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The Effects of a Roundtrip Trans-American Jet Travel on Physiological Stress, Neuromuscular Performance and Recovery

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Running Head: Trans-American Jet Travel and Performance

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Abstract

The purpose was to examine a round trip trans-American jet travel on performance, hormonal alterations, and recovery. Ten matched pairs of recreationally trained men were randomized to either a compression group (COMP) (n= 10, age: 23.1 ± 2.4 years, height: 174.8 ± 5.3cm, body mass: 84.96 ± 10.16 kg, body fat: 15.3 ± 6.0%) or control group (CONT) (n= 9, age: 23.2 ± 2.3 years, height: 177.5 ± 6.3cm, weight: 84.35 ± 8.99 kg, body fat: 15.1 ± 6.4%). Subjects flew directly from Hartford, CT to Los Angeles, CA one day prior to a simulated sport competition (SSC) designed to create muscle damage and returned the next morning on an overnight flight back home. Both groups demonstrated jet lag symptoms and associated decreases in sleep quality at all time points. Melatonin significantly ($P < 0.05$) increased over the first two days and then remained constant after the SSC. Epinephrine, testosterone, and cortisol values significantly increased above resting values before and after the SSC with norepinephrine increases only after the SSC. Physical performances significantly decreased from control values on each day for the CONT group with COMP group exhibiting no significant declines. Muscle damage markers were significantly elevated following the SSC with the COMP group having significantly lower values while maintaining neuromuscular performance measures that were not different from baseline testing. Trans-American jet travel has a significant impact on parameters related to jet lag, sleep quality, hormonal responses, muscle tissue damage markers, and physical performance with an attenuation observed with extended wear compression garments.

Key Words: muscular performance, circadian patterns, power, speed, endocrine system, neuromuscular

New & Noteworthy

This study demonstrated trans-American jet travel going from east to west to participate in a rigorous simulated sport competition had dramatic effects on hormonal responses, sleep quality and neuromuscular performances. Return travel to the east after the simulated sport competition resulted in muscle tissue damage and delays in neuromuscular and muscle tissue recovery upon return home. The use of extended wear whole body compression garments reduced the recovery times upon the homebound arrival.

Introduction

If anyone has ever been in a plane for over 5 hours it might be obvious that there is a great deal of stress and what we understand about this phenomenon is woefully lacking. Thus, due to the dramatic impact on human physiology, jet travel across multiple time zones has been a topic of some interest (24, 33). However our understanding of jet travel on performance and recovery after intense exercise stress is less understood. In part, this is due to the need for an extensive and costly experimental undertaking to investigate such questions.

While the disruption of the body's circadian mechanism is most notably reflected in the changes in the pineal gland's secretion of melatonin, which is sensitive to established light-dark cycles (1, 11), a multitude of other factors can contribute to travel fatigue and exacerbate the magnitude and duration of "jet lag" (33). Jet lag can result in a sensation of disorientation as well as other symptoms including tiredness, inability to sleep at the normal time in the new time zone, loss of concentration, loss of psychological drive, headaches and general malaise (29). However, sleep loss appears to be one factor that may mediate many of the fatigue symptoms of jet lag and primarily contribute to performance decrements (37).

Although the concept of jet lag is well established, its effects on physical performance have not been well studied. At present, only a small number of studies have observed these effects and the parameters that have been assessed are diverse, including running speed alone (6), sprint and middle-distance performance (45), grip strength and reaction time (30) and subjective assessments of training quality (25). However, these studies examined the effects of long-haul flights traversing relatively large time zone changes, ranging from 5-8 time zones crossed. In addition to long-haul flights, performance decrements have been suggested to occur when as few as 2-3 times zones are traversed (3, 16, 36, 38). However, these studies observed and analyzed the effects of travel on the results of athletic competitions, and did not include direct scientific study of performance or its associated physiological mechanisms.

Support for possible impairments in performance from shorter flights comes from the suggestion that the time required to recover from symptoms of jet lag is approximately half a day per time zone westward, and 1 day per time zone eastward (15). In this case, a 3 hour time zone change eastward would require 3 days of recovery. This would be of concern to professional and collegiate sport teams in the United States and other countries, because frequently travel across 3 times zones occurs shortly before an athletic event, either due to condensed schedules or regulations of the sport governing bodies, such as the National Collegiate Athletic Association (NCCA). It has been suggested that jet lag and performance decrements may occur with short flights traversing 2-3 times zones primarily due to sleep disruption (2,3). This is may be due to the fact that melatonin concentrations will not be increased enough at the time of the event of impact performance and therefore other mechanisms such as sleep loss may be playing a role to negatively affect performance (2,3,11,25).

Not only do the effects of time zone travel impact athletic teams before an event by potentially negatively affecting performance, but the recovery processes that are required following an athletic event may also be hindered on the return flight. As trans-American jet travel takes approximately 5-6 hours, and is coupled with limited space available for many passengers traveling in economy class on commercial flights, travelers are forced into prolonged periods of sitting with little movement. Such prolonged periods of sitting have been shown to lead to significant reductions in thigh and calf blood flow, with concomitant increases in calf and thigh blood pooling (34). These hemodynamic effects could drastically impair performance upon arrival in a time zone as well as the ability to recover upon return to the original time zone.

Addressing the recovery process of skeletal muscle from strenuous exercise which produces tissue damage has been thought to be an important concern for many individuals who routinely travel for athletic competitions or strenuous recreational activities (24). Apart from pharmaceutical interventions that have been used to assist in recovery, prior research on compressive garments have shown promise in helping in recovery and provided an interesting and unique experimental secondary dimension to our understanding of jet-lag/travel stress (18, 20, 27, 40). The physiological effects of such compressive therapy after damaging exercise has been shown to reduce indirect markers of skeletal muscle tissue damage and allow performance recovery at a more rapid rate (18, 19, 27). Such an effect would appear beneficial to trans-American jet travel when highly stressful exercise is performed prior to returning home from competitive or recreational events. Consistent with our prior research, we hypothesized that within the jet-lag/travel stress model we used, enhanced recovery would be possible using extended wear of compression garments.

Our current understanding of the associated hormonal responses to actual trans-American jet travel resulting in jet lag and travel stress beyond the obvious focus on melatonin secretion remains unclear and imprecise at best. It is well established that several endocrine factors display distinct circadian oscillations, which are controlled by both endogenous factors and external stimuli. Disruptions of such circadian rhythmicity could result from disrupted sleep-wake-cycles (10), imposed by jet lag/travel stress. Considering the role of epinephrine, norepinephrine and cortisol in preparing the human body for an increased need for alertness and energy demands prior to physical activity, avoiding disruptions in the circadian cycles may be crucial for athletic populations traveling across several time zones shortly prior to athletic events.

The catecholamines epinephrine and norepinephrine both display similar circadian patterns, with the lowest levels occurring during nighttime. While the norepinephrine rhythm is strongly dictated by changes in posture and the sleep-wake -state, the circadian oscillation of epinephrine does not appear to be as strongly dictated by the same variables (26). Cortisol release, with the peak occurring in the morning (41), displays a lower sensitivity to behavioral changes, likely indicating strong endogenous regulation similar to epinephrine (8, 10). However, the effect of time-zone travel on these endocrine factors has not been previously established.

Therefore, the primary purpose of this investigation was to examine the impact of trans-American travel on physical performance and associated hormonal and sleep related responses in order to gain some insights into potential mechanistic contributions to any reductions in physical performance. Secondarily, we wanted to assess the impact of a return flight on recovery processes following demanding physical activity and determine whether a compression garment intervention can ameliorate any of tissue damage effects upon return to the original time zone.

Methods

Experimental Design

This study design represented an extensive and comprehensive examination of trans-American travel. A detailed schedule is presented in Table 1. A battery of physiological, psychological, and physical performance tests were administered during a United States east coast to west coast and return travel schedule. After extensive familiarization, baseline testing was performed the day before travel. Subjects were asked not to ingest any alcohol during the course of the study. Similar to our prior muscle damage studies after the simulated sporting event creating muscle damage subjects were ask to refrain from the use of any medication or extended showers. For all testing each of the participants wore their same athletic equipment including shoes. The schedule developed would be typical for many NCAA teams of athletes following NCAA regulations, who are based in the northeast United States participating in competitions on the west coast. We used this team approach in conducting our investigation as typical to schedules and organization of event sequences in order to provide insights and generalizations to multitude of similar jet travel to and from recreational and competitive events each year in the United States.

Table 1 about here

Participants

Following a detailed explanation of study procedures as well as the risks and benefits involved in the study, all participants provided informed consent prior to the start of the study. The study was approved by the university's Institutional Review Board for use of human subjects in research. Ten pairs of subjects were matched for Ponderel Index and body fat percentage and activity backgrounds and then randomized into one of two groups. Body composition was measured by a trained technician via the 3 site Jackson-Pollock skinfold technique (14). One subject could not make the flight and thus nineteen recreationally trained men (i.e., had been weight training and endurance training for over 6 months) participated in the study consisting of either a compression group (COMP) (n=10; age: 23.1 ± 2.4 years, height: 174.8 ± 5.3cm, body mass: 84.9 ± 10.1 kg, body fat: 15.3 ± 6.0%) or control group (CONT) (n=9; age: 23.2 ± 2.3 years, height: 177.5 ± 6.3cm, weight: 84.3 ± 8.99 kg, body fat: 15.1 ± 6.4%). While no formal training study was undertaken with the subjects in the investigation, each of the subjects reported to have been involved with progressive heavy resistance training with complementary endurance training, each performed 3 to 4 times a week. Resistance training was characterized by periodized, multiple sets, whole body, large muscle groups exercises with targets for muscle strength and size. Subjects were former high school and college athletes who participated in a variety of sports including football, basketball, track and field, wrestling, baseball and some were former warfighters in the military who were all accustomed with intense weekly physical training routines.

Clothing Apparel and Compression Garments

After randomization the groups were supplied with two sets of either loose fitting apparel or compression garments so that they could be laundered during the study time frame. The garments were worn after the first baseline testing session and continued to be worn for the entire experimental time frame. The compression garments had been designed for long term wear. The garments were worn at all times during the study (including sleep) except during the simulated sporting event (muscle damage protocol), during brief showers, or when blood draws were obtained. The compression garments used was the Under Armour Recharge™ upper and lower body garments constructed to produce needed compression and to allow long-term wear with comfort (75% nylon and 25% spandex) [Under Armour, Baltimore, MD, USA]). In this study we used the Under Armour Recharge™ long sleeve shirt lower body leggings for easy use in everyday activities. All testing and the simulated sport competition took place without the use of the garments. Prior work on the Under Armour Recharge™ whole body suit had been previously shown to effectively improve recovery after high intensity resistance training workouts (20).

Procedures

Familiarization

We used an extensive familiarization process prior to data collection. Familiarization sessions (i.e., 3-4 as needed before the final Day 1 familiarization session, see Table 1) were conducted with the participants to reduce or limit learning effects. During these sessions each participant practiced the test so that each participant was fully familiarized with each of the testing procedures. Each participant had all questionnaires explained to them and investigators answered questions so that they understood the different elements of each questionnaire. The participants took the questionnaires with them to further familiarize themselves with the questionnaires and were allowed to ask any subsequent questions that arose for proper completion.

Controls

All participants were non-smokers and had not used any anabolic drugs and were cleared medically by a physician so as not to have any clinical, orthopedic, or pathological conditions that would confound the effects of the study. In addition, subjects were requested to refrain from taking any oral pain medications including NSAIDs during the study and to abstain from any normal heavy lifting for a period beginning 3 days prior to the study. After completing the simulated sporting event, subjects were asked to limit water temperature and duration when bathing, to abstain from physical activity other than those activities required during daily living tasks, and to use no pain-relieving modalities including heat, ice, or massage during the study. In addition, a registered dietician monitored food intakes and screened subjects for any usual diets or supplements which might have compromised or confound the variables measured in the study. Normal caffeine intakes were observed and no attempt was made to limit caffeine ingestion as only water was allowed 4 hrs prior to testing.

Testing Battery

Urine and Blood Sampling

Prior to the physical testing battery, urine and blood samples were collected.

Urine Samples: Upon arrival to the laboratory, participants provided a urine sample and hydration state was confirmed by measurement of urine specific gravity (USG) with a handheld refractometer (Reichert, New York, NY). A USG < 1.020 indicated euhydration. Due to frequent verbal instructions to keep hydrated and to drink 0.5 liters of water at night and in the morning almost all subjects met this requirement before all testing sessions during the study. If USG was > 1.020, then participants were instructed to drink water until their USG was < 1.020.

Blood Samples: An indwelling Teflon cannula was inserted by a trained phlebotomist into superficial antecubital forearm vein and after sitting quietly for 10 minutes in the seated position a 33 ml blood sample was collected from a vacutainer set-up into serum (10ml), EDTA (10ml), Na citrate (5ml) and Na Heparin (8ml) tubes. Serum and plasma samples were immediately centrifuged at 1,500 g for 15 min at 4 ° C aliquoted in to appropriately sized and labeled Eppendorf tubes and stored at –80° C until subsequent analyses. Samples were thawed only once for analysis. All blood samples were performed in duplicate analyses.

Total creatine kinase was measured in duplicate from serum samples using liquid creatine kinase reagents (Sekisui Diagnostics, Canton, MI) and assayed according to manufacture instructions. Intra-and inter-assay coefficients of variations for creatine kinase were below 3.9%. Myoglobin was measured from EDTA-plasma in duplicate via enzyme linked immunosorbancy assay (ELISA) (CALBiotech, Spring Valley, CA). The mean intra-assay coefficients of variation (CVs) were 5.6% and inter-assay coefficients of variation were 7.9%.

All ELISAs were performed on a VersaMax tunable microplate reader (Molecular Devices, Sunnyvale, CA) at the appropriate wavelength for that particular assay and customized data analytics. Cortisol and total testosterone were measured by ELISA from serum (CALBiotech, Spring Valley, CA). The intra-assay coefficients of variation were 5.4% and 4.1% and the inter-assay coefficients of variation were 6.8% and 7.6% for cortisol and testosterone, respectively.

Epinephrine and norepinephrine were extracted from serum samples and acylated according to manufactures instructions (ALPCO Diagnostics Salem, NH). The prepared samples were then measured by ELISA. The intra-assay coefficients of variation were 8.1% and 3.6% and the inter-assay coefficients of variation were 10.8% and 5.8% for epinephrine and norepinephrine, respectively.

Melatonin was analyzed from the EDTA-plasma samples by ELISA (Abnova, Walnut, CA). Intra-and inter-assay coefficients of variations for melatonin were below 7.3%.

Physical Testing

Per Table 1, when specific time frame physical performance testing was to be performed, it followed the urine and blood sampling procedures. Prior to the testing battery being administered, each participant performed a warm-up protocol. The warm-up included 5 minutes on a cycle ergometer with light resistance and a constant speed of 60rpm. This was followed by a series of standard dynamic stretches, including forward lunges, lateral lunges, knee hugs, quad pulls and straight leg march.

Countermovement Vertical Jump: While typical in many athletic testing facilities and in order to have identical equipment set ups in each laboratory, a *Vertec* device (JumpUSA, Sunnyvale, CA) was used to measure vertical jump capabilities. Participants stood with feet hip width apart directly under the *Vertec* before performing a rapid countermovement and jumping with maximal effort. Participants were instructed to reach the highest possible vane with their dominant hand. About 2 to 3 minutes rest was taken between attempts and the highest jump height was used for subsequent analysis.

Hand Grip Strength: This measure was determined using a hand grip dynamometer. Participants stood with feet hip-width apart and shoulders level. The dynamometer (T.K.K.5401 GRIP-D [DIGITAL GRIP DYNAMOMETER, Niigata City, Japan) was held in their hand with their dominant (i.e., determined by what hand they write with and throw a ball the furthest with) arm hanging straight down at their side with no bend in the elbow. Each subject was allowed three attempts with the best of the three attempts used for analysis. From our work with NHANES we used the same testing protocol as described (i.e., chapter 3) for grip strength (http://www.cdc.gov/nchs/n(nyfs/manuals.htm). Each subject was tested on the same calibrated dynamometer over the course of the study at both testing sites.

Quickness and Reaction: Per Table 1, the Quick Board™ test was only performed at the *Human Performance Laboratory* in CT before and after the air travel. The Quick Board™ system (Memphis, TN) was used to measure foot quickness and reaction time of lower body stepping movements (17). Briefly, the Quick Board™ system is comprised of a visual stimulus board with five lights consisting of two on the top, one in the middle and two on the bottom and a corresponding step pad on placed on the ground. Once the test began, one of five lights illuminates. The participant then steps on the pad located on the floor that corresponds to the light in the same position. Once the participant stepped on the correct pad, a new light illuminated. If the participant steps on an incorrect pad, a buzzer sounded and the participant was required to contact the correct pad before a new light would appear. The test continues for 10 seconds and the number of correct were recorded and used for analyses in this investigation. About one minute rest was taken between trials and in this study the best score of three trials was used for analysis.

Pro-Agility Drill (5-10-5 Drill): This Pro-Agility drill is a common shuttle run test used by many coaches (e.g., NFL and College Combines) to test athletes' lateral quickness and speed (35). On a gym floor, the same experienced tester using a stopwatch timed each participant in this drill. The subject starts the drill running for 5 yards (4.572 m) to the right, touches the line and then changes direction and runs 10 yards (9.144 m) to the left and touches the line and then runs 5 yards (4.572) straight through the finish line. Each participant had three trials with about 5 minutes rest between trails with and the fastest time used for analysis.

40 Yard Sprint (36.576 m): A maximal effort sprint of 40 yards (36.576 m), typical of most athletic sprints tests done by coaches in the USA, was used to assess sprint speed in this study (4). On a fieldhouse floor, an experienced tester using a stopwatch timed each participant in this drill (28). Approximately 5 minutes rest was taken between two trials. The faster of the two trials was used for analysis.

Perceptual Testing

Liverpool Jet Lag Questionnaire (LJLQ): Jet lag symptoms (e.g., sleep quality, fatigue, perception of jet lag) were reported by completing the LJLQ (43) each evening and morning during the data collection period. This questionnaire was designed to measure all of the symptoms of jet lag at different times of day and is a common validated tool used to assess jet lag in athletes and was the underlying reason why we chose to use it in this study (44). Questionnaires for each day of the investigation were collected by the research team.

Travel -Connecticut to California:

Baseline testing was performed the day before travel starting at 1300 hrs ET. The entire research team and all participants traveled together during the entire investigation similar to an athletic team. Study participants arrived at the *Human Performance Laboratory* at the

University of Connecticut at 05:00 ET. For both the East and West bound flights, all subjects went through the Transportation Security Administration |(TSA) security check points but the lines were not long and time to make it through the process was not excessive but was an added component of the travel stress. Following urine and blood sampling at 0600 ET, participants were transported by chartered bus for 30 minutes to Bradley International Airport (BDL) in Hartford, CT for the departing flight at 09:00 ET. The flight was direct to Los Angeles International Airport (LAX) flying on a Boeing 737-800 airliner with participants traveling in coach class, randomly ticketed throughout the plane in coach class with a travel time of 6 hrs and 20 minutes arriving at 12:20 PT. Participants were then transported by another chartered coach to the *Human Performance Laboratory* at California State University-Fullerton, for testing with a travel time of 1 hour. Participants changed and rested in the locker rooms and prepared for testing which began at 1500 hrs PT.

Upon completion of the testing, participants showered and changed and were transported to the campus hotel and were checked into their rooms. As with a team, a group dinner was scheduled at 1830 hrs. After dinner, all participants were instructed as to the schedule for Day 2, rested in the hotel and instructed to turn in by 2200 hrs to get ready for the next day's events.

Day 2 started with a scheduled group breakfast from 0700 to 800 hrs. Participants then rested and later were instructed as to what the schedule would be for the rest of the day, including reviewing the experimental simulated sporting event routine. Participants than packed and along with the research team checked out of the campus hotel and returned to back to the laboratory for testing. Per Table 1, testing of the participants started at 1300 hrs PT with the research team and was completed in preparation for the "simulated sporting event" by 1400 hrs PT.

Simulated Sporting Event

At 1400 hrs PT all of the participants gathered at an outdoor grass athletic field on the campus of California State University – Fullerton to participate in an intense exercise protocol to simulate an athletic event. At the onset of the exercise protocol the temperature was 21.6 °C (71°F) and an average humidity for the day at 63%. The participants completed the following exercises designed to simulate the muscle damage due to physical activity that would occur during a high-intensity intermittent sporting event such as soccer. The exercise was performed as the total group on the field with an exercise leader and other members of the research team cheering and encouraging performances. A lot of verbal encouragement within the group created a highly aroused environment for the exercise protocol. We added additional plyometric and eccentric exercise stress to a repeated sprint protocol already shown to produce significant muscle tissue damage (13). Our protocol consisted of five sets of 10 repeated maximal effort countermovement jumps, 5 sets of 10 plyometric push-ups, 5 sets of 10 Nordic hamstring curls and 5 sets of 10 standard pushups. All exercises were performed with 60s rest between sets. These exercises were followed by the repeated sprint protocol (13). Subjects performed 15 20m sprints with a maximum of 10m deceleration distance (thereby producing eccentric damage). Sprints were performed on the minute, therefore the rest period between sprints was the time remaining in each minute. At the completion of the simulated sporting event the participants immediately returned to the laboratory at 1500 hrs PT for post-event urine and blood sampling. After testing participants prepared for travel back to CT.

California to Connecticut:

The research team and participants left California State University Fullerton at 20:00 hrs PT, where they were then transported by coach for 1 hour back to LAX for the departing flight at 23:30 hrs PT. The flight was direct to Bradley International Airport in Hartford CT (BDL) again flying on a Boeing 737-800 airliner with participants traveling in coach class, randomly ticketed throughout the plane in coach class with a travel time of 5 hours and 20 minutes, which arrived at 07:50 hrs ET. Participants were transported by chartered bus for 30 minutes back to the *Human Performance Laboratory* at the University of Connecticut for post-travel testing. Per Table 1, at 0900 hrs ET following air travel from California, post-West coast testing was initiated. The entire testing battery was performed staring with urine and blood sampling ending with the 40 Yard Sprint (36.576 m) testing. Each participant then showered and dressed and were then again instructed not to use any external showers, alcohol or drugs during the recovery period and when to report the next day to the laboratory for final testing.

Final Recovery Testing

The next day at 13:00 hrs ET subjects reported to the laboratory for the final set of tests to complete the investigation. All subjects had been instructed to follow the same schedule in the morning with a 7:00 to 8:00 ET breakfast and then again as with the 13:00 hrs testing consume only water to remain hydrated. The entire test battery was again completed and all questionnaires were documented to have been completed and handed into the research team. Each of the subjects was then follow-up on over the next few days to assure that they were satisfactorily recovered. No injuries or adverse events occurred over the course of the investigation.

Statistical Analyses

These data are presented as means ±SD. Statistical power was determined to range from 0.83 to 0.96 for the n sizes used in the study (nQuery Advisor; Statistical Solutions, Saugus, MA, USA). Reliability range for the dependent variables intra-class correlation coefficients were $R \geq 0.85$. We met all statistical assumptions for linear statistics. Any variables that did not meet this assumption were logarithmically (log_{10}) corrected and tested again. An independent t-test was used to compare demographic characteristics between the experimental groups and no significant differences were observed with the matching process. The statistical evaluation of the experimental data was accomplished using a 2-way analysis of variance with repeated measures for treatment and time. When appropriate, Fisher's LSD post hoc tests were used to determine pairwise differences. A $p \leq 0.05$ was defined as being statistically significant.

Results

Physical Performances

The physical performance testing can be observed in Table 2. From the baseline (BL) through the entire experimental period no changes were observed over time or between groups for the grip strength measure. No significant main effects or interactions effects were observed for grip strength.

Table 2 about here

Countermovement Vertical Jump

Significant main effects and interaction effects were observed for the CMJ performances. In the CONT group a significant decrease in the countermovement vertical jump (CMJ) height was observed upon arrival at the west coast on day 2 and differences from BL continued through the rest of the experimental time period through day 5. For the COMP group no significant differences from BL were observed over the experimental period yet jump height was significantly higher from the CONT group on day 3 prior to the simulated sporting event and remained higher on days 4 and 5 upon return to the east coast.

Pro Agility Drill (5-10-5)

Significant main effects and interaction effects were observed for pro agility drill (5-10-5) (PAD). Significantly slower times were observed in the CONT group upon arrival at the west coast on day 2 and this difference from BL continued through days 3 and 4 but recovered to BL values on recovery day 5 back on the east coast. No significant changes were observed for the COMP group from BL over the entire experimental period but at each time point after arrival on the west coast the times were significantly lower than the CONT group.

40 Yard Sprint (36.576 m)

The 40 Yard Sprint (36.576 m) (40YS) results mirrored the changes seen in the PAD. Thus high speed locomotor capabilities demonstrated similar changes again with significant main effects and interaction effects for the testing. The 40YS showed significantly slower times upon arrival at the west coast on day 2 when compared to the BL testing for the CONT group. This difference from BL continued through until the final recovery day 5 testing back on the east coast when no differences from BL were observed. No significant changes were observed for the COMP group from BL testing over the entire experimental period but again at each time point after arrival on the west coast on day 2 the times were significantly faster than the CONT group.

Quickness and Reaction Testing

The testing for quickness and reaction of the lower body using the Quick Board was measured only at BL and then again on days 4 and 5 after return to the east coast. In contrast to the locomotor speed tests the CONT group saw a greater number of correct touches when compared to BL when they arrived back to the east coast on day 4 testing but on day 5 no significant differences were observed from BL. The COMP group saw no significant changes from BL however on day 4 demonstrated fewer correct touches than the CONT group.

Psychological and Testing

Table 3 shows the results of the Liverpool Jet Lag Questionnaires (LJLQ) over the experimental time period. The perception of jet lag manifested itself significantly higher than the Day 1 PM measure on the evening (PM) of Day 2 and while fluctuations occurred this perception remained significantly elevated until getting a night's sleep before the morning (AM) of Day 5. No differences were observed between the two experimental groups.

The fatigue perceptions of the participants did not significantly change over Day 1 PM to Day 2 AM. A significant increase in perceived fatigue occurred in both groups in the evening of Day 2. Recovery occurred in the morning of Day 3 AM but was again significantly elevated on the evening of Day 4 after which the simulated sporting event was held that afternoon. The fatigue levels remained significantly elevated on the morning of Day 4 after the "overnight" flight. Some reduction by the PM of Day 4 occurred but after a night's sleep, fatigue levels returned back to what had been observed at the beginning of the study on Day 1. There was no differences observed between the groups.

Before the subjects went to sleep in the evenings rated their perception of how well they would sleep with the higher number indicative of expectations of good sleep. After arriving on the west coast participants had significantly higher expectations for good sleep on the night of Day 2. The only group differences occurred on the night of Day 3 where the CONT group felt they would gain much better sleep than other nights but the COMP group, potentially due to feeling the effects of the damage being compressed did not feel they would sleep very well that night. However, each group returned to Day 1 values which revolved around the neutral zero rating on the scale. Over the entire experiment the actual perceived quality of sleep revolved around the neutral Likert scaling of around 0. However, the actual quality of the sleep was negatively rated after in the morning of Day 4 upon return to the east coast after the "overnight" flight. No significant differences were observed between the groups.

Table 3 about here

Hormonal Responses

Figure 1 presents the responses over the experimental period the responses of plasma epinephrine and norepinephrine along with melatonin.

Catecholamines are presented in the first two panels. For plasma norepinephrine, significant elevations were observed only after the simulated sport competition (i.e., post-damage) on Day 3. All other concentrations were similar to baseline values. No experimental group differences were observed. For plasma epinephrine, significant elevations over baseline and other time points were observed before and following the simulated sport competition (i.e., post-damage). Interestingly, the values for each of the other time points were a bit higher than typically observed at resting conditions reflecting the potentially enhanced adrenergic stimulation with the overall set of stressors in young men (21). No differences were observed between the groups.

Plasma melatonin is presented n Figure 1 in the third panel. Melatonin concentrations were significantly higher than baseline on Day 2 AM at 6:00 hrs. Significant elevation over baseline were again observed on Day 4 AM upon return to east coast. No differences were observed between groups.

Figure 1 about here

Figure 2 presents the indirect markers of muscle tissue damage over the time frame of the experimental design for the two treatment groups. Creatine kinase in the first panel shows that the values were not elevated over baseline values until after the simulated sport competition (i.e., post-damage) on Day 3. These values remained significantly elevated above baseline values at each of the remaining time points for both treatment groups. These elevations were significantly higher than other times points after the baseline values. However, there was a treatment difference with the CONT group demonstrating significantly higher values than the COMP group for each time point after the simulated sport competition onward indicating an effect of the compression therapy. Myoglobin concentrations showed elevations above resting baseline values after the simulated sport competition on Day 3 with small elevation in the CONT group on Day 4. All elevations were also greater than other time points as well. Differences between the treatment groups was again noted on Day 3 with the COMP group significantly lower than the control group reflecting the influence of the compression therapy.

Figure 2 about here

Figure 3 presents the serum cortisol and testosterone values in two panels over the experimental time line. Cortisol concentrations were significantly elevated over baseline only on Day 3 after the simulated sports competition. No significant treatment effects were noted. Serum concentrations of testosterone were also elevated after the simulated sport competition on Day 3 but also remained elevated on the morning of Day 4 after returning to the east coast. The significantly higher than baseline values of cortisol and testosterone were also significantly higher than other time points.

Figure 3 about here

Discussion

With the high number of short term trips (3-4 days) requiring trans-American jet flights that occur for individuals or athletes participating in strenuous competitive athletic or recreational events, few data are available to simultaneously document the physiological, perceptual, and performance effects and/or offer additional solutions to potential problems associated with the concept of jet lag. The primary finding of this study is that travelling westbound 3 times zones can have a significant effect on power, agility and speed performances in physically trained young men if performed both immediately following, as well as approximately 24 hours following arrival, at least in the case of the CONT group. These differences are similar to previous research demonstrating impaired performance following traversing a greater number of time zones of 5-8 time zones (25, 30, 45). Although prior studies have observed team performances in sporting competitions (3, 16, 36, 38), this is the first study to identify the specific parameters that are affected following travel across 3 time zones.

The mechanism that has been proposed to cause these performance disturbances is the phenomenon known as jet lag, where via circadian disruption sleep is impaired, general fatigue is increased and cognitive and physical performance degrades. Much like prior research, this study showed significant jet lag, fatigue and reduced sleep quality following a westbound flight. In the CONT group only, the psychological effects, indicated by the LJLQ, were manifested as negative effects on physical performance with reductions in power, agility and speed shown in Table 2.

We were particularly interested in the physiological mechanisms as mediated by hormonal responses which may help in our understanding of the jet lag phenomenon and its effects. What has not been identified in prior work is the hormonal milieu that is a consequence of the circadian disruption and is associated with the changes in jet lag phenomenon and physical performance. As can be seen in Figure 1, adrenergic responses were not significantly elevated until just prior to the anticipation of impending physical activity as represented in this study as a simulated sport competition workout. Prior studies have shown that anticipatory stress of physical activity is a dramatic physiological regulation of the "fight-flight" response (9, 22). Interestingly, norepinephrine did not significantly elevate until after the exercise stress again representing the more sympathetic neural demands of the workout. The highly specific adrenal medullary pre-exercise response supports the neuropsychological stimulated release of epinephrine and the lower concentration of norepinephrine content in the adrenal medulla secretions (<10% of adrenal medulla content). The observation that epinephrine concentrations may have been a marginally elevated over the entire experimental protocol compared to our prior extensive measurement of resting values (i.e., typically under 200 pmol • L^{-1}) may reflect some of the more subtle travel stress that was perceived by the subjects with fatigue and sleep disturbances that existed (21).

Melatonin concentrations reflect release of the hormone by the pineal gland which is regulated by the light/dark information from the eyes where retinal photosensitive ganglion cells exist and produce the shrouding effects upon or waking from sleep (31, 32). Significant elevations were observed the morning of the westbound trip at 6:00 hrs most likely due to the morning circadian time frame as norepinephrine did not provide any additional stimuli (32). The lack of any melatonin increases at the time of performance testing prior to the damage protocol suggests that the influence of any light/dark cycle or weariness characteristic of pre-sleep time frames were not present and would have been off-set by adrenal adrenergic pre-exercise effects (17). For the most part the AM and PM values reflected what might be expected with light/dark cycles and sleep. The higher melatonin values prior to the westbound trip were concomitant with better sleep quality perception by the subjects. Whereas the lower elevations observed at 9:00 hrs following the eastbound late night "overnight" flight and transport to the laboratory were concomitant with much lower sleep quality from the prior night on the morning of Day 4. This combination of time and travel may have altered the circadian pattern of melatonin upon waking. No treatment group effects were observed for melatonin reflecting the lack of any differential effects long wear compression therapy. Circadian disruptions have been implicated in jet-lag induced performance attenuations, these disruptions do not appear to apply to the adrenergic response or melatonin, upon the arrival out west for Day 2 testing. The decline in performance in the CONT group cannot be attributed to sleep deprivation, as this was not significantly affected the morning prior to the flight. The only explanation of the performance data on Day 2 in the CONT group was that they reported several hours later to be suffering significant jet lag and fatigue, and expected to sleep poorly the next night (Table 3, Day 2 PM).

Despite a substantial adrenergic response on Day 3 concomitant with no changes in melatonin, it might be postulated that physical performance related to power, agility and speed would not decline as observed in the CONT group (17). Conversely, the COMP group demonstrated no significant physical performance differences from baseline testing and also showed significantly better performances than the CONT group at the corresponding time points. Thus it could be speculated that the enhanced venous return due to wearing the compression garments with adequate pressure was having a notable effect immediately upon arrival, as well as 24 hours following the westbound flight (42).

No studies have really examined the effects of long term wear compressive garments making the reasons for the performance maintenance over the westbound travel open to speculation. A variety of reasons might be proposed including such concepts as increased oxygenation of muscle, better toleration to airline coach travel with regards to resting circulatory dynamics and oxygenation, and/or better muscle repair from confined limb stress configurations (5, 7, 40). What is fascinating is that despite significant jet lag, fatigue and perceptions of poor sleep quality, as well elevated melatonin the COMP group continues to show no reductions in any parameters of physical performance, indicating to the potential importance of maintaining blood flow during recovery as well as during long periods of travel.

Consistent with ours and other investigative studies the performance of the COMP group following the simulated game was to be expected, due the substantial enhancement of the recovery process that has been shown previously due to compression garments (18, 20). Different from prior work, this study used the same garments in an extended wear context. As can be seen in Figure 2, the COMP group demonstrated significant attenuations in markers of muscle damage immediately following the simulated event, as well as immediately following the eastbound return trip, and even 24 hours following arrival on the East Coast. The higher markers of muscle damage in the CONT group likely reflect the damage to the muscle tissues' myosin motors in part mediating the significantly reduced power, agility and speed performance in comparison with the COMP group (19, 20).

As expected, cortisol and testosterone showed significantly elevated concentrations in both groups after the simulated sport competition which emphasized eccentric and decelerating loads (12, 39). Interestingly, testosterone was again elevated following the eastbound flight again in both groups suggesting a continued anabolic signaling being maintained during the recovery period (see Figure 3). However, this effect in potential response to travel stress was augmented by the typical diurnal variation of testosterone, with a peak between 7-10am. Interestingly, cortisol was not elevated after the eastbound flight which may be due to the trained nature of our test participants (23).

In summary, we had the unique opportunity to study a host of different questions about jet lag/travel stress over a distance traveled by a host of competitive teams and recreational sport enthusiasts. This study demonstrated that trans-American travel, when compared to prior research traverses a relatively low number of time zones but still leads to attenuations in most physical performance tests in the CONT condition immediately following the flight going in both directions(2). For the most part (i.e., except for CMVJ in CONT group) recovery is observed 24 hrs after landing. Grip strength often used to represent an individual's strength capability, showed no alterations and may not be a simple biomarker of performance losses. The use of extended wear compression garments demonstrated remarkable effects in helping with recovery from the flight stress potentially due to circulatory dynamics and from the simulated sport competition most likely due to helping in muscle tissue recovery following the exercise stress. Such data reflect the need for individuals traveling for competitive sport or recreational competitions arrive 24 hr. prior to an event. These data also uniquely now show that the performance reductions related to long distance travel are not associated with changes in melatonin, or a dampening of the adrenergic response. In trans-American travel, time zone adjustment is not typically recommended, therefore compression garments could be a novel way to remedy athletic or recreational performance reductions following such travel.

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Figure Legends

Figure 1. Changes in melatonin, epinephrine and norepinephrine following westbound and eastbound Trans-American flights before and after a simulated sporting event respectively in subjects wearing non-compressive (gray bars) and full body compression (black bars) garments. * = Significantly ($P \leq 0.05$) different from baseline.

Figure 2. Changes in markers of muscle damage following westbound and eastbound Trans-American flights before and after a simulated sporting event respectively in subjects wearing non-compressive (gray bars) and full body compression (black bars) garments. * = Significantly different from baseline. # = significantly different from corresponding COMP group.

Figure 3. Changes in testosterone and cortisol following westbound and eastbound Trans-American flights before and after a simulated sporting event respectively in subjects wearing non-compressive (gray bars) and full body compression (black bars) garments. * = Significantly ($P \leq 0.05$) different from baseline.

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Table 1. Experimental Design. 'X' denotes assessment occurred. All times are in 24 hour clock format. UC = University of Connecticut; CSUF = California State University Fullerton; FAM = Familiarizations; BL = Baseline; ET = Eastern Time; PT = Pacific Time; CMJ = Countermovement Jump; POMS = Profile of Mood States; PMS = Perceived Muscle Soreness; LJLQ = Liverpool Jet Lag Questionnaire.

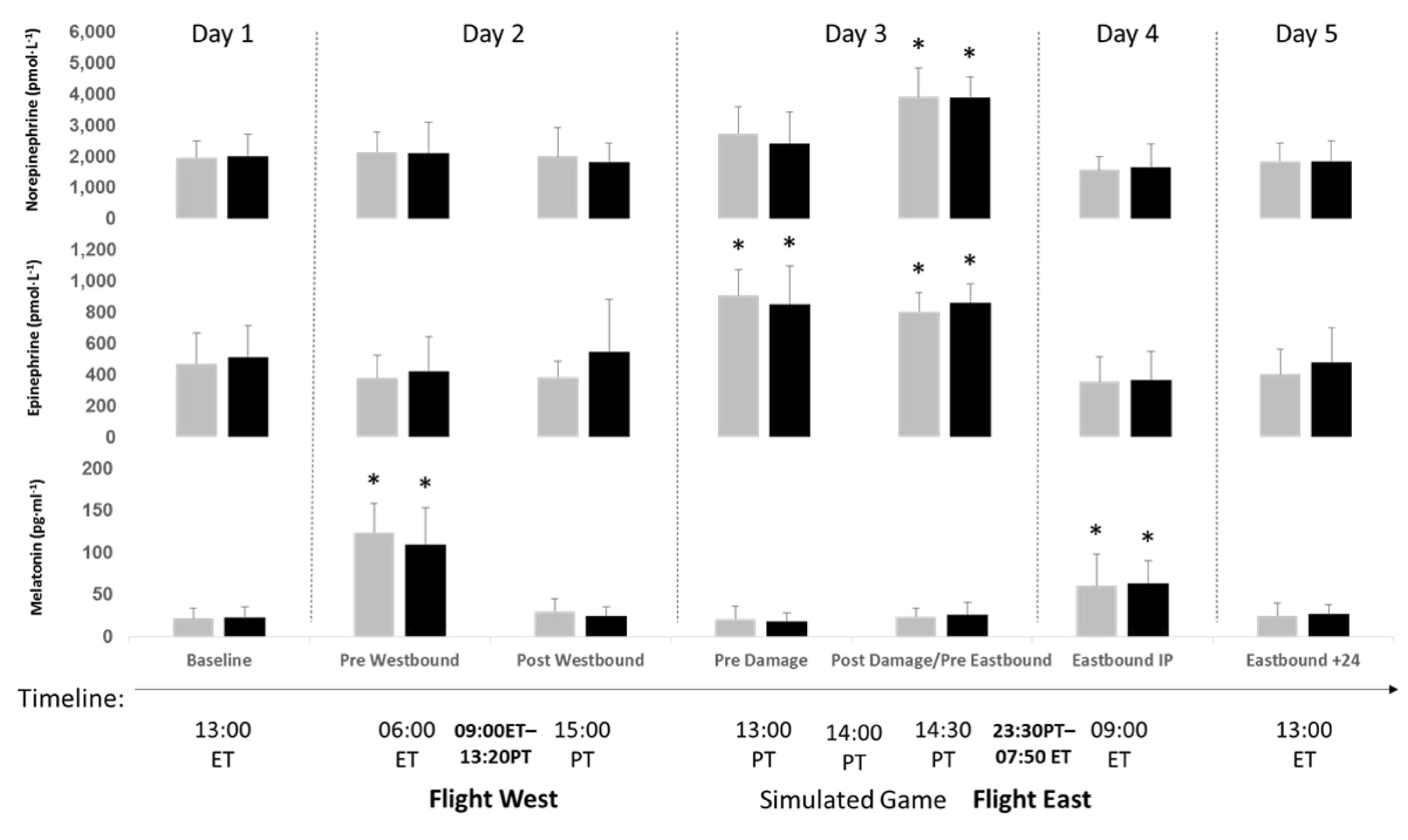
Day			**Day 1**	**Flight: CT (9:00 ET) to CA (13:20 PT)**	**Day 1**	**Day 2**	**Simulated Sporting Event (14:00 PT)**	**Day 2**	**Flight: CA (23:30 PT) to CT (07:50 ET)**	**Day 3**	**Day 4**
Location	**UC**	**UC**	**UC**		**CSUF**	**CSUF**		**CSUF**		**UC**	**UC**
Test Name	FAMs on day 1 and 3-4 before as needed	BL	Pre Westbound		Post Westbound	Pre-Damage		Post-Damage		Post Eastbound	Post Eastbound +24
Time of Day	Variable	13:00 ET	06:00 ET		15:00 PT	13:00 PT		15:00 PT		09:00 ET	13:00 ET
Physiological Assessments											
Urine Sample		X	X		X	X		X		X	X
Blood Sample		X	X		X	X		X		X	X
Physical Performance Assessments											
CMJ	X	X			X	X				X	X
Hand grip	X	X			X	X				X	X
Quick board	X	X								X	X
5-10-5	X	X			X	X				X	X
40yd	X	X			X	X				X	X
Psychological Assessments											
LJLQ	X	Each evening and morning throughout testing									

Table 2. Physical Performance Testing. * = Significantly ($P \leq 0.05$) different from baseline, # = significantly ($P \leq 0.05$) different from corresponding control condition time point. Post Westbound = immediately following westbound flight; Post Eastbound = immediately following eastbound flight; Post Eastbound+24 = 24 hours following eastbound flight. CMJ = countermovement jump.

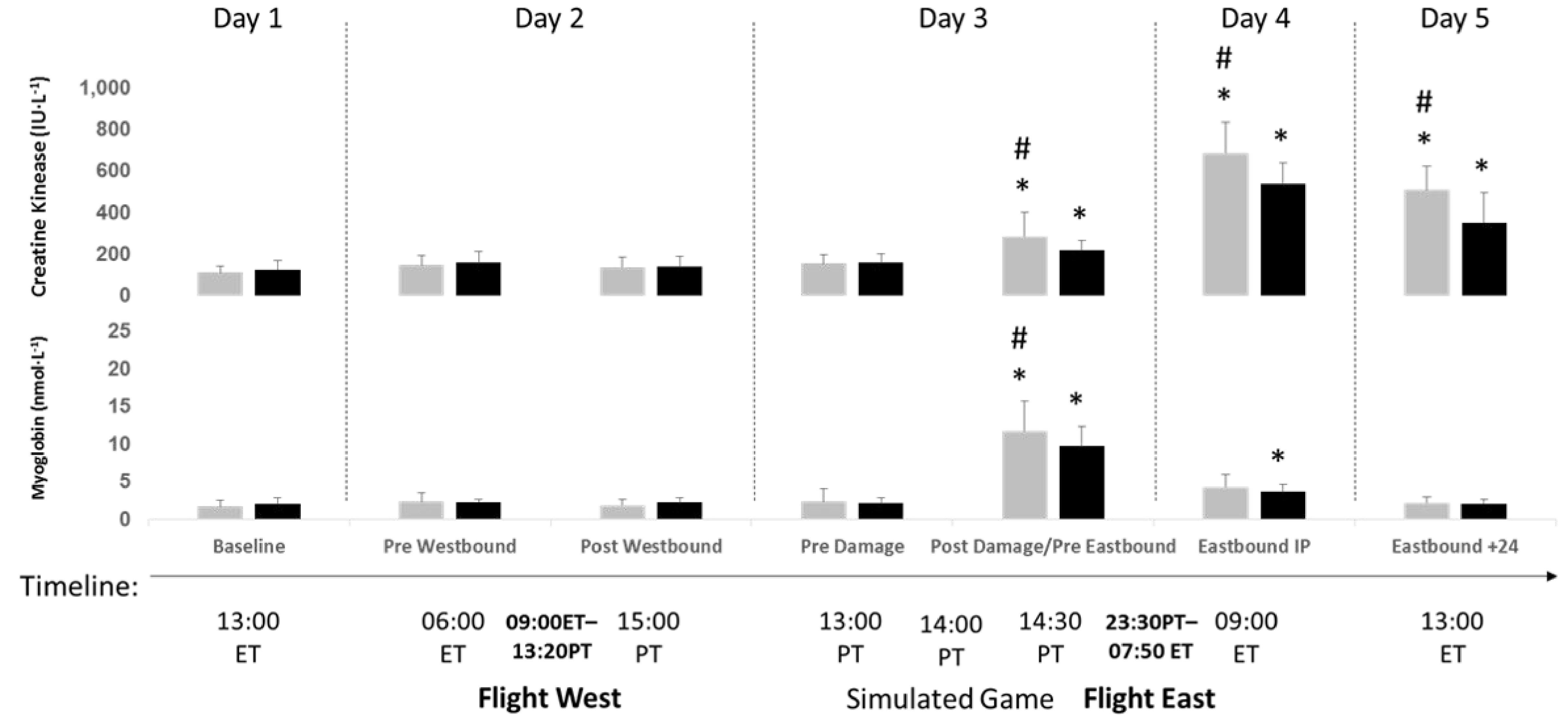
	Day:	**1**	**2**	**3**	**4**	**5**
Group	Timepoint:	Baseline	Post Westbound	Pre Exercise	Post Eastbound	Post Eastbound +24
Handgrip (kg)						
Control	Mean:	51.5	48.5	49.8	47.4	48.4
	SD:	*7.5*	*5.2*	*4.8*	*5.0*	*5.9*
Compression	Mean:	49.0	47.7	49.8	48.1	50.6
	SD:	*5.3*	*5.2*	*4.6*	*5.5*	*6.0*
CMJ (cm)						
Control	Mean:	67.4	60.3*	61.7*	57.2*	60.5*
	SD:	*6.9*	*7.6*	*6.3*	*5.6*	*6.4*
Compression	Mean:	61.9	64.0	66.3#	62.5#	63.8#
	SD:	*9.6*	*10.6*	*9.7*	*6.3*	*9.8*
Quickboard (correct touches)						
Control	Mean:	14.2			15.9*	14.8
	SD:	*1.7*			*1.4*	*0.8*
Compression	Mean:	14.9			14.3#	14.7
	SD:	*1.6*			*1.0*	*1.2*
Pro Agility Drill (5-10-5) (s)						
Control	Mean:	4.99	5.23*	5.26*	5.29*	5.14
	SD:	*0.38*	*0.49*	*0.37*	*0.32*	*0.35*
Compression	Mean:	5.01	5.03#	4.90#	4.92#	4.91#
	SD:	*0.41*	*0.44*	*0.15*	*0.18*	*0.45*
40yd Sprint (s)						
Control	Mean:	5.27	5.53*	5.58*	5.65*	5.36
	SD:	*0.32*	*0.43*	*0.45*	*0.50*	*0.46*
Compression	Mean:	5.10	5.13#	5.19#	5.17#	5.09#
	SD:	*0.20*	*0.27*	*0.23*	*0.25*	*0.24*

Table 3. Liverpool Jet Lag Questionnaire (LJLQ) results. * = Significantly ($P \leq 0.05$) different from Day 1 PM, # = significantly ($P \leq 0.05$) different from corresponding control treatment time point. AM = LJLQ responses in the morning immediately following sleep; PM = LJLQ responses in the evening immediately before sleep.

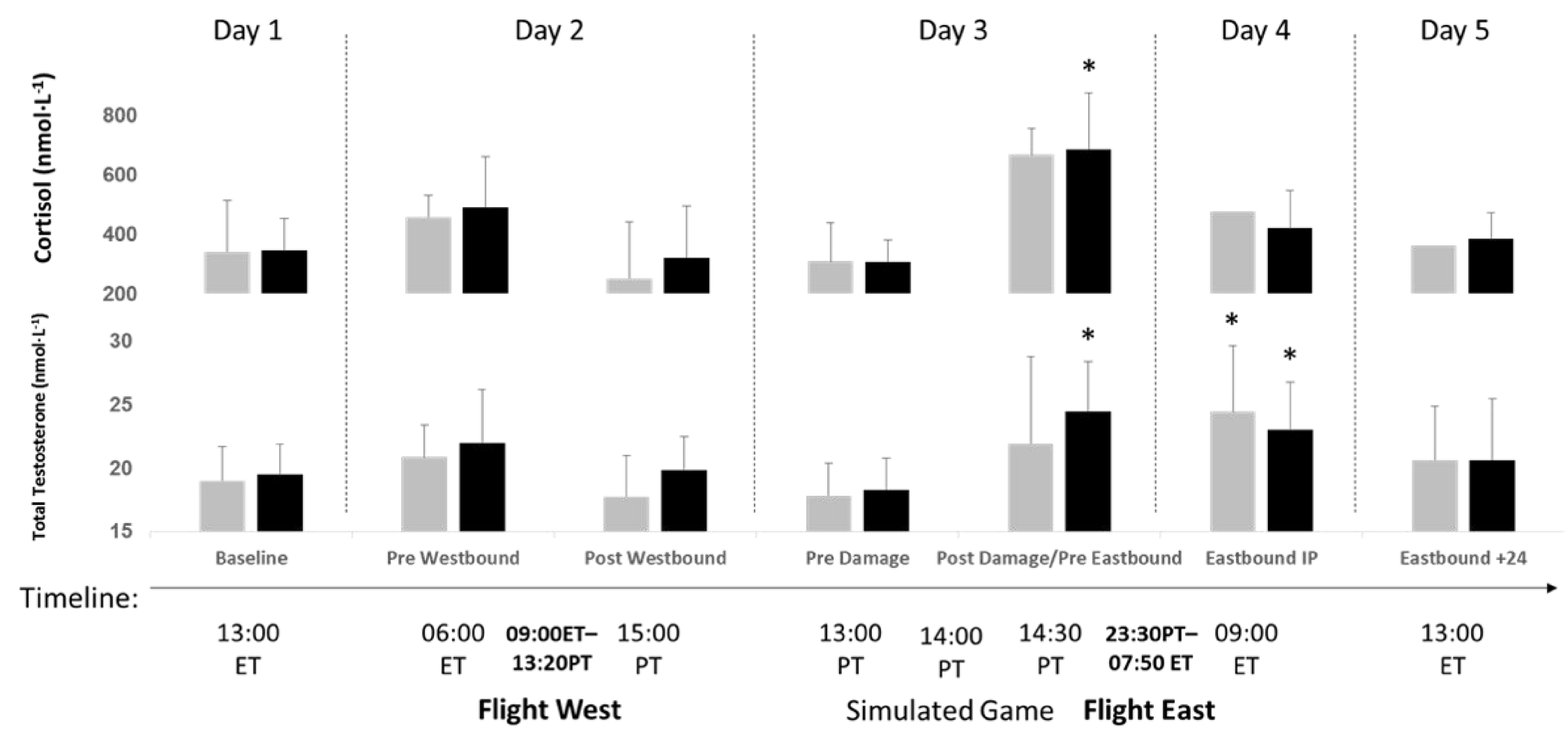
Group	Day:	1	2		3		4		5
		Pre Westbound	Post Westbound	Post Westbound	Post Westbound	Post Westbound	Post Eastbound	Post Eastbound	Post East Bound +24
	Time Point:	PM	AM	PM	AM	PM	AM	PM	AM
Jet Lag (0-10):									
Control	Mean:	0.07	0.10	6.45*	2.14*	5.40*	5.64*	4.30*	2.81
	SD:	*0.16*	*0.32*	*2.25*	*1.59*	*2.60*	*2.35*	*3.74*	*3.10*
Compression	Mean:	0.00	0.00	5.16*	3.23*	6.13*	6.13*	4.64*	2.03*
	SD:	*0.00*	*0.00*	*2.72*	*2.83*	*2.30*	*2.30*	*2.87*	*2.44*
Fatigue (-5 – 5):									
Control	Mean:	-0.32	-0.23	-1.92*	0.51	-3.20*	-3.57*	-0.63	-1.48
	SD:	*0.67*	*2.41*	*2.67*	*1.82*	*0.79*	*0.93*	*2.58*	*1.78*
Compression	Mean:	-0.47	-0.75	-3.37*	-0.21	-3.29*	-3.82*	-1.35	-0.16
	SD:	*1.22*	*1.55*	*1.22*	*1.50*	*1.99*	*1.47*	*1.00*	*1.14*
Expected Sleep (-5 – 5):									
Control	Mean:	0.14		2.55*		0.04		1.25	
	SD:	*0.89*		*1.96*		*3.53*		*1.74*	
Compression	Mean:	-0.75		2.57*		-4.22*#		-0.15	
	SD:	*1.79*		*1.81*		*0.47*		*1.63*	
Actual Sleep (-5 – 5):									
Control	Mean:		0.64		0.15		-3.50*		0.28
	SD:		*2.11*		*2.26*		*2.09*		*2.74*
Compression	Mean:		-1.27		-0.28		-4.68*		0.46
	SD:		*2.37*		*2.05*		*0.37*		*0.45*



Day 1
Day 2
Day 3
Day 4
Day 5
Norepinephrine (pmol·L⁻¹)
6,000
5,000
4,000
3,000
2,000
1,000
0
Epinephrine (pmol·L⁻¹)
1,200
1,000
800
600
400
200
0
Melatonin (pg·ml⁻¹)
200
150
100
50
0
*
Baseline
Pre Westbound
Post Westbound
Pre Damage
Post Damage/Pre Eastbound
Eastbound IP
Eastbound +24
Timeline:
13:00 ET
06:00 ET
09:00ET– 13:20PT
15:00 PT
13:00 PT
14:00 PT
14:30 PT
23:30PT– 07:50 ET
09:00 ET
13:00 ET
Flight West
Simulated Game
Flight East



Day 1
Day 2
Day 3
Day 4
Day 5
Creatine Kinease (IU·L⁻¹)
1,000
800
600
400
200
0
Myoglobin (nmol·L⁻¹)
25
20
15
10
5
0
#
*
Baseline
Pre Westbound
Post Westbound
Pre Damage
Post Damage/Pre Eastbound
Eastbound IP
Eastbound +24
Timeline:
13:00 ET
06:00 ET
09:00ET– 13:20PT
15:00 PT
13:00 PT
14:00 PT
14:30 PT
23:30PT– 07:50 ET
09:00 ET
13:00 ET
Flight West
Simulated Game
Flight East



Day 1
Day 2
Day 3
Day 4
Day 5
Cortisol (nmol·L-1)
800
600
400
200
*
Total Testosterone (nmol·L-1)
30
25
20
15
*
*
*
Baseline
Pre Westbound
Post Westbound
Pre Damage
Post Damage/Pre Eastbound
Eastbound IP
Eastbound +24
Timeline:
13:00 ET
06:00 ET
09:00ET– 13:20PT
15:00 PT
13:00 PT
14:00 PT
14:30 PT
23:30PT– 07:50 ET
09:00 ET
13:00 ET
Flight West
Simulated Game
Flight East