETL during practice/game sessions two days prior to games; GD-1 ETL = ETL during practice/game sessions one day prior to games. * denotes significance at the .05 level; ** denotes significance at the .01 level

4.12 Chapter IV Supplementary Materials

Figure S4.1. List of study terms

Travel Stress Metrics		
Term	**Symbol**	**Description**
Acute Travel Stress	ATS	Composite measure of travel stress for a single bout of travel; sum of several travel parameters such as travel distance, time zone change, etc.
7-Day Travel Stress	7DTS	Sum of all ATS points accumulated over the course of 7 days prior to a game
Chronic Travel Stress	CTS	Sum of all ATS points accumulated over the course of 1 month prior to a game
Catapult GPS Metrics		
Total Prior Week ETL	PWETL	Accumulated ETL for the week prior to the current week of games
Prior Week ETL/Session	PWETL /session	Average practice and game intensity for the week prior to the current week of games (duration of session/total ETL)
Game Day -2 ETL	GD-2 ETL	Accumulated ETL for the practice or game session that occurred two days prior to the current game
Game Day -2 ETL/min	GD-2 ETL/mi n	Practice/game intensity for the session two days prior to the current game
Game Day -1 ETL	GD-1 ETL	Accumulated ETL for the practice or game session that occurred two days prior to the current game
Game Day -1 ETL/min	GD-1 ETL/mi n	Practice/game intensity for the session two days prior to the current game
Basketball Performance Metrics		
Team Performance Efficiency Rating	PER	Sum of all individual PER scores for player playing more than 5 minutes PER = [(points+rebounds+assists+steals+blocks)-(turnovers+missed FG's+missed FT's)]
End-Game Scoring Margin	EGSM	The margin of the final score between the winning and losing teams; positive values reflect a win for the study team whereas negative values reflect a loss
Catapult Performance Quality Metric	PQM	GPS-measured physical performance for basketball games

Table S4.1 Team means for statistical performance across different phases of season

Performance Outcome Means (SD)						
Phase of Season	**Team PER Means**	**EGSM Means**	**Team FG % Means**	**Team 3-Point % Means**	**Team Free Throw %**	**Catapult GPS PQM**
Non-Conference	80.3 (23.1)	+8.4 (16.0)	42.5% (6.6)	29.4% (10.6)	63.2% (12.7)	4.1 (0.6)
Conference	56.4 (15.6)	-12.9 (13.2)	38.9% (5.3)	27.5% (10.3)	76.4% (10.5)	4.2 (0.5)
Season	66.2 (22.6)	-3.7 (17.8)	40.5% (6.0)	27.4% (10.4)	70.2% (12.9)	4.2 (0.6)

Note: Table reflects means (standard deviations) at different phases of the season. PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; FG = Field Goal; PQM = Catapult Performance Quality Metric

Table S4.2. Mean team statistical performance per game across different phases of season

In-Game Mean Team Statistics								
Phase of Season	**Points**	**Rebounds**	**Assists**	**Steals**	**Blocks**	**Missed Field Goals**	**Missed Free Throws**	**Turnovers**
Non-Conference	69.4 (12.7)	37.0 (8.7)	17.5 (7.4)	9.0 (3.8)	3.8 (3.3)	34.9 (6.6)	6.9 (3.3)	14.3 (4.7)
Conference	58.9 (9.2)	29.9 (7.0)	11.4 (2.3)	6.7 (3.3)	2.4 (1.6)	35.1 (5.3)	3.2 (1.9)	15.6 (3.3)
Season	63.2 (11.9)	32.7 (8.5)	14.1 (5.9)	7.7 (3.6)	3.0 (2.5)	34.9 (5.8)	4.9 (3.1)	15.0 (3.9)

Note: Table reflects mean (standard deviations) statistics at different phases of the season

Table S4.3. Mean team catapult GPS data across different phases of the season

Mean Catapult GPS Data								
Phase of Season	**Total Weekly ETL**	**Weekly ETL per Session**	**GD-2 ETL**	**GD-2 ETL per minute**	**GD-1 ETL**	**GD-1 ETL per minute**	**In-Game ETL**	**In-Game ETL per Minute**
Non-Conference	3638.8 (608.0)	685.5 (72.3)	567.1 (287.6)	3.57 (1.84)	611.1 (138.6)	4.02 (0.79)	729.1 (69.9)	5.74 (0.52)
Conference	3494.5 (604.3)	618.4 (110.1)	423.5 (234.6)	2.96 (1.48)	516.0 (74.4)	3.4 (0.34)	646.2 (118.6)	5.78 (0.36)
Season	3557.0 (599.8)	647.5 (99.9)	582.9 (159.4)	3.9 (0.8)	556.1 (115.5)	3.7 (0.7)	682.1 (107.4)	5.8 (0.4)

Note: Table reflects mean (standard deviation) GPS data at different phases of the season. ETL = External Training Load; GD-2 = Two days before game; GD-1 = One day before game. Weekly Catapult measures reflect the accumulation of ETL during basketball sessions from the week prior to the current week of games and each week was defined as Monday-Saturday. Both GD-2 and GD-1 ETL per minute reflect the intensity of basketball practice sessions by dividing the accumulated ETL for that session by the duration of that session in minutes

Table S4.4A. Correlations between team performance and composite travel stress parameters unadjusted for opponent quality

Team Performance Outcome Measures						
Travel Parameters	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Acute TS	-.338	-.251	-.074	-.178	-.261	-.148
7-Day Rolling TS	-.219	-.206	.126	-.041	.105	.015
Chronic TS	-.117	-.212	.106	.120	.309	.299
Chronic TS	-.117	-.212	.106	.120	.309	.299

Note: Table correlation values for Acute TS reflect Spearman's rho correlations as this variable was not normally distributed; all other correlations represent Pearson correlations. TS = Travel Stress; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S4.4B. Correlations between team performance and individual travel stress parameters unadjusted for opponent quality

Team Performance Outcome Measures						
Individual TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Travel Distance	-.363*	-.273	-.105	-.210	-.264	.107
Time Zone Change	-.601*	-.601**	-.437*	-.287	.027	.032
Time of the Game	-.202	-.300	-.258	-.180	-.019	-.052

Note: Table correlation values for Travel Distance and Time Zone Change reflect Spearman's rho correlations as these variables were not normally distributed; all other correlations represent Pearson correlations. TS = Travel Stress; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S4.5. Pearson correlations between team performance and catapult GPS parameters unadjusted for opponent quality

Team Performance Outcome Measures						
Catapult GPS Metrics	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Total Prior Week ETL	-.042	-.028	-.161	-.086	-.153	-.323
Prior Week ETL/Session	.119	.130	-.132	-.039	-.016	-.116
Game Day -2 ETL	-.045	-.023	-.222	.026	-.228	.057
Game Day -2 ETL/min	-.055	-.111	-.167	.015	-.178	.184
Game Day -1 ETL	.281	.331	.182	.110	-.431*	-.325
Game Day -1 ETL/min	.180	.255	.229	.285	-.543**	.069

Note: Table reflects Pearson bivariate correlations between GPS Catapult data and in-game team performance. ETL = External Training Load; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric; GD-2 = Two days before game; GD-1 = One day before game; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S4.6. Correlations between opponent travel stress and study population team performance for home games (n=15) adjusted for opponent quality

	Team Performance Measures					
Opponent Travel Stress	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Opponent Travel Distance (miles)	-.367	.161	-.243	-.433	.532	.118
Opponent Time Zone Change	-.131	.229	.229	.033	.180	.000
Opponent Hours since last Game	.060	-.289	.072	-.017	-.074	-.172

Note: Table reflects Spearman bivariate correlations between opponent time zone change and study population team performance adjusted for opponent quality; all other correlations reflect Pearson partial correlations between opponent travel stress and study population team performance with Opponent Quality as the controlled variable; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric Opponent Quality reflects opposing team Massey Power Rating (Lower Rating = Higher Opponent Quality). *denotes significance at the p < 0.05 level; **denotes significance at the p < 0.01 level

Table S4.7. Pearson correlations between Massey Rating opponent quality and in-game performance by study team population

Team Performance Measures						
Massey Rating for Opponent Quality	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**	**GPS PQM**
Opponent Quality	.744**	.784**	.459*	-.006	-.160	-.450*

Note: Table data reflects Pearson correlations between in-game performance and Massey Rating Opponent Quality; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric Opponent Quality reflects opposing team Massey Power Rating (Lower Rating = Higher Opponent Quality). *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Chapter 5.

Assessment of the Association between Travel Stress and Basketball-Specific Statistical Performance over a Five-Year period in NCAA DI Women's Basketball Athletes

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5.1 Abstract

Purpose: The aim of this study was to assess the effects of travel stress (TS) on measures of in-game performance of a NCAA DI Women's Basketball team over five competitive seasons. **Methods**: An NCAA DI Women's Basketball program was assessed via in-game statistical measures of performance such as the Player Efficiency Rating (PER), end-game scoring margin (EGSM), and shooting efficiency for each game over five consecutive seasons. TS was quantified by creating an evaluative travel checklist and was assessed at both the acute and chronic level. Outcome measures were adjusted for both opponent quality and seasonal differences in study team quality. **Results:** A small, but statistically significant, negative correlation was observed between the occurrence of time zone change during travel and EGSM ($r = -.120$; $p < .05$) and also between game start time and EGSM ($r = -.173$; $p < .01$). No statistically significant associations were observed between any composite TS metric and in-game basketball performance. **Conclusions:** Both travel-related time zone change and later game start time were observed to negatively impact EGSM, such that the team was more likely to lose if competing in a different time zone or if the game took place in the evening. Additional research to substantiate and expand on this study's findings, especially among universities competing in new conferences that will require travel across multiple time zones on a frequent basis.

Key Words: NCAA DI Women's Basketball, travel, in-game performance, scoring margin, time zone change

5.2 Introduction

Detrimental effects of frequent, long-distance travel on exercise and sports performance has been well documented, with most prior research focusing on professional sports performance. One review documented the characteristics of both travel fatigue and jet lag associated with travel across multiple time zones in elite athletes, with acute detrimental effects observed relating to both cognitive and physical performance, including excessive daytime fatigue due to circadian dysregulation and sleep loss, detriments in the performance items of strength, maximal speed, and endurance, as well as unfavorable changes in the ability to concentrate, motivation, and the mood states of anger and irritability.[1] More recent reviews on the effect of travel-related circadian desynchronization support this phenomenon, with travel distance, direction of travel, and time spent on an airplane all listed as factors contributing to reductions in sleep quantity and quality, alertness, subjective stress, perceived fatigue, mood states, and countermovement jump performance in team sports.[2−8]

Frequent, long-distance travel on in-game performance in professional athletes has also been well documented to reduce in-game performance.[2,4,5,9−20] One review on the effect of air travel and jet lag on athletic performance suggested performance items such as leg strength, jumping performance, sprint and anaerobic efforts, and sports-specific tasks might be negatively influenced following long-distance air travel with potential contributing factors including the oscillating circadian rhythm of athletic performance, circadian desynchronization, slow rate of resynchronization, and performance tasks being performed hours outside of a “peak circadian window” all cited in the current literature.[6] Particular to the sport of basketball, performance by professional basketball athletes in the National Basketball Association (NBA) has been reported to be negatively affected by high travel stress, with significantly lower team winning percentages observed in cases of multiple time zone travel, evening games, and westward travel taking place.[16] This finding is supported by a retrospective analysis over five years of NBA data, which reported that regardless of the direction of travel (east or west), travel distance from home location negatively influenced in-game performance and end-game point differential.[10] Additional reviews across multiple years of NBA games provide support to these findings and demonstrate a relatively consistent pattern of travel stress negatively influencing in-game performance and winning percentage in professional basketball athletes.[9,11,13,14]

Similar attempts to observe this relationship between travel stress and collegiate basketball performance at the NCAA DI level are fewer in quantity. One study demonstrated that more points were scored and more games won when traveling fewer miles away from the team's home city, in addition to a significantly higher field goal shooting percentage when there was more time in between games over ten years of NAIA Women's Basketball games.[15] Further, a study with NCAA DII Women's Basketball athletes added context as to why in-game performance might suffer from travel stress by demonstrating significant unfavorable changes in markers of health status such as resting salivary cortisol, heart rate, and blood pressure, as well as diminished knee flexion strength and vertical jump performance during the period of the season in which flight and travel frequency was at its highest.[2]

The collection of literature on the effect of travel stress on in-game performance in athletes, particularly women's basketball athletes at the NCAA DI level, indicates significant gaps in knowledge on how the acute or chronic travel stress experienced during a competitive season affect items of in-game performance. Filling this knowledge gap should be of particular interest to athletes and performance coaches at the NCAA DI level, who might soon encounter a greater magnitude of travel than ever before due to recent conference realignment. The primary study hypothesis was that acute and chronic travel stress each have a significant negative effect on all measures of in-game performance over five competitive seasons for an NCAA DI Women's College Basketball program, such that as travel stress increases, in-game statistical performance measures will significantly decrease.

5.3 Methods

Participants

Publicly available online box score statistics over the course of five competitive seasons for an NCAA DI Women's Basketball team were used as the source of data for all outcome measures of in-game performance for this study. Due to the publicly sourced data, no individual participants were recruited to participate in this study and the team as a whole was observed over five years of games played. The study protocol and use of collected data was approved by the university's institutional review board.

Design

This study was observational in its design to assess the effect of travel stress (TS) on items of in-game performance in NCAA Women's Basketball athletes over the course of five competitive seasons, spanning from November 2019 – March 2024 (https://georgiadogs.com/sports/womens-basketball/schedule). TS was measured for each game using a custom, evaluative TS checklist that quantified the TS imposed on the team during each instance of travel that included total distance traveled, instance of time zone change, and mode of travel. In-game performance was assessed using items of in-game statistical efficiency, end-game scoring margin, and shooting percentages. A total of 153 games played over five consecutive seasons were observed for this study.

Measures

Travel Stress (TS)

Three separate composite TS metrics were used to quantify the overall amount of TS for each game of each season. These composite TS metrics represent a sum of different isolated travel parameters such as distance traveled, time zone change, and travel modality for each instance of travel over five seasons. An Acute TS (ATS) metric summed all individual TS parameters associated with each instance of travel. In more detail, ATS was quantified using a checklist of travel parameters such as the occurrence of time zone change, total distance traveled (miles), mode of travel, etc. and Figure 5.1 provides the full list of travel parameters evaluated and how each parameter was scored. Total distance traveled and time zone change were weighted more heavily than other travel parameters to reflect the negative effect of each parameter on performance cited in the current literature. Home games received a "zero" score for ATS to reflect the fact that no acute travel was required for those competitions. A 7-Day TS (7DTS) metric and a Chronic TS (CTS) metric, were also calculated and represent, respectively, the rolling sum of all ATS points accumulated over seven days (7DTS) and the rolling sum of all ATS points accumulated for one month (CTS) leading into a game. Isolated travel parameters such as travel distance and instance of time zone change were also assessed independently, as prior research indicates an independent effect of travel distance and time zone change on exercise and sports performance.[3,9–11,14–16,18,20–22] Figure S5.1 in the supplementary materials for this study provides a full list of TS variables observed in this study, with abbreviations and descriptions provided for each TS variable.

In-Game Basketball Performance

In-game performance statistics were extracted from publicly available box score statistics for each game and performance was assessed through a combination of efficiency metrics to assess team performance over five years of games played. Player efficiency rating (PER) was calculated for each athlete during each game, and the sum of all athlete's individual PER was used to represent the "Team PER" for each game over five seasons. A full description of how PER was calculated for this study can be found in Figure S5.1 in the supplementary materials for this study. End-game scoring margin (EGSM) reflects the margin of either victory or defeat for each game observed, with positive values ("+7") representing a 7-point victory and negative values ("-7") representing the inverse. Finally, shooting efficiency was separated into three categories, with field goal percentage (FG%) representing the total number of shots made divided by the total number of shots taken, multiplied by 100. The same method was used to calculate 3-point shooting percentage (3P%) and free throw percentage (FT%). Figure S5.1 in the supplementary materials for this study provides a full list of basketball performance measures observed in this study, including abbreviations and descriptions for each.

Opponent Quality

To account for potential confounding by opponent quality on the observed relationships in this study, each team played over five seasons was assigned an "Opponent Quality Score". Opponent quality scores were extracted from the "Massey Ratings for NCAA DI Women's College Basketball" database, which quantifies the quality of a team via measures such as offensive efficiency, defensive efficiency, and strength of schedule (https://masseyratings.com). Opponent quality via Massey Ratings were on an ordinal scale with lower ratings reflecting a stronger opponent, such that a rating of "1" represented the best team in NCAA DI Women's basketball according to the Massey Rating database. Finally, opponent quality ratings were extracted upon the completion of the five seasons observed so that the rating for each team was finalized. Table S5.6 provides correlation values between Massey Rating Opponent Quality and in-game performance measures for the study team.

Statistical Analysis

Descriptive statistics were obtained for all continuous variables to assess normality and to screen for data anomalies and histograms were used to visually assess data normality. Associations between TS variables and in-game performance were assessed via standardized beta values generated from linear regression models adjusted for both opponent quality and study season. Due to the strength of the correlations between opponent quality and the dependent variables of performance observed in this study, all statistical analyses except for analysis of FT% were adjusted for opponent quality and Pearson correlations between opponent quality and items of in-game performance for the study sample can be found in the supplementary materials of this study in Table S5.6. To account for variations in study team quality, and its likely impact on performance metrics, associations between travel stress and performance measures were also adjusted for the season of play (Years 1-5). Independent samples t-tests were used to assess group mean differences in team performance across different categorical travel parameters. All statistical analyses were completed using SPSS version 26.0 (IBM Corp, Somers, NY) with an alpha level <0.05 indicating statistical significance.

5.4 Results

Tables 5.1 and 5.2 provide descriptive data on how TS (Table 5.1) and performance (Table 5.2) measures varied over the course of the five years observed in this study. Table 5.1 reports that ATS was, on average, at its highest during Year 4 of the study while mean CTS was higher across Year 3. Further descriptive tables for team performance separated by phase of the season (Tables S5.1-S5.2) can be found in the supplementary materials for this study, which demonstrate that team PER, EGSM, 3P%, and FT% was at its highest in Year 2.

Because of the previously described associations between team performance with opponent quality and season, correlations were reexamined after adjusting for these factors (opponent quality and season). Table 5.3A presents adjusted correlations between the three composite measures of TS (ATS, 7DTS, CTS) and performance metrics. All correlations were non-significant with the exception of an unexpected positive association between 7DTS and FT%. Table 5.3B demonstrates a low, significant negative correlation ($r = -.120$, $p < 0.05$) between time zone change and EGSM and also between the time of the game and EGSM ($r = -.173$, $p < 0.01$). Table 5.4 also demonstrates no significant mean differences between travel subcategories following an independent samples t-test except for the significant 7.5% increase in team FT% for away games involving a time zone change ($p < .003$), suggesting significant improvement in team FT% for away games played in a different time zone. Unadjusted correlation tables (Tables S5.3A-S5.4B), and correlations between opponent travel stress and study team performance (Table S5.5) can be found in the supplementary materials for this study, with Table S5.5 reporting no associations between opponent TS and study team performance over the five seasons observed in this study. Additionally, table S5.6 in the supplementary materials for this study report associations between opponent quality and study team performance, with significant positive associations observed between Massey Rating opponent quality and team PER, EGSM, and field goal percentage, suggesting that study team performance improved when playing against teams of lower quality and a higher Massey Rating.

Finally, Table S5.7 reports group mean differences between two levels of observed travel parameters and opponent adjusted performance measures. Data in table S5.7 demonstrates that the only significant difference between travel parameters on in-game performance is the significant, positive association between the occurrence of a time zone change and FT%, with FT% increasing by approximately 8% when games were played in a different time zone.

5.5 Discussion

This study observed the associations between measures of in-season travel and in-game statistical performance over five competitive seasons for one NCAA DI Women's College Basketball team. As discussed previously, strong associations reported in this study between opponent quality and study team performance, as well as variance in quality from the team observed in this study, required all associations observed in this study to be adjusted for both factors. Adjusting for each factor reduced all observed associations in both magnitude and significance, which would indicate that any future research on travel-related influences on sports performance should attempt to account for both factors, if possible. After adjusting for each factor, and contrary to the study hypothesis, composite measures of acute (ATS, 7DTS) and chronic travel stress were not associated with study performance measures, with the exception of a unexpected positive association between 7DTS and FT%. Despite composite measures demonstrating no influence on in-game performance, results of this study did demonstrate a significant, negative association between the occurrence of a time zone change and end-game scoring margin, such that the study team was significantly more likely to lose a game if it occurred in a different time zone. Game start time was also negatively associated with EGSM, such that games occurring earlier in the day were more likely to produce a favorable scoring margin (more likely to win) than games occurring later in the day.

The finding that the study team was more likely to lose a game played outside of its home time zone, regardless of opponent quality or quality of the team observed in this study, suggests the possibility of a circadian rhythm effect on in-game performance for the study team. This effect can potentially be explained through the effect of jet lag or travel fatigue associated with travel requiring one or more time zones changed, with jet lag demonstrating the potential to cause circadian desynchronization associated with sleep disturbance, intermittent fatigue, and impaired cognitive function, persistent fatigue, changes in mood state, and loss of motivation.[1,23] Further, the findings of this study on the effect of time zone change specifically during sport-related travel would support past research that demonstrated negative effects of travel on basketball performance in a sample of women's basketball athletes.[2,15,17] Inversely, and contrary to this study's hypothesis, study team FT% improved when 7DTS was higher and during games played outside of their home time zone. While speculative, this finding could be a reflection of coaching lineup changes in which athletes who were poor free throw shooters were given less playing time later in the season in which 7DTS and the occurrence of time zone change was at its highest. This positive association between 7DTS and time zone change on team FT% could also be coincidental and due to random chance as it does not match other negative associations between travel and performance observed in this study or reported in previous research.

This study also assessed opponent TS parameters such as travel distance, time zone change, and time since the last game played in hours for each opponent over the five years observed in this study for potential associations with in-game performance for the team observed in this study. It was hypothesized that study team performance might improve in games in which opponent TS is high leading into a competition against the study team, such as the opposing team having to travel a long distance or to a different time zone. However, opponent TS was not observed to contribute to any significant or practical improvements in study team performance over the course of five competitive seasons. Similar to the explanation above, a potential reason for this lack of effect could be that all games in the conference portion of the season required manageable travel distances for opposing teams as well, as all teams competing within the same conference were located in the same region of the U.S. Additionally, instances of time zone change for the opponent usually only involved a change of one time zone, with at least one day before the game to adjust to the new time zone in which the game was played, which research would indicate is enough time for circadian resynchronization to occur following a change of time zone for opponents.[23]

An interesting result of this study was the effect of the time of the game on in-game performance from the observed team over five years, such that games played later in the day led to less favorable EGSM compared to games played earlier in the day, which remained significant after adjusting for both opponent quality and seasonal differences in study team quality. One potential explanation is that residual fatigue from the day-to-day aspects of being an NCAA DI student-athlete accumulate throughout the day before evening games, leading the athletes to feel fresher and less fatigued in earlier games than games later in the evening. Another potential contributing factor for this finding could have been the tendency for the team of NCAA DI athletes observed in this study to skew towards "morningness" regarding diurnal preference or chronotype. This potential explanation can't be supported with prior research on the topic of chronotype distribution in groups of athletes stemming from the conflicting evidence with prior studies of much larger sample sizes than this study, with some studies highlighting a tendency for elite athletes to skew towards a "morning-type" chronotype,[24,25] while other studies demonstrate a virtual absence of "morning-type" preference in large groups of elite athletes.[26,27]. As it stands, the results of this study would contradict past research on time of day effects on peak performance, as multiple reviews on the circadian influence on performance would indicate a tendency for peak physical performance to occur later in the evening as opposed to earlier in the day.[28,29]

This study and its findings contribute to the very limited literature on NCAA DI student-athletes, particularly NCAA DI Women's Basketball athletes, while also providing a feasible template for future research on how TS might affect in-game performance for NCAA DI student-athletes. Despite the observed effects of time zone change on EGSM, results from this study do not suggest strong negative effects of TS on basketball performance as observed in similar studies conducted on professional basketball athletes. Specifically, prior studies with professional basketball athletes suggest a negative effect of jet lag and/or travel fatigue on winning percentage, point, rebound, and shooting percentage differentials, free throw shooting percentage, and in-game PER.[11,13,16,19] While most research with professional basketball athletes include a significantly larger sample of games observed than this study, one potential explanation for dissimilar results regarding the effects of travel could be the scheduling structure of the NCAA DI Women's Basketball season. There is a substantial difference in both the total number of in-season competitions between the NBA season (n = 82) and the NCAA season (n ~ 30) and, therefore, a significantly higher number of travel bouts in professional basketball. The team observed in this study also almost always had one or more days between competitions, allowing for travel to be scheduled more conveniently, with a more gradual acclimation to a new location after travel, whereas the NBA has historically scheduled games on back-to-back days, sometimes with travel in-between games on two consecutive days.[11] With recent conference realignment requiring increased travel demands for many NCAA DI athletes that is similar to professional sports, with new conferences covering large distances across multiple time zones, future research on the topic would help discern if TS produces the same unfavorable changes to outcome measures of performance cited in the literature with professional athletes.

5.6 Practical Applications

Recent and upcoming changes in NCAA DI conference affiliation for many universities necessitates further research on the effect of high TS on measures of sport-specific performance for all athletes competing at this level. This study demonstrated little to no effect of composite measures of TS on measures of basketball-specific performance, with the exception of a small, significant negative association observed between the occurrence of a time zone change and the end-game scoring margin. Results of this study could be of value for sports performance practitioners and athletes at NCAA DI universities that will be required to compete outside of their home time zone on a more frequent basis due to recent conference realignment.

Potential limiting factors for the results observed in this study include its observational design, small sample size, and focus on a single NCAA women's basketball team over five seasons. There were also no corrections for multiple statistical testing within this study, therefore, there is a greater likelihood of observing statistically significant associations by chance alone. These factors combine to reduce the statistical power and overall generalizability of this study. Also, athletes in this study travelled shorter distances than some of their peers at the NCAA DI level, as the conference they compete in is much more regional that other conferences of similar size. Finally, the measures of in-game performance used in this study are largely offensive statistics, which fail to capture positive or negative contributions on the defensive side of the sport to their full extent. These limitations could be addressed with similar future research that examines performance in NCAA DI athletes required to experience greater TS than the team observed in this study.

5.7 Conclusions

This study observed a small, but statistically significant, negative effect of time zone change on opponent and season-adjusted EGSM, suggesting that the occurrence of time zone change during travel decreases winning percentage compared to games played in a team's home time zone. Additionally, this study found a small inverse correlation between game start time and adjusted EGSM, suggesting a time of day effect on this sample of NCAA DI athletes. No significant adverse associations were observed between composite measures of acute and chronic TS and in-game performance measures.

5.8 Acknowledgements

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5.10 Figures

Figure 5.1. Travel Stress Evaluation to create Acute Travel Stress (ATS) Metric

The following criteria was used to evaluate the stress of travel throughout each week of the competitive season, with points assigned to each category based on the logistics of the travel taking place.

I. **Time Zone Change (Y/N)**
   a. 2 points for "yes", 0 points for "no"

II. **Number of games played during trip**
   a. 1 point for each game played during the trip

III. **Mode of transportation (Bus v. Commercial Flight v. Charter Flight)**
   a. 1 point for bus, 2 points for charter flight, 3 points for ATL commercial flight

IV. **Total Distance Traveled (There and Back)**
   a. 0 points if less than 100 miles, 1 point for every 100 miles traveled (i.e. 150 miles = 1 point; 450 miles = 4 points; 1400 miles = 14 points)

V. **Time of Departure from Home Location**
   a. 1 point if 7:00AM or earlier, 0 points for later than 7:00AM

VI. **Time of Arrival back in Home Location**
   a. 1 point if later than 12:00AM, 0 points if earlier than 12:00AM

VII. **Time since last Competition**
   a. 2 points if last game is less than 24 hours between end of game and departure time; 1 point if less than 48 hours between end of game and departure time; 0 points if greater than 48 hours between end of game and departure time

5.11 Tables

Table 5.1. Acute and chronic travel stress by year and phase of the season

Acute and Chronic Travel Stress Means						
Seasons	**Non- Conf. ATS**	**Conf. ATS**	**Non-Conf. CTS**	**Conf. CTS**	**Season ATS**	**Season CTS**
Year 1	4.0 (7.9)	7.2 (8.1)	12.7 (17.9)	42.3 (21.2)	5.9 (8.1)	29.9 (24.6)
Year 2	2.3 (3.9)	7.9 (9.3)	12.6 (7.7)	28.8 (17.2)	6.3 (8.5)	24.1 (16.7)
Year 3	5.7 (9.6)	10.2 (10.7)	21.2 (24.2)	45.4 (11.8)	8.4 (10.3)	36.0 (21.0)
Year 4	11.1 (16.4)	7.9 (8.2)	18.4 (20.8)	39.9 (14.9)	9.2 (12.1)	31.1 (20.3)
Year 5	6.8 (8.8)	6.4 (7.5)	21.1 (14.0)	39.8 (15.5)	6.6 (7.9)	31.7 (17.4)

Note: Table reflects acute and chronic travel stress means (standard deviations) at different phases of the season over five seasons; ATS = Acute Travel Stress; CTS = Chronic Travel Stress

Table 5.2. Team performance efficiency rating, end-game scoring margin, opponent quality, & field goal, 3-point, and free throw shooting percentage over 5 years

Team Performance Means (SD) by Season						
Seasons	**PER**	**EGSM**	**OPP QUAL**	**FG%**	**3P%**	**FT%**
Year 1	56.5 (6.4)	0.7 (18.6)	94.5 (99.6)	40.7 (6.8)	31.9 (20.3)	72.1 (11.5)
Year 2	84.6 (24.6)	10.8 (16.4)	77.8 (73.7)	43.8 (8.1)	33.1 (15.7)	74.9 (11.0)
Year 3	83.4 (21.8)	9.3 (18.0)	89.7 (94.5)	42.8 (6.2)	30.5 (14.4)	74.5 (11.7)
Year 4	76.0 (21.3)	8.3 (15.5)	88.2 (85.9)	43.8 (7.5)	29.7 (14.4)	70.0 (12.6)
Year 5	66.2 (22.6)	-3.7 (17.8)	82.3 (69.1)	40.5 (6.0)	27.4 (10.4)	70.2 (12.9)

Note: Table reflects team performance means (standard deviations) across five seasons. PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; OPP QUAL = Opponent Quality; Opponent Quality reflects opposing team Massey Power Rating (Lower Rating = Higher Opponent Quality)

Table 5.3A. Correlations between composite travel stress parameters and team performance adjusted for opponent quality and seasonal differences in study team performance

Team Performance Outcome Measures Adjusted for Opponent Quality and Seasonal Differences in Study Team Performance					
Composite TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**
Acute TS	.009	-.039	-.021	.035	.107
7-Day Rolling TS	.072	-.022	.029	.104	.189*
Chronic TS	.049	.096	.153	.082	.138

Note: Data reflects correlations derived from linear regression to adjust associations for both opponent quality and seasonal differences in study team quality. TS = Travel Stress; PER = Performance Efficiency Rating; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table 5.3B. Correlations between travel stress parameters and team performance adjusted for opponent quality and seasonal differences in study team performance

Team Performance Outcome Measures Adjusted for Opponent Quality and Seasonal Differences in Study Team Performance					
Individual TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**
Travel Distance	-.007	-.036	-.044	.032	.107
Time Zone Change	-.048	-.120*	-.023	-.021	.203*
Time of the Game	-.063	-.173**	-.088	-.009	-.002

Note: Data reflects correlations derived from linear regression to adjust associations for both opponent quality and seasonal differences in study team quality. TS = Travel Stress; PER = Performance Efficiency Rating; *denotes significance at the p < 0.05 level; **denotes significance at the p < 0.01 level

Table 5.4. Group mean differences between two levels of observed travel parameters and opponent adjusted performance measures

Location	N	PER	EGSM	Field Goal %	3-Point %	Free Throw %
Home	78	72.86 (21.07)	5.26 (12.78)	41.72 (6.05)	30.65 (15.53)	72.06 (12.73)
Away	76	73.64 (18.58)	4.93 (13.13)	42.95 (7.09)	30.29 (15.16)	72.47 (11.30)
P-value		.807	.877	.250	.886	.833
Time Zone Change						
No	37	74.60 (17.32)	7.89 (11.39)	43.78 (6.23)	30.76 (17.69)	68.63 (11.47)
Yes	39	72.74 (19.89)	2.13 (14.16)	42.17 (7.83)	29.86 (12.50)	76.10 (9.98)
P-value		.664	.054	.325	.799	.003**
Mode of Transportation						
Bus	20	74.28 (17.84)	5.54 (12.92)	43.61 (5.38)	32.02 (16.71)	70.52 (10.69)
Plane	56	73.41 (18.99)	4.72 (13.31)	42.71 (7.65)	29.68 (14.67)	73.16 (11.53)
P-Value		.856	.809	.571	.584	.359
Time since Last Game before Travel						
> 48 hours	55	74.87 (18.08)	4.78 (12.45)	42.82 (6.28)	31.43 (15.99)	72.50 (10.66)
< 48hours	21	70.45 (19.93)	5.34 (15.09)	43.29 (9.06)	27.34 (12.56)	72.37 (13.12)
P-Value		.382	.880	.830	.247	.969

Note: Table data reflects group means (standard deviations) between different categories of travel stress parameters with an independent samples T-test performed to observe potential significant differences between group means. Assessment of significant differences between time zone change, mode of travel, and time since last game at the time of travel were restricted to away games only with home game data filtered out. PER = Team Performance Efficiency Rating; EGSM = End-Game Scoring Margin. *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

5.12 Chapter V. Supplementary Materials

Figure S5.1. List of terms and abbreviations for different variables assessed in this study

Travel Stress Metrics		
Term	**Symbol**	**Description**
Acute Travel Stress	ATS	Composite measure of travel stress for a single bout of travel; sum of several travel parameters such as travel distance, time zone change, etc.
7-Day Travel Stress	7DTS	Sum of all ATS points accumulated over the course of 7 days prior to a game
Chronic Travel Stress	CTS	Sum of all ATS points accumulated over the course of 1 month prior to a game
Time Zone Change	-	Instance of a time zone change during travel for an away game
Total Distance	-	Total distance (miles) of an away game from the study team's home location
Basketball Performance Metrics		
Team Performance Efficiency Rating	PER	Sum of all individual PER scores for players playing more than 5 minutes PER = [(points+rebounds+assists+steals+blocks)-(turnovers+missed FG's+missed FT's)]
End-Game Scoring Margin	EGSM	The margin of the final score between the winning and losing teams; positive values reflect a win for the study team whereas negative values reflect a loss
Field Goal Percentage	FG%	Ratio of made shots to total shots taken (FG% = [made shots/total shots]x100)
3-Point Percentage	3P%	Ratio of made 3-pointers to total 3-pointers taken (3P% = [made 3's/total 3's]x100)
Free-Throw Percentage	FT%	Ratio of made free throws to total free throws taken (FT% = [made FT's/total FT's] x100)

Table S5.1. Team performance efficiency rating, end-game scoring margin, and opponent quality by year and phase of the season

Team Performance Means (SD) by Season									
	Performance Efficiency Rating			End-Game Scoring Margin			Opponent Quality		
Seasons	**Non-Conf.**	**Conf.**	**Season**	**Non-Conf.**	**Conf.**	**Season**	**Non-Conf.**	**Conf. OPP**	**Season**
Year 1	56.8 (4.9)	56.3 (7.5)	56.5 (6.4)	7.2 (21.8)	-3.9 (14.9)	0.7 (18.6)	153.5 (117.5)	51.9 (56.3)	94.5 (99.6)
Year 2	103.9 (22.9)	76.9 (21.2)	84.6 (24.6)	25.4 (17.3)	5.0 (12.0)	10.8 (16.4)	155.6 (84.9)	46.7 (38.8)	77.8 (73.7)
Year 3	96.3 (24.7)	75.3 (15.6)	83.4 (21.8)	23.3 (17.0)	0.4 (12.1)	9.3 (18.0)	162.6 (118.6)	43.6 (22.2)	89.7 (94.5)
Year 4	83.4 (23.8)	70.9 (18.2)	76.0 (21.3)	14.4 (15.7)	4.1 (14.1)	8.3 (15.5)	155.4 (95.2)	41.1 (30.9)	88.2 (85.9)
Year 5	80.3 (23.1)	55.5 (15.6)	66.2 (22.6)	8.4 (16.0)	-12.9 (13.2)	-3.7 (17.8)	129.3 (79.7)	46.3 (26.9)	82.3 (69.1)

Note: Table reflects team performance means (standard deviations) across five seasons by phase of each season. PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; OPP QUAL = Opponent Quality; Opponent Quality reflects opposing team Massey Power Rating (Lower Rating = Higher Opponent Quality)

Table S5.2. Field goal percentage, 3-point percentage, and free throw percentage by year and phase of the season

Team Shooting Percentage Means (SD) by Season									
	Field Goal Percentage (FG%)			3-Point Percentage (3P%)			Free Throw Percentage (FT%)		
Season	Non-Conf. FG%	Conf. FG%	Season FG%	Non-Conf. 3P%	Conf. 3P%	Season 3P%	Non-Conf. FT%	Conf. FT%	Season FT%
Year 1	41.1 (6.9)	40.4 (6.8)	40.7 (6.8)	27.5 (15.2)	35.0 (23.2)	31.9 (20.3)	73.0 (13.8)	71.5 (9.8)	72.1 (11.5)
Year 2	48.1 (8.7)	42.5 (7.6)	43.8 (8.1)	35.0 (17.0)	32.3 (15.7)	33.1 (15.7)	77.6 (7.9)	73.8 (12.1)	74.9 (11.0)
Year 3	44.7 (6.3)	41.6 (5.9)	42.8 (6.2)	30.1 (14.7)	30.7 (14.6)	30.5 (14.4)	70.3 (11.6)	77.2 (11.3)	74.5 (11.7)
Year 4	43.8 (7.2)	43.7 (7.9)	43.8 (7.5)	31.8 (14.6)	28.3 (14.5)	29.7 (14.4)	66.3 (13.4)	72.6 (11.6)	70.0 (12.6)
Year 5	42.5 (6.6)	38.9 (5.3)	40.5 (6.0)	29.5 (10.6)	25.9 (10.3)	27.4 (10.4)	63.2 (12.7)	75.5 (10.5)	70.2 (12.9)

Note: Table reflects team shooting percentage means (standard deviations) across five seasons by phase of season; FG% = Field Goal Percentage; 3P% = 3-point Percentage; FT% = Free Throw Percentage

Table S5.3A. Correlations between composite travel stress variables and team performance unadjusted for opponent quality or seasonal differences in study team population

Team Performance Outcome Measures					
Composite TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**
Acute TS	-.106	-.229**	-.063	.029	.025
7-Day Rolling TS	-.080	-.229**	-.078	.084	.152
Chronic TS	-.128	-.161*	.007	.054	.099

Note: Table correlation values for Acute TS reflect Spearman's rho correlations as these variables were not normally distributed; all other correlations represent Pearson correlations. TS = Travel Stress; PER = Performance Efficiency Rating; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S5.3B. Correlations between composite travel stress parameters and team performance adjusted for opponent quality

Team Performance Outcome Measures Adjusted for Opponent Quality					
Composite TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**
Acute TS	.004	.008	.050	.033	.025
7-Day Rolling TS	.091	-.011	.034	.092	.173*
Chronic TS	.039	.099	.134	.060	.118

Note: Table correlation values for Acute TS reflect Spearman rho correlations with Opponent Quality adjusted outcome variables as they were not normally distributed; all other correlations reflect Pearson partial correlations with Opponent Quality as the controlled variable. TS = Travel Stress; PER = Performance Efficiency Rating; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S5.4A. Correlations between individual travel stress parameters and team performance

Team Performance Outcome Measures					
Individual TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**
Travel Distance	-.105	-.216*	-.060	.010	.022
Time Zone Change	-.087	-.236**	-.094	-.012	.170*
Time of the Game	-.054	-.164*	.087	-.005	.006

Note: Table correlation values for Time Zone change reflect Spearman's rho correlation as this variable was not normally distributed; all other correlations reflect Pearson correlations. TS = Travel Stress; PER = Performance Efficiency Rating; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S5.4B. Correlations between travel stress parameters and team performance adjusted for opponent quality

Team Performance Outcome Measures Adjusted for Opponent Quality					
Individual TS Variables	**PER**	**End-Game Scoring Margin**	**Field Goal %**	**3-Point %**	**Free Throw %**
Travel Distance	.007	.027	.052	.015	.022
Time Zone Change	-.015	-.110	-.033	-.008	.170*
Time of the Game	-.061	-.225**	-.091	-.005	.006

Note: Table correlation values for Time Zone change reflect Spearman's rho correlation as this variable was not normally distributed; all other correlations reflect Pearson partial correlations with Opponent Quality as the controlled variable. TS = Travel Stress; PER = Performance Efficiency Rating; *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S5.5. Correlations between opponent travel stress and study population team performance adjusted for opponent quality

Opponent Travel Parameters	PER	End-Game Scoring Margin	Field Goal %	3-Point %	Free Throw %
Opponent Travel Distance (miles)	-.017	.102	.039	.032	.147
Opponent Time Zone Change	.033	.175	.157	-.096	.093
Opponent Hours since last Game	.050	-.118	-.121	-.102	-.168

Note: Table reflects Spearman bivariate correlations between opponent time zone change and study population team performance adjusted for opponent quality; all other correlations reflect Pearson partial correlations between opponent travel stress and study population team performance with Opponent Quality as the controlled variable; PER = Performance Efficiency Rating; Opponent Quality reflects opposing team Massey Power Rating (Lower Rating = Higher Opponent Quality);*denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Table S5.6. Pearson correlations between Massey Rating opponent quality and in-game performance by study team population

Team Performance Measures					
Massey Rating for Opponent Quality	**PER**	**EGSM**	**Field Goal %**	**3-Point %**	**Free Throw %**
Opponent Quality	.487**	.693**	.339**	.007	.039

Note: Table data reflects Pearson correlations between in-game performance and Massey Rating Opponent Quality; PER = Performance Efficiency Rating; EGSM = End-Game Scoring Margin; GPS PQM = Catapult Performance Quality Metric Opponent Quality reflects opposing team Massey Power Rating (Lower Rating = Higher Opponent Quality). *denotes significance at the $p < 0.05$ level; **denotes significance at the $p < 0.01$ level

Chapter 6

Summary and Conclusions

The collective findings of these studies add to the literature regarding how travel stress and sport-specific training load (TL) might independently affect, or combine to affect, measures of recovery and performance in NCAA DI student-athletes. These results come at a time of great change in the landscape of NCAA DI athletics, as many student-athletes at this level will soon be required to experience greater travel stress than ever before due to recent conference realignment. While detrimental associations of travel stress have been well documented at the professional level of many sports, fewer attempts have been made to observe similar associations at the NCAA level. These studies and their findings can hopefully serve as a template for future investigations on how travel stress during the competitive season affects items of recovery and in-game performance in this sample of athletes. Additionally, these studies were able to objectively quantify the physiological TL experienced by the athletes observed in this study with sport-specific GPS technology, which is becoming increasingly popular at the NCAA DI level of sports. The findings regarding GPS-measured TL and how it might impact recovery or performance can be used to better guide sport performance personnel who have been or might soon be using GPS technology to monitor sport-specific TL.

The first study aimed to assess the association of in-season travel stress and sport-specific TL on specific items of subjective sleep quality, subjective mood states, subjective physical readiness, and countermovement jump (CMJ) performance in a group of NCAA DI Women's Basketball athletes (n = 13). Assessments for each outcome measure occurred weekly throughout the course of one competitive season, spanning approximately four months. Key findings of this study include a significant, negative association between Chronic Travel Stress (CTS) and the subjective mood state of happiness and a significant, negative association between TL and the subjective states of soreness and fatigue. While statistically insignificant, results of this study also suggested a negative association of CTS with subjective sleep quality (SLQ) and a negative association of accumulated prior week TL (PWETL) with sleep onset latency (SOL), which Contrary the stated hypothesis, no significant negative associations between either travel stress or TL were observed with any outcome measure related to subjective sleep quality or CMJ performance, despite mean changes in both sleep quality and CMJ performance across the season. Finally, subjective sleep quality reported in this study indicate that these athletes would be classified as “poor sleepers”, as they reported lower average total sleep times and subjective feelings of restoration than what is recommended for their demographic by the National Sleep Foundation. The findings of this study are split in their agreement with previous research, with results regarding the negative association between travel stress and TL with subjective mood states of happiness, soreness, and fatigue supporting previous literature while results suggesting no association of either travel stress or TL with sleep quality or CMJ performance contradicting previous research on the topic.

The second study aimed to measure the independent and combined associations of travel stress and sport-specific TL with items of in-game basketball performance in an NCAA DI Women’s basketball team over the course of one competitive season. This study found that composite measures of travel stress were not significantly associated with any measure of in-game basketball performance after adjusting for the quality of opponent. However, the individual travel stress parameter of the occurrence of a time zone change demonstrated a significant, moderate negative association with both team performance efficiency rating (PER) and the end-game scoring margin (EGSM), such that games played in a different time zone had significantly reduced in-game efficiency and lower chances of having won that particular game. Additionally, results from this study demonstrated a significant, moderate negative association between TL accumulated on the day prior to a game and team free throw percentage (FT%), such that increases in either the volume of TL (GD-1 ETL) or intensity of TL (GD-1 ETL/min) were associated with significantly reduced team FT%. Prior week accumulated TL (PWETL) also demonstrated a low-moderate, insignificant negative association with GPS-measured movement quality (PQM), suggesting the potential for a significant association in studies with a larger sample of athletes or games. Finally, no significant interactions between travel stress and TL with in-game performance were observed following assessment via linear regression. Rather, time zone change was observed to be negatively associated with team PER, EGSM, and team field goal percentage (FG%) independent of measures of training load. In contrast, in models adjusted for time zone changes, the only significant association observed between training load and performance was a weak negative association between GD-1 ETL and team FT%. Overall, results of this study would contradict prior research on how travel and TL might negatively affect in-game performance in athletes, as none of the composite measures of TS were significantly associated with any measure of in-game performance assessed in this study. However, the significant, negative association between time zone change and in-game performance would agree with previous research on how time zone change might negatively influence in-game sports performance.

The final study observed associations between travel stress with in-game basketball performance for an NCAA DI Women's Basketball team over five competitive seasons. The results of this study somewhat mirrored results from the second study, finding no associations between composite travel stress measures with any item of in-game performance but significant, negative associations between the occurrence of a time zone change for a game with the EGSM.

This finding suggests that a game was significantly more likely to be lost if it was played in a different time zone than the study team's home time zone. Interestingly, this study also demonstrated a significant association between the start time of a game and the EGSM, such that games starting later in the day were more likely to be lost than games played earlier in the day. These negative associations for time zone change and the start time of the game remained statistically significant even when adjusting for both opponent quality and seasonal differences in study team quality, indicating that these two findings were not driven by variance in quality of either the study team or their opponents over the course of the five seasons observed in this study. Further, the observed negative association between time zone change and sports performance supports previous research that has also reported negative associations between time zone change and sport-specific performance. However, the finding that games later in the day were associated with a lower chance of winning the game is harder to interpret as prior research suggests that physical performance peaks in the late afternoon/early evening time window (1530-2030 hours). However, prior research on time-of-day associations with sports performance largely focus on individual sports performance, whereas this study reports time of day associations with team sports performance, which hinders comparisons with prior studies.

To conclude, these studies suggest significant, small to moderate negative associations between specific items of travel stress, such as CTS and occurrence of time zone change, with subjective mood states of happiness, soreness, and fatigue, and in-game performance measures of team PER and EGSM. Further, small, but significant, negative associations were observed between TL team FT%, particularly if high TL was accumulated on the day prior to a game. Finally, and interestingly, these results suggest that games played earlier in the day are significantly more likely to have a more favorable scoring margin and a greater chance of winning than games starting later in the evening. Conversely, no significant associations were observed between travel stress or TL with items of sleep quality or CMJ performance, and no interactions between travel stress and TL were observed with measures of in-game women's basketball performance.

Future research is warranted to expand current knowledge on how travel stress influences recovery and performance in NCAA DI athletes, particularly those that will be competing in conferences that will require large travel distances across multiple time zones frequently throughout the competitive season. Further, future research should compare the associations of travel between different NCAA DI sports that require more in-season travel than the team observed in this study. Continuing to expand this line of research could be particularly useful for sports performance practitioners across all levels of NCAA athletics to better understand how travel stress, either in isolation or combined with measures of sport-specific TL, might negatively affect the recovery status or performance of athletes.