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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

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

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

New & Noteworthy

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

Introduction

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

34

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

43

44 Although the concept of jet lag is well established, its effects on physical performance
45 have not been well studied. At present, only a small number of studies have observed these
46 effects and the parameters that have been assessed are diverse, including running speed alone (6),
47 sprint and middle-distance performance (45), grip strength and reaction time (30) and subjective
48 assessments of training quality (25). However, these studies examined the effects of long-haul

49 flights traversing relatively large time zone changes, ranging from 5-8 time zones crossed. In
50 addition to long-haul flights, performance decrements have been suggested to occur when as few
51 as 2-3 times zones are traversed (3, 16, 36, 38). However, these studies observed and analyzed
52 the effects of travel on the results of athletic competitions, and did not include direct scientific
53 study of performance or its associated physiological mechanisms.

54

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

67

68 Not only do the effects of time zone travel impact athletic teams before an event by
69 potentially negatively affecting performance, but the recovery processes that are required
70 following an athletic event may also be hindered on the return flight. As trans-American jet

71 travel takes approximately 5-6 hours, and is coupled with limited space available for many
72 passengers traveling in economy class on commercial flights, travelers are forced into prolonged
73 periods of sitting with little movement. Such prolonged periods of sitting have been shown to
74 lead to significant reductions in thigh and calf blood flow, with concomitant increases in calf and
75 thigh blood pooling (34). These hemodynamic effects could drastically impair performance
76 upon arrival in a time zone as well as the ability to recover upon return to the original time zone.

77

78 Addressing the recovery process of skeletal muscle from strenuous exercise which
79 produces tissue damage has been thought to be an important concern for many individuals who
80 routinely travel for athletic competitions or strenuous recreational activities (24). Apart from
81 pharmaceutical interventions that have been used to assist in recovery, prior research on
82 compressive garments have shown promise in helping in recovery and provided an interesting
83 and unique experimental secondary dimension to our understanding of jet-lag/travel stress (18,
84 20, 27, 40). The physiological effects of such compressive therapy after damaging exercise has
85 been shown to reduce indirect markers of skeletal muscle tissue damage and allow performance
86 recovery at a more rapid rate (18, 19, 27). Such an effect would appear beneficial to trans-
87 American jet travel when highly stressful exercise is performed prior to returning home from
88 competitive or recreational events. Consistent with our prior research, we hypothesized that
89 within the jet-lag/travel stress model we used, enhanced recovery would be possible using
90 extended wear of compression garments.

91

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

101

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

109

110 Therefore, the primary purpose of this investigation was to examine the impact of trans-
111 American travel on physical performance and associated hormonal and sleep related responses in
112 order to gain some insights into potential mechanistic contributions to any reductions in physical
113 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.

116

117 Methods

118 *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.

133 ***Table 1 about here***

134

135

136 *Participants*

137 Following a detailed explanation of study procedures as well as the risks and benefits
138 involved in the study, all participants provided informed consent prior to the start of the study.
139 The study was approved by the university's Institutional Review Board for use of human
140 subjects in research. Ten pairs of subjects were matched for Ponderel Index and body fat
141 percentage and activity backgrounds and then randomized into one of two groups. Body
142 composition was measured by a trained technician via the 3 site Jackson-Pollok skinfold
143 technique (14). One subject could not make the flight and thus nineteen recreationally trained
144 men (i.e., had been weight training and endurance training for over 6 months) participated in the
145 study consisting of either a compression group (COMP) (n=10; age: 23.1 ± 2.4 years, height:
146 174.8 ± 5.3 cm, body mass: 84.9 ± 10.1 kg, body fat: $15.3 \pm 6.0\%$) or control group (CONT) (n=9;
147 age: 23.2 ± 2.3 years, height: 177.5 ± 6.3 cm, weight: 84.3 ± 8.99 kg, body fat: $15.1 \pm 6.4\%$). While no formal training study was undertaken with the subjects in the investigation,
148 each of the subjects reported to have been involved with progressive heavy resistance training
149 with complementary endurance training, each performed 3 to 4 times a week. Resistance
150 training was characterized by periodized, multiple sets, whole body, large muscle groups
151 exercises with targets for muscle strength and size. Subjects were former high school and
152 college athletes who participated in a variety of sports including football, basketball, track and
153 field, wrestling, baseball and some were former warfighters in the military who were all
154 accustomed with intense weekly physical training routines.

156

157

158

159 *Clothing Apparel and Compression Garments*

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

174

175 *Procedures*176 *Familiarization*

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

186

187 *Controls*

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

200

201 ***Testing Battery***202 *Urine and Blood Sampling*

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

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

210

211 *Blood Samples:* An indwelling Teflon cannula was inserted by a trained phlebotomist
212 into superficial antecubital forearm vein and after sitting quietly for 10 minutes in the seated
213 position a 33 ml blood sample was collected from a vacutainer set-up into serum (10ml), EDTA
214 (10ml), Na citrate (5ml) and Na Heparin (8ml) tubes. Serum and plasma samples were
215 immediately centrifuged at 1,500 g for 15 min at 4 ° C aliquoted in to appropriately sized and
216 labeled Eppendorf tubes and stored at –80° C until subsequent analyses. Samples were thawed
217 only once for analysis. All blood samples were performed in duplicate analyses.

218

219 Total creatine kinase was measured in duplicate from serum samples using liquid creatine
220 kinase reagents (Sekisui Diagnostics, Canton, MI) and assayed according to manufacture

221 instructions. Intra-and inter-assay coefficients of variations for creatine kinase were below 3.9%.
222 Myoglobin was measured from EDTA-plasma in duplicate via enzyme linked immunosorbancy
223 assay (ELISA) (CALBiotech, Spring Valley, CA). The mean intra-assay coefficients of
224 variation (CVs) were 5.6% and inter-assay coefficients of variation were 7.9%.

225

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

232

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

238

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

241 ***Physical Testing***

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

248

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

256

257 *Hand Grip Strength:* This measure was determined using a hand grip dynamometer.
258 Participants stood with feet hip-width apart and shoulders level. The dynamometer (T.K.K.5401
259 GRIP-D [DIGITAL GRIP DYNAMOMETER, Niigata City, Japan) was held in their hand with
260 their dominant (i.e., determined by what hand they write with and throw a ball the furthest with)
261 arm hanging straight down at their side with no bend in the elbow. Each subject was allowed
262 three attempts with the best of the three attempts used for analysis. From our work with
263 NHANES we used the same testing protocol as described (i.e., chapter 3) for grip strength

264 ([http://www.cdc.gov/nchs/n\(nyfs/manuals.htm](http://www.cdc.gov/nchs/n(nyfs/manuals.htm)). Each subject was tested on the same calibrated
265 dynamometer over the course of the study at both testing sites.

266

267 *Quickness and Reaction:* Per Table 1, the Quick Board™ test was only performed at the
268 *Human Performance Laboratory* in CT before and after the air travel. The Quick Board™
269 system (Memphis, TN) was used to measure foot quickness and reaction time of lower body
270 stepping movements (17). Briefly, the Quick Board™ system is comprised of a visual stimulus
271 board with five lights consisting of two on the top, one in the middle and two on the bottom and
272 a corresponding step pad on placed on the ground. Once the test began, one of five lights
273 illuminates. The participant then steps on the pad located on the floor that corresponds to the
274 light in the same position. Once the participant stepped on the correct pad, a new light
275 illuminated. If the participant steps on an incorrect pad, a buzzer sounded and the participant
276 was required to contact the correct pad before a new light would appear. The test continues for
277 10 seconds and the number of correct were recorded and used for analyses in this investigation.
278 About one minute rest was taken between trials and in this study the best score of three trials was
279 used for analysis.

280

281 *Pro-Agility Drill (5-10-5 Drill):* This Pro-Agility drill is a common shuttle run test used
282 by many coaches (e.g., NFL and College Combines) to test athletes' lateral quickness and speed
283 (35). On a gym floor, the same experienced tester using a stopwatch timed each participant in
284 this drill. The subject starts the drill running for 5 yards (4.572 m) to the right, touches the line
285 and then changes direction and runs 10 yards (9.144 m) to the left and touches the line and then

286 runs 5 yards (4.572) straight through the finish line. Each participant had three trials with about
287 5 minutes rest between trials with and the fastest time used for analysis.

288

289 *40 Yard Sprint (36.576 m)*: A maximal effort sprint of 40 yards (36.576 m), typical of
290 most athletic sprints tests done by coaches in the USA, was used to assess sprint speed in this
291 study (4). On a fieldhouse floor, an experienced tester using a stopwatch timed each participant
292 in this drill (28). Approximately 5 minutes rest was taken between two trials. The faster of the
293 two trials was used for analysis.

294

295 *Perceptual Testing*

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

302

303 *Travel -Connecticut to California:*

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

307 University of Connecticut at 05:00 ET. For both the East and West bound flights, all subjects
308 went through the Transportation Security Administration |(TSA) security check points but the
309 lines were not long and time to make it through the process was not excessive but was an added
310 component of the travel stress. Following urine and blood sampling at 0600 ET, participants
311 were transported by chartered bus for 30 minutes to Bradley International Airport (BDL) in
312 Hartford, CT for the departing flight at 09:00 ET. The flight was direct to Los Angeles
313 International Airport (LAX) flying on a Boeing 737-800 airliner with participants traveling in
314 coach class, randomly ticketed throughout the plane in coach class with a travel time of 6 hrs and
315 20 minutes arriving at 12:20 PT. Participants were then transported by another chartered coach
316 to the *Human Performance Laboratory* at California State University-Fullerton, for testing with
317 a travel time of 1 hour. Participants changed and rested in the locker rooms and prepared for
318 testing which began at 1500 hrs PT.

319

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

324

325 Day 2 started with a scheduled group breakfast from 0700 to 800 hrs. Participants then
326 rested and later were instructed as to what the schedule would be for the rest of the day,
327 including reviewing the experimental simulated sporting event routine. Participants than packed
328 and along with the research team checked out of the campus hotel and returned to back to the

329 laboratory for testing. Per Table 1, testing of the participants started at 1300 hrs PT with the
330 research team and was completed in preparation for the “simulated sporting event” by 1400 hrs
331 PT.

332

333 *Simulated Sporting Event*

334 At 1400 hrs PT all of the participants gathered at an outdoor grass athletic field on the
335 campus of California State University – Fullerton to participate in an intense exercise protocol to
336 simulate an athletic event. At the onset of the exercise protocol the temperature was 21.6 °C
337 (71°F) and an average humidity for the day at 63%. The participants completed the following
338 exercises designed to simulate the muscle damage due to physical activity that would occur
339 during a high-intensity intermittent sporting event such as soccer. The exercise was performed
340 as the total group on the field with an exercise leader and other members of the research team
341 cheering and encouraging performances. A lot of verbal encouragement within the group created
342 a highly aroused environment for the exercise protocol. We added additional plyometric and
343 eccentric exercise stress to a repeated sprint protocol already shown to produce significant
344 muscle tissue damage (13). Our protocol consisted of five sets of 10 repeated maximal effort
345 countermovement jumps, 5 sets of 10 plyometric push-ups, 5 sets of 10 Nordic hamstring curls
346 and 5 sets of 10 standard pushups. All exercises were performed with 60s rest between sets.
347 These exercises were followed by the repeated sprint protocol (13). Subjects performed 15 20m
348 sprints with a maximum of 10m deceleration distance (thereby producing eccentric damage).
349 Sprints were performed on the minute, therefore the rest period between sprints was the time
350 remaining in each minute. At the completion of the simulated sporting event the participants

351 immediately returned to the laboratory at 1500 hrs PT for post-event urine and blood sampling.
352 After testing participants prepared for travel back to CT.

353

354 *California to Connecticut:*

355 The research team and participants left California State University Fullerton at 20:00 hrs
356 PT, where they were then transported by coach for 1 hour back to LAX for the departing flight at
357 23:30 hrs PT. The flight was direct to Bradley International Airport in Hartford CT (BDL) again
358 flying on a Boeing 737-800 airliner with participants traveling in coach class, randomly ticketed
359 throughout the plane in coach class with a travel time of 5 hours and 20 minutes, which arrived
360 at 07:50 hrs ET. Participants were transported by chartered bus for 30 minutes back to the
361 *Human Performance Laboratory* at the University of Connecticut for post-travel testing. Per
362 Table 1, at 0900 hrs ET following air travel from California, post-West coast testing was
363 initiated. The entire testing battery was performed starting with urine and blood sampling ending
364 with the 40 Yard Sprint (36.576 m) testing. Each participant then showered and dressed and were
365 then again instructed not to use any external showers, alcohol or drugs during the recovery
366 period and when to report the next day to the laboratory for final testing.

367

368 *Final Recovery Testing*

369 The next day at 13:00 hrs ET subjects reported to the laboratory for the final set of tests
370 to complete the investigation. All subjects had been instructed to follow the same schedule in
371 the morning with a 7:00 to 8:00 ET breakfast and then again as with the 13:00 hrs testing
372 consume only water to remain hydrated. The entire test battery was again completed and all

373 questionnaires were documented to have been completed and handed into the research team.
374 Each of the subjects was then follow-up on over the next few days to assure that they were
375 satisfactorily recovered. No injuries or adverse events occurred over the course of the
376 investigation.

377 ***Statistical Analyses***

378 These data are presented as means \pm SD. Statistical power was determined to range from
379 0.83 to 0.96 for the n sizes used in the study (nQuery Advisor; Statistical Solutions, Saugus, MA,
380 USA). Reliability range for the dependent variables intra-class correlation coefficients were $R \geq$
381 0.85. We met all statistical assumptions for linear statistics. Any variables that did not meet this
382 assumption were logarithmically (\log_{10}) corrected and tested again. An independent t-test was
383 used to compare demographic characteristics between the experimental groups and no significant
384 differences were observed with the matching process. The statistical evaluation of the
385 experimental data was accomplished using a 2-way analysis of variance with repeated measures
386 for treatment and time. When appropriate, Fisher's LSD post hoc tests were used to determine
387 pairwise differences. A $p \leq 0.05$ was defined as being statistically significant.

388

389 **Results**390 *Physical Performances*

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

395 *Table 2 about here*

396 *Countermovement Vertical Jump*

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

404

405

406

407

408 *Pro Agility Drill (5-10-5)*

409

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

416

417 *40 Yard Sprint (36.576 m)*

418

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

428

429 *Quickness and Reaction Testing*

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

436

437 *Psychological and Testing*

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

443

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

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

463 *Table 3 about here*

464 *Hormonal Responses*

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

467 Catecholamines are presented in the first two panels. For plasma norepinephrine,
468 significant elevations were observed only after the simulated sport competition (i.e., post-
469 damage) on Day 3. All other concentrations were similar to baseline values. No experimental
470 group differences were observed. For plasma epinephrine, significant elevations over baseline
471 and other time points were observed before and following the simulated sport competition (i.e.,
472 post-damage). Interestingly, the values for each of the other time points were a bit higher than
473 typically observed at resting conditions reflecting the potentially enhanced adrenergic

474 stimulation with the overall set of stressors in young men (21). No differences were observed
475 between the groups.

476

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

481 *Figure 1 about here*

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

495 *Figure 2 about here*

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

503 *Figure 3 about here*

504 **Discussion**

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

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

524

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

540 of the more subtle travel stress that was perceived by the subjects with fatigue and sleep
541 disturbances that existed (21).

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

562 in the CONT group was that they reported several hours later to be suffering significant jet lag
563 and fatigue, and expected to sleep poorly the next night (Table 3, Day 2 PM).

564

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

573

574 No studies have really examined the effects of long term wear compressive garments
575 making the reasons for the performance maintenance over the westbound travel open to
576 speculation. A variety of reasons might be proposed including such concepts as increased
577 oxygenation of muscle, better toleration to airline coach travel with regards to resting circulatory
578 dynamics and oxygenation, and/or better muscle repair from confined limb stress configurations
579 (5, 7, 40). What is fascinating is that despite significant jet lag, fatigue and perceptions of poor
580 sleep quality, as well elevated melatonin the COMP group continues to show no reductions in
581 any parameters of physical performance, indicating to the potential importance of maintaining
582 blood flow during recovery as well as during long periods of travel.

583

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

594

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

603

604 In summary, we had the unique opportunity to study a host of different questions
605 about jet lag/travel stress over a distance traveled by a host of competitive teams and recreational

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

621

622 .

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632

633 **Figure Legends**

634

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

639

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

644

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

649

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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) Simulated Sporting Event (14:00 PT) Flight: CA (23:30 PT) to CT (07:50 ET)	Day 1	Day 2	Flight: CT (9:00 ET) to CA (13:20 PT) Simulated Sporting Event (14:00 PT) Flight: CA (23:30 PT) to CT (07:50 ET)	Day 2	Flight: CT (9:00 ET) to CA (13:20 PT) Simulated Sporting Event (14:00 PT) Flight: CA (23:30 PT) to CT (07:50 ET)	Day 3	Day 4
Location	UC	UC	UC		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			
Time of Day	Variable	13:00 ET	06:00 ET		15:00 PT	13:00 PT		15:00 PT			
Physiological Assessments											
Urine Sample		X	X		X	X		X			
Blood Sample		X	X		X	X		X			
Physical Performance Assessments											
CMJ	X	X			X	X		X			
Hand grip	X	X			X	X		X			
Quick board	X	X						X			
5-10-5	X	X			X	X		X			
40yd	X	X			X	X		X			
Psychological Assessments											
LJLQ	X										

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 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





