Effects of sports compression socks on performance, physiological, and hematological alterations after long-haul air travel in elite female volleyballers

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Title

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ABSTRACT

The purpose of this investigation was to assess the merit of sports compression socks in minimizing travel-induced performance, physiological, and hematological alterations in elite female volleyball athletes. Twelve elite female volleyballers (age, 25 ± 2 y) travelled from Canberra (Australia) to Manila (Philippines), and were assigned to one of two conditions; compression socks (COMP, *n* = 6) worn during travel, or a passive control (CON, *n* = 6). Dependent measures included counter-movement jump (CMJ) performance, subjective ratings of well-being, cardiovascular function, calf girth, and markers of blood clotting, collected before (-24 h, CMJ; -12 h, all measures), during (+6.5 h and +9 h, subjective ratings and cardiovascular function), and after (+12 h, all measures except CMJ; + 24 h and + 48 h, CMJ) travel. As compared with CON, small-to-large effects were observed for COMP to improve heart rate (+9 h), oxygen saturation (+6.5 h and +9 h), alertness (+6.5 h), fatigue (+6.5 h), muscle soreness (+6.5 h and +9 h), and overall health (+6.5 h) during travel. After travel, small-to-moderate effects were observed for COMP to improve systolic blood pressure (+12 h), right calf girth (+12 h), and CMJ height (+24 h), mean velocity (+24 h), and relative power (+48 h), as compared with CON. COMP had no effect on markers blood clotting. This study suggests that compression socks are beneficial in combating the stressors imposed by long-haul travel in elite athletes, and may have merit for individuals frequenting long-haul travel and/or competing soon after flying.

Keywords: Travel fatigue, jet lag, circadian, team sport, elite athletes.

INTRODUCTION

Travelling away from home for training and competition is standard practice for elite athletes across numerous sports. Frequent long-haul air travel is often unavoidable (10), a practice that has been reported to impair athletic performance (35). Circadian dysrhythmia, or 'jet lag', is a common occurrence for the travelling athlete and often manifests as a general feeling of tiredness, sleep disruption, a lack of concentration and motivation, and/or decreased mental and physical performance (44). Jet lag is typically associated with individuals rapidly travelling across three or more meridian time zones (32); however performance decrements have also been suggested to occur when as few as two time zones are traversed (5). Symptoms of jet lag may persist until re-synchronization to the new environment occurs (44), and recovery time is considered to be dependent on the number of time zones crossed (30).

Another potential complication for athletes during air travel following training and competition is the development of venous thromboembolisms (VTE), consisting of either pulmonary embolisms or deep vein thrombosis (DVT) (18, 41). The limited space (1), cramped seating arrangements (23), and hypobaric hypoxic environment (4, 37) experienced in airline cabins may contribute to the slowing of venous circulation (4), promoting venous stasis, pro-coagulant activity, and inhibition of fibrinolysis (i.e., breakdown and removal of blood clots) (23). Furthermore, the risk of a thromboembolic event occurring is compounded by underlying and acquired risk factors associated with hypercoagulability, including oral contraceptive use, frequent long-haul travel, and/or genetic predisposition to hypercoagulability (e.g., prothrombin G22010A and Factor V Leiden mutations) (33). The successful treatment of a thrombotic embolism may take months to resolve, limiting the athlete's participation whilst impacting negatively on team competition planning and performance (15).

In addition to flight-induced thrombosis, VTE risk is exacerbated in athletes as a result of the large volume and high intensity exercise typically performed. While physical activity and exercise appear to be protective against thromboembolic disorders (1), it has been reported that exhaustive exercise, particularly long durations and/or high intensities, may enhance activation of the blood coagulation system (15), resulting in an increased risk for thrombosis development (1). Indeed, the mode, volume, and intensity of training undertaken by some elite athletes has been recognized as a cause of "effort thrombosis" (Paget-Schroetter syndrome) (17), as evidenced by a number of case reports documenting the development of VTE in athletes (6, 14, 41). It has been reported that 1 in 1000 athletes will experience a post-exercise thrombotic event (22), 40% of which may develop post-thrombotic syndrome (PTS) (38). Symptoms of PTS include chronic leg pain, leg heaviness, leg swelling, and leg cramping (38). In conjunction with other athlete-related risk factors (e.g., recent orthopedic trauma and surgery, limb immobilization, dehydration and hemoconcentration after exercise, and/or altitude training), frequent and/or prolonged air travel following exhaustive exercise may significantly contribute to an increased risk of thrombosis and PTS in trained athletes (1).

Currently, the use of compression garments is the most accepted and commonly available method of external compression for the prevention of flight-related thrombosis (23). Associated benefits include blood vessel dilation, reduced lower-limb swelling, and increased blood flow/venous return (31), as well as an inhibition in the outflow of blood through the endothelial gaps (i.e., subsequent contact with tissue factors and initiation of coagulation) (37). These improvements in resting circulatory dynamics may also increase muscle oxygenation and/or improve muscle repair from confined stress configurations (8, 42), and as a result minimize the detrimental effects of long-haul air travel on exercise performance in travelling athletes (28). In support of this, wearing compression during long-haul trans-meridian air travel has been reported to maintain counter-movement jump performance (28), as well as improve subjective ratings of leg pain, discomfort, energy levels, ability to concentrate, and alertness (21), as compared with a passive control.

The use of compression garments during international air travel may therefore reduce the risk of travel-related performance decrements and thrombosis, but this has not been investigated in an elite population following long-haul air travel. Given that long-distance air travel is regularly frequented by the modern-day elite athlete (10), as well as the exacerbated risk for athletes to develop VTE (1), this is an important and unanswered omission in the literature. The aim of the current study was to determine the effects of wearing compression socks during long-haul travel on sports-specific performance, physiological, and hematological alterations in elite female volleyball athletes, thereby assessing its potential as an effective means to minimize the detrimental effects of air travel on travelling athletes. We hypothesized that wearing compression socks during long-haul travel would minimize the detrimental effects of long-haul air travel on exercise (counter-movement jump) performance, markers of VTE, and subjective ratings of travel fatigue and jet-lag.

METHODS

Experimental Approach to the Problem

To examine the effects of wearing compression socks during long-haul air travel on performance, physiological, and hematological alterations in elite female volleyballers, athletes travelling from Canberra (Australia) to Manila (Philippines) for the Women's Asian Championships (August, 2017) volunteered as participants. The study followed a two-group, parallel study design, in which participants were assigned (in a randomized and counter-balanced fashion) to one of two conditions; compression socks (COMP, n = 6), or a passive control (CON, n = 6). Participants were matched for counter-movement jump (CMJ) height, and required to wear compression (COMP) or normal (CON) socks underneath a loose-fitting team tracksuit for the duration of travel. Within-subject difference in performance, physiological, and hematological alterations were compared over time (before, during, and after travel) and between groups (COMP v CON).

Subjects

Twelve elite Australian female volleyball athletes (mean ± SD: age, 25 ± 2 y and range 22 to 27 y; body mass, 78.9 ± 4.5 kg; years competing at international level, 5 ± 2 y) completed the study. As confirmed by the coaching staff, the team was in a tapering phase leading up to the Asian Championships. Participants were first provided with an institutionally-approved informed consent form presenting all the information pertinent to the investigation, and were also verbally informed of the benefits and risks of the investigation. If the participants agreed to participate in the study, they were then requested to sign the informed consent form. All participants were screened for cardiovascular risk factors that may increase the risk of an adverse event occurring during exercise. All experimental procedures were approved by the Australian Institute of Sport's (AIS) Human Research Ethics Committee, and adhered to the American College of Sports Medicine's policies with regards to human experimentation. All participants had no known history or clinical signs of coagulation disorders or previous history of VTE. Participants were asked to refrain from nicotine, alcohol, and caffeine consumption for 24 h prior to each testing session, as monitored by 24 h food diaries. Given the implications of diet, and especially fat, on blood hemostasis (34), participants were also provided with dietary recommendations to adhere to during the study (e.g., consistent dietary fat content). In addition, participants were asked to avoid the use of anti-coagulant (i.e., aspirin, heparin, and warfarin) and non-steroidal anti-inflammatory medications for at least two weeks before, and throughout, the testing period.

Procedures

An outline of the experimental procedures is demonstrated in Figure 1. Participants first reported to the AIS Physiology Laboratory 24 h prior to travel (-24 h). During this session, familiarization and baseline testing of the counter-movement jump (CMJ) protocol was performed. On the same day (-12 h) after a day of training and a recovery session, baseline measures of CMJ performance, subjective ratings of well-being, cardiovascular function, calf girth, as well as a blood sample, were collected. This time point was chosen as baseline so as to minimize diurnal variation between the baseline and post-flight measures (i.e., both were performed at a similar time of day, ~1600 AEDT). On the next morning, participants reported to Canberra Airport to begin travel (0800 AEDT). Prior to boarding, participants assigned to the COMP group were presented with knee-high sports compression socks (2XU Compression Socks, Melbourne, Australia), to be worn for the entire duration of travel (i.e., Canberra to Manila). These compression socks have previously be reported to elicit compression of 23 ± 11 mmHg at the maximal calf girth, and between 19 and 22 (± 8) mmHg at the ankle, in well-trained runners (9). Subjective ratings of well-being and cardiovascular function were taken at 2.5 and 5 h into the Sydney-Manila flight leg, corresponding to 6.5 h (+6.5 h) and 9 h (+9 h) after the start of travel. Upon arrival to the hotel in Manila, all baseline (-12 h) measures were repeated. Physical performance measures were also collected for two days (+24 h and +48 h) after landing in Manila. All morning testing sessions (Canberra and Manila), were performed at the same time of day (0800 AEDT) to minimize diurnal variation.

**** FIGURE 1 ABOUT HERE****

Flight Details

Participants, coaching staff, and the testing personnel travelled from Canberra to Manila with Qantas Airlines (Qantas, Sydney, Australia). The total flight duration was ~9.5 h, divided into two legs; 1) QF 1494 (De Havilland-Bombardier Dash-8), ~1 h Canberra to Sydney; 2) QF 19 (Airbus A330), ~8.5 h Sydney to Manila, with a ~2.5-h stop-over in Sydney. Participants sat in economy class for both flights (Seat Width/Pitch 46/79-81 cm), and a total of 2 time zones were crossed from Sydney to Manila. Cabin temperature was maintained at ~ 23° C, and the cabin was pressurized to a maximum altitude of 2440 meters (minimum pressure of 75 kPa). Participants were instructed to 'move (their) legs and feet for three to four minutes per hour while seated', but to avoid excessive movement throughout the cabin (apart from necessary toilet breaks). Meals were provided on the Sydney-Manila leg only, comprising of lunch, and afternoon snack, and an evening meal prior to arrival. During the flight, participants were instructed to avoid alcohol and caffeine consumption, and to consume 500 mL of water every 2 h to ensure adequate hydration. All participants were informed that hydration during air travel will maintain blood volume, thereby limiting the risk of blood clotting and its subsequent effect on exercise performance. As such, this recommendation ensured adequate hydration during air travel, but also doubled as an attempt to limit the effects of a potential placebo effect on performance.

Pre-Flight Training and Recovery Sessions

On the day prior to travel, the 12 volleyball athletes performed two training sessions at the AIS in preparation for an upcoming tournament (2017 Women's Asian Championships). The first training session (0830 to 1030 AEDT) was a moderate-to-high intensity (~session RPE 5 to 6) session, comprising of mobility/warm-up (15 min), ball control drills (15 min), skill-based drills (30 min) and 6-on-6 game play (1 h), and was completed immediately after the baseline measures. This session had a jump focus, in that hitters and setters performed approximately 90 to 120 and 150 to 200 jumps during the 2-h session, respectively. The second training session (1430 to 1530 AEDT) was a low-intensity (~session RPE 2 to 3), skill-based session, compromising of serve and pass drills only. Immediately after the second training session, participants performed a 30-min recovery session, comprising of 10 min of hydrotherapy at the AIS Recovery Centre (4 min active recovery in 25˚ C, 3 min passive in 37˚ C, and 3 min passive in 17˚ C) and 20 min of compression therapy of the legs using pneumatic compression boots (Normatec PULSE Leg Recovery System, Normatec, Watertown, MS, United States).

Counter-Movement Jumps

To assess the effects of travel on volleyball-specific performance, participants performed maximal counter-movement jumps (CMJ) on four occasions: twice during baseline testing (-24 h and -12 h), the morning after landing in Manila (+24 h), and the following morning (+48 h). Before the CMJ protocol, participants completed a standardized warm up of 5 lunges per leg, 5 body weight squats, 5 tuck jumps, 3 CMJ (bar on shoulders) at 70% maximal effort, 3 CMJ (bar on shoulders) at 90%, and 2 CMJ (bar on shoulders) at 100%. For the CMJ protocol, a position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) was connected to a lightweight bar (~400 g) held across the posterior deltoids at the base of the neck. Starting from the initial standing position (upright position with feet approximately shoulder width apart), participants lowered themselves to a self-selected depth and then jumped for maximal height with no pause between eccentric and concentric movements [24]. Encouragement was provided such that participants were to be as explosive as possible in their movements, and jump as high as possible (n.b., the bar was to remain firmly against shoulders at all times for the CMJ). Each athlete completed 5 maximal jumps, with peak jump height (m), mean concentric velocity (m/s), relative power (W/kg), and jump-to-dip height (ratio) used for analysis. These measures were chosen to demonstrate the recovery of volleyball-specific performance, namely lower-body power production. Baseline CMJ (-24 h and -12 h) were performed in the AIS Physiology Laboratory, whereas post-travel CMJ (+24 h and +48 h) were performed on the teams training court in Manila. All CMJ were performed away from the main group (i.e., other participants and coaches) so as to remove the effects of social facilitation on jump performance.

Jet Lag Questionnaire

To assess the effects of travel on psychological well-being, participants were required to complete an adapted version of the Liverpool Jet Lag questionnaire (JLQ) at a number of time points during the study. The JLQ was designed to assess participant feelings of jet lag, ability to concentrate, mood, fatigue levels, muscle soreness, motivation, and overall health. Instructions were given to mark an “X” on a 10-cm visual analog scale between two extremes (0 = ‘not at all jet lagged’, ‘focused’, ‘amicable’, ‘not fatigued at all’, ‘not sore at all’, ‘extremely motivated’, and ‘very healthy’; 10 = ‘extremely jet lagged’, ‘easily distracted’, ‘antagonistic’, ‘extremely fatigued’, ‘extremely sore’, ‘not motivated at all’, and ‘not healthy at all’). The questionnaire was completed at baseline (-12 h), during the Sydney to Manila flight (+6.5 h and +9 h), and post travel (+12 h).

Cardiovascular Function

Upon arriving to the AIS laboratory for baseline testing, participants were asked to be seated for 15 min. Following this, resting blood pressure and heart rate (HR; UB-542 Wrist Blood Pressure Monitor, A&D), and oxygen saturation (SO_2; Onyx Vantage 9590 Finger Pulse Oximeter, Nonin) were measured. Following 15 min of seated passive rest on each occasion, these measures were again taken during the Sydney to Manila flight (+6.5 h and +9 h), and post travel (+12 h). These measures were used as surrogate markers of compression-induced changes in blood flow.

Calf Girth

Used as an objective measure of lower-limb swelling, calf girth measurements were obtained during baseline testing at the AIS (-12 h) and upon arrival at the team's hotel in Manila (+ 12 h). On both occasions, calf girth measurements were taken immediately after the cardiovascular function measurements. With the participants standing, an Executive steel tape measure (Lufkin, USA) was used to measure calf girth as per the International Standards for Anthropometric Assessment guidelines (40). Girth measurements were repeated twice and the average of two measures per site were used for data analysis. Following the baseline measures, a mark was made on the participant's calf to ensure the same site was used for the post-travel measurement.

Blood Samples

Venous blood samples (~10 mL) were drawn without stasis by venipuncture from the antecubital fossa on two separate occasions; during baseline testing at the AIS (-12 h), and at the hotel in Manila (+12 h). Blood samples were collected into sodium citrate Vacutainers® (Becton Dickinson, New Jersey, USA). Baseline samples were spun for 15 min at 4° C and 1000 *g* in a centrifuge (CF 20-R, Awel Centrifugation, Blain, France), and collected plasma was aliquoted and stored at -20° C for subsequent analysis. Blood collected at the hotel in Manila was spun for 15 min at 4° C and 1000 *g* using a portable centrifuge (EBA 20, Hettich, Tuttlingen, Germany), with the aliquoted plasma stored at 4° C for 24 h until couriered back to the AIS (World Courier, Stamford, CT, United States) for subsequent storage at –20° C. All samples were subsequently thawed and analyzed for markers coagulation and fibrinolytic activity in the blood, thereby providing including tissue factor (TF), tissue factor pathway inhibitor (TFPI), thrombin anti-thrombin complex (TAT), and D-Dimer with commercially available enzyme-linked immunosorbent assay (ELISA) kits (Abcam, Melbourne, Australia), according to manufacturer's guidelines. All samples were measured in duplicate using a spectrometer-based absorbance microplate reader (SPECTROstar Nano, BMG Labtech, Offenburg, Germany).

Statistical Analyses

The data were analyzed with a linear mixed model using IBM SPSS Statistics V19 (IBM Corporation, USA). A random intercept for subjects was included to account for intra-individual dependencies and inter-individual heterogeneity. This also allowed for individual baseline adjustment. Fixed effects for time, condition, and their interaction (time x condition) were analyzed, and all models were estimated using Restricted Maximum Likelihood. The level of significance was set at $P < 0.05$. Data are presented as mean estimates and 95% confidence intervals, unless otherwise stated. To complement the statistical hypothesis testing, effect sizes (ES) were calculated to assess the practical significance of changes (from baseline) in calf girth, hematological markers, autonomic function, subjective ratings and physical performance between conditions. Effects of compression on these factors were log transformed before analysis (to permit the effect of the treatment to be analyzed as factors or percent), and magnitudes of effects were determined by standardization of the log-transformed variable. Performance outcomes were assessed by standardization; 0.20 of the pooled between-subject standard deviation in the two groups. Differences between group means of subject characteristics were assessed with a modification of Cohen's scale for standardized effects (small, 0.20-0.60; moderate, 0.60-1.20; large, >1.20). ES were only reported when there was a ≥ 75% likelihood of the effect being equal to or greater than the smallest worthwhile change (ES = 0.2), and uncertainty in the estimates are reported as 90% confidence intervals. All ES were calculated using a custom excel spreadsheet [4].

Calculated intra-class correlation coefficients (ICCs), considering the average for all variables analyzed, demonstrated excellent reliability for CMJ height (ICC = 0.90), CMJ mean velocity (ICC = 0.91), D-Dimer (ICC = 0.943), TF (ICC = 0.97), TAT (ICC = 0.96), HR (ICC = 0.92), L calf girth (ICC = 0.98), and R calf girth (ICC = 0.94), good reliability for CMJ peak power (ICC = 0.84), CMJ jump to dip ratio (ICC = 0.86), TFPI (ICC = 0.79), and SBP (ICC = 0.77), and poor reliability for oxygen saturation (ICC = 0.32) (27).

RESULTS

Counter-Movement Jumps

There were no time or interaction effects for CMJ height (P = 0.717 and 0.942), mean velocity (P = 0.466 and 0.800), relative power (P = 0.331 and 0.675), or jump to dip height ratio (P = 0.457 and 0.991) (Fig. 2). However, when compared with CON, effect size analysis revealed that CMJ height (5.2 ± 6.1%; ES = 0.69 ± 0.66) and mean velocity (3.9 ± 5.0%; ES = 0.55 ± 0.70) were higher for COMP at +24 h. Similarly, CMJ relative power was 8.0 ± 9.2% higher for COMP, as compared with CON, at +48 h (ES = 0.74 ± 0.84) (Fig. 2).

**** FIGURE 2 ABOUT HERE****

Jet Lag Questionnaire

There was a main effect of time (P < 0.001) for jet lag, in that all participants felt significantly jet lagged after travel (+12 h). There were no main effects of time for subjective ratings of alertness (P = 0.186), mood (P = 0.636), fatigue (P = 0.247), muscle soreness (P = 0.671), motivation (P = 0.875), or overall health (P = 0.636). There were no interaction effects for jet lag (P = 0.853), alertness (P = 0.679), mood (P = 0.853), fatigue (P = 0.712), muscle soreness (P = 0.689), motivation (P = 0.872), or overall health (P = 0.853). However, effect size analysis revealed that changes from baseline in subjective ratings of alertness, fatigue, muscle soreness, and overall health were all improved for COMP, as compared with CON.

Specifically, fatigue (ES = 1.07 ± 1.68), muscle soreness (ES = 0.66 ± 0.90), and overall health (ES = 0.35 ± 0.37) were all improved at +6.5 h, with alertness (ES = 0.75 ± 1.48) and muscle soreness (ES = 1.27 ± 1.44) both improved at +9 h (Table 1).

*** *TABLE 1 ABOUT HERE****

Cardiovascular Function

There was a main effect of time for SO_2 ($P < 0.001$), which was significantly reduced at +6.5 h ($P = 0.003$) and +9 h ($P < 0.001$). There were no main effects of time for systolic blood pressure (SBP; $P = 0.469$) or HR ($P = 0.891$), nor interaction effects for SBP ($P = 0.741$), HR ($P = 0.839$), or SO_2 ($P = 0.719$). However, effect size analysis revealed that changes from baseline in SBP at +12 h (8.1 ± 12.2 %; ES = 0.64 ± 0.87), HR at +9 h (9.3 ± 12.7 %; ES = 0.71 ± 0.87), and SO_2 at +6.5 h (1.1 ± 2.6 %; ES = 1.90 ± 4.49) and +9 h (1.2 ± 2.1 %; ES = 2.20 ± 3.77), were higher (SO_2) or lower (SBP and HR) for the COMP condition as compared with CON (Fig. 3).

*** *FIGURE 3 ABOUT HERE****

Calf Girth

There were no main time or interaction effects for left (P = 0.960 and 0.710) and right (P = 0.654 and 0.550) calf girth. However, when compared with CON, effect size analysis revealed right calf girth to be less (1.7 ± 1.9 %; ES = 0.44 ± 0.51) following travel for the COMP condition (Fig. 4).

*** *FIGURE 4 ABOUT HERE****

Blood Samples

There were no time or interaction effects for TF (P = 0.468 and 0.977), TFPI (P = 0.414 and 0.806), TAT (P =0.549 and 0.997), or D-Dimer (P = 0.494 and 0.796) (Fig. 5).

**** FIGURE 5 ABOUT HERE****

DISCUSSION

The primary findings of this study were that sports compression socks maintained exercise performance, and reduced lower-limb swelling, when worn during ~8.5 h of air travel in elite female athletes, as compared with a control condition (i.e., no compression socks). This also coincided with improved subjective ratings of alertness, fatigue, muscle soreness, and overall health in participants assigned to wearing compression socks. However, the results appear to be independent of altered cardiovascular function (i.e., SBP, HR, and SO_2) and/or indicators of blood coagulation.

Recovery of counter-movement jump performance in the days following travel was superior in the COMP as compared with CON. Coinciding with improved subjective ratings during (mood and soreness) and after (jet lag) air travel, jump height, mean velocity and relative velocity were higher for COMP at 24 h (height and mean velocity) and 48 h (relative power) after the commencement of travel. Consistent with reports of performance decrements with air travel across two time zones (5), it has been suggested that half a day per time zone is needed to recover from symptoms of jet lag when travelling westward (26). As such, the 2 hour time zone change in the current study (i.e., Sydney to Manila) suggests a full day may have been required for athletes to recover fully. In support of this, jump height, mean velocity and relative power were all below baseline levels at the 24 h post-travel time point for the CON condition. However, the return to baseline for all countermovement jump performance variables consistently occurred sooner in the COMP as compared with CON, consistent with CMJ performance in non-elite individuals travelling 6 h and 20 min westward from Hartford to Los Angeles (three time zones) (28). In this study, Kraemer et al (28) suggest multiple explanations for compression to improve the recovery of CMJ performance, including increased muscle oxygenation, improved resting circulatory dynamics, and/or better muscle repair from confined stress configurations (8, 42). Although not measured in the current study, sleep disruption may have occurred as a result of long-haul travel across multiple time zones (5). Considering the participants wearing compression in the current study felt less fatigued and sore during travel, it is also possible they had a better night's sleep post-travel, which may have contributed to the superior CMJ performance.

Improved subjective ratings of alertness, fatigue, muscle soreness and overall health reported by the COMP participants may have played a role in improving CMJ performance. Individuals travelling over 8 h have previously reported whole-leg compression tights to improve ratings of pain, discomfort, energy levels, alertness, and the ability to concentrate (21). Consistent with the study by Hagan (21), reduced edema (actual or perceived) may have contributed to improved ratings of fatigue and muscle soreness and jet lag in the current study. Subsequently, and considering fatigue (36) and muscle soreness (11) are known to effect performance, improved ratings of these perceptual measures in the COMP group are likely to have contributed to improved CMJ performance.

As compression has been reported to improve hemodynamic responses at rest (29), we also assessed the effects of compression socks on in-flight cardiovascular responses. When compared with pre-travel baseline values, in-flight HR for COMP was reduced by ~8.4 % (+9 h), compared with a negligible increase (~1.3 %) for the CON condition. These data suggest that compression of a small area of muscle (i.e., foot and shank) may alter central circulatory and cardiac parameters such as HR, cardiac output and SBP, despite previous suggestions (7) and data (2) refuting this. In further support that compression may alter HR and subsequently cardiovascular strain, SBP was also lower in COMP post-travel as compared with CON. As expected, SO_2 was decreased during air travel, most likely as a result of an altitude-induced reduction in the fraction of inspired oxygen (24). However, wearing compression socks during travel attenuated the flight-induced decrease in SO_2 (+6.5 h and +9 h). Although improved venous return has been reported to increase arteriovenous pressure gradient (43) and tissue SO_2 (16), this is the first study to report an increase in SO_2 when wearing compression during air travel. A hypothetical mechanism for this occurrence is that a compression-induced increased in venous return, as evidenced by a lower HR, improved the volume of blood presented at the alveolar membranes per beat of the heart, thereby allowing greater saturation levels. Future research to confirm the effects of compression on SO_2 during air travel is warranted, especially considering that reduced SO_2 has been implicated in reduced cognitive function in pilots and cabin crew (19).

It is well established that compression garments are an effective strategy to reduce flight-induced lower-limb edema (12). Consistent with this, the current study reported a small reduction (~0.7 cm; 1.7 %) in right calf girth for the participants who wore compression socks during ~9.5 h of air travel. Considering lower-limb edema is a symptom of inadequate venous blood flow (21), these data also support the notion that sports compression garments are effective in reducing the risk of travel-related thrombosis (e.g., DVT). The external pressure applied by compression is thought to decrease vein diameter, thereby increasing deep venous velocity/return and reducing the risk of thrombosis forming due to venous pooling (39). Lower-limb edema may also reduce range of motion in the ankle and knee joints, which in turn may have important implications for jump performance (7). Although this is likely to be resolved quickly without the presence of exercise-induced muscle damage, this is an important consideration for athletes required to compete or train soon after an extended period of stationary travel (e.g., car, bus, train and/or airplane).

A novel component of this study was to investigate the effects of wearing compression socks during long-haul air travel on markers of coagulation and fibrinolysis in elite female athletes. We investigated markers of blood coagulation activation (TF) and regulation (TFPI), hyper-coagulation (TAT), and thrombosis and fibrinolytic activity (D-Dimer), but found no effects of travel or compression for these markers as a result of long-haul travel. A potential explanation for these inconsistencies is the training sessions that were performed on the day prior to travel. For example, TF and D-Dimer concentrations have been reported to increase by up to ~1.9-fold and ~6.5-fold (respectively) in participants following a marathon (45). Although the training sessions performed in the current study were of a much shorter duration and/or lower intensity than those previously associated with heightened coagulation risk (25, 45), it is possible that the coagulation markers had already increased. As such, any potential increases in these markers as a result of travel may have been masked by prior exercise and increased baseline concentrations. For example, TAT has previously been reported to increase by ~30% following an 8-h flight in a non-athletic population (37), yet only increased ~6% in the current study. Although fibrinolytic activity has been shown to be influenced by circadian rhythms (3), baseline and post-travel blood samples were taken at the same time of day AEDST, thereby discounting this as a potential confounder. However, since some participants are more susceptible to coagulation activation than others (e.g., genetic disposition and/or females using oral contraceptives (13, 33)), as well as the increased prevalence of effort thrombosis in sports requiring extensive and repetitive use of the upper body (20), these factors may have confounded the results of the current study.

PRACTICAL APPLICATIONS

The current study suggests that compression socks are beneficial in combating the physiological stressors imposed by long-haul travel in elite female volleyball athletes, consistent with improvements reported in recreationally-active individuals following long-haul travel across a similar number of meridian time zones (28). These findings translate into a real-world practical benefits for athletes and coaches, and it is recommended that coaches promote the use of compression as a necessary precaution to maximize the capacity and quality of training and/or competition performed soon after long-haul air travel. Although the training sessions performed prior to travel may have influenced some baseline measures, it is common practice for an athlete group to perform a training session on the day before flying, and as such the current study also provides an ecologically valid investigation.

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FIGURE LEGENDS:

Figure 1: Schematic diagram of the study. Fam; familiarization session; CF, cardiovascular function measures; PQ, psychological questionnaires; CMJ, counter-movement jumps; Leg 1, Canberra–Sydney flight leg; Leg 2, Sydney–Manila flight leg; blood drop, blood sample. Time (h) shown represents the duration before (-) and after (+) travel commenced in Sydney.

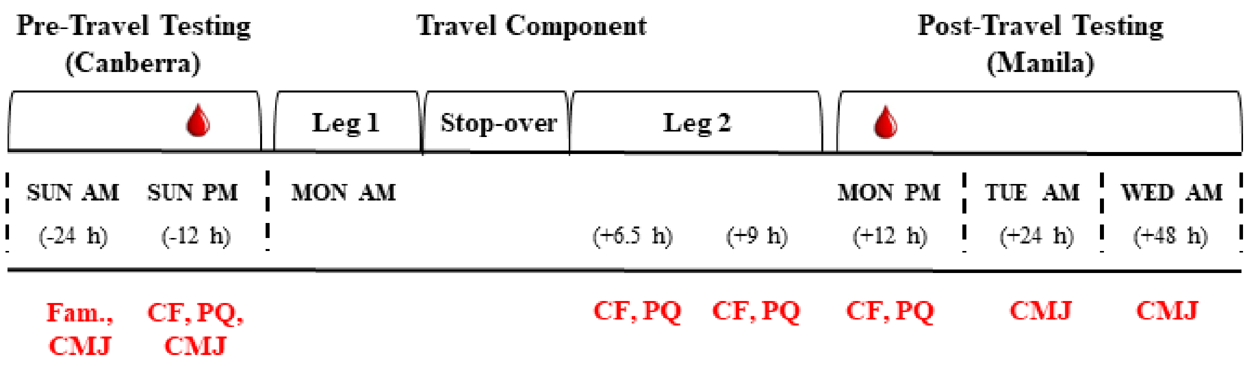

Figure 2: Counter-movement jump height (A), mean velocity (B), relative power (C), and jump to dip height ratio (D) for the control (CON) and compression (COMP) conditions. Values are presented as a percentage of baseline (24 h before travel; -24 h), as measured 12 h before (-12 h), 24 h after (+24 h), and 48 h after (+48 h) travel. All data are presented as mean ± SD. ^ Small effect (ES = 0.55 ± 0.70) as compared with CON. # Moderate effect (ES = 0.6-1.2) as compared with CON.

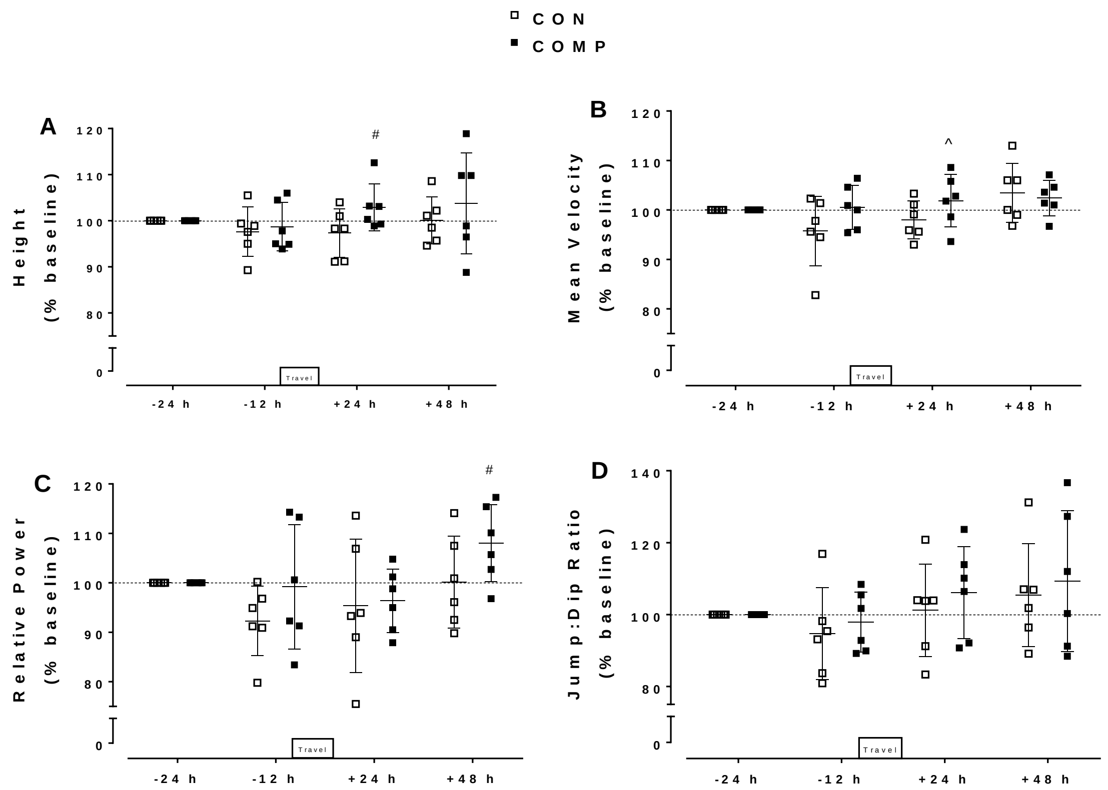

Figure 3: Systolic blood pressure (A), heart rate (B) and oxygen saturation (C) for the control (CON) and compression (COMP) conditions. Time points are before travel (-12 h), 6.5 h into travel (+6.5 h), 9 h into travel (+9 h), and post-travel (+12 h). * Significantly lower (P < 0.05) than baseline. # Moderate effect (ES = 0.6-1.2) as compared with CON. All data are presented as mean ± SD.

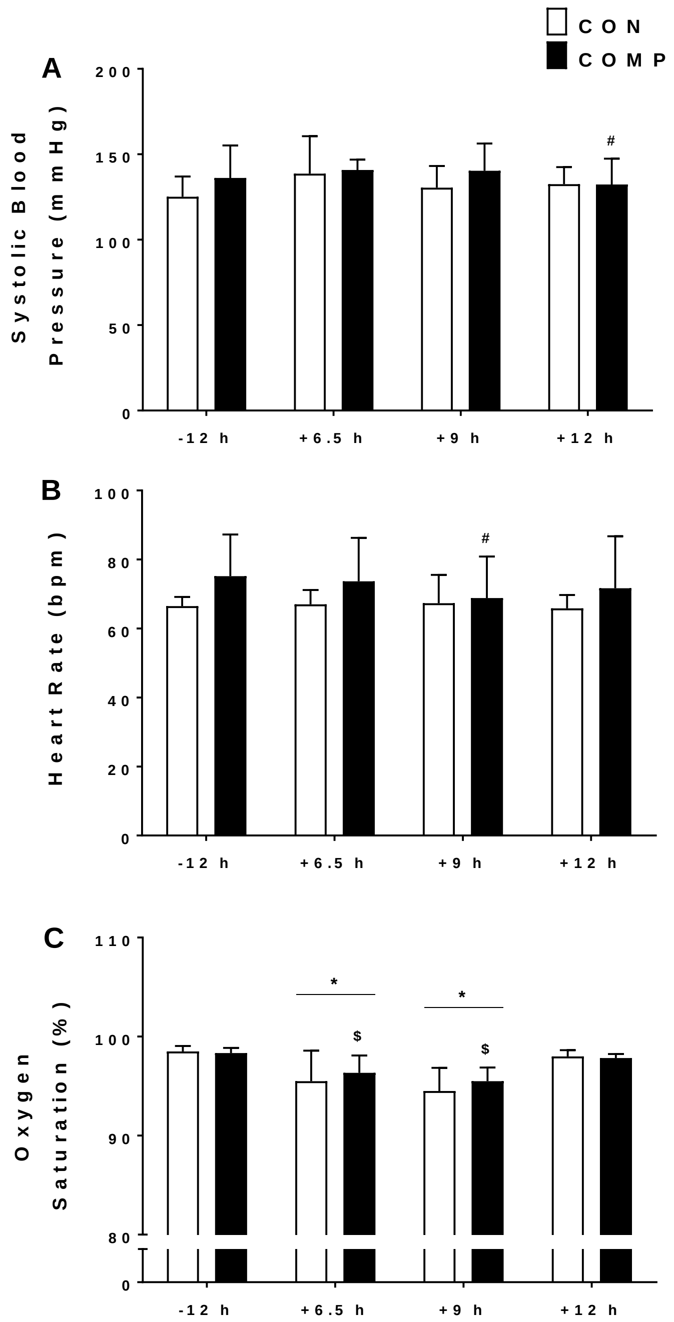

Figure 4: Calf girth of the left (A) and right (B) limbs, for the control (CON) and compression (COMP) conditions. Time points are before (-12 h) and after (+12 h) travel. ^ Small effect (ES = 0.2-0.6) as compared with CON. All data are presented as mean ± SD.

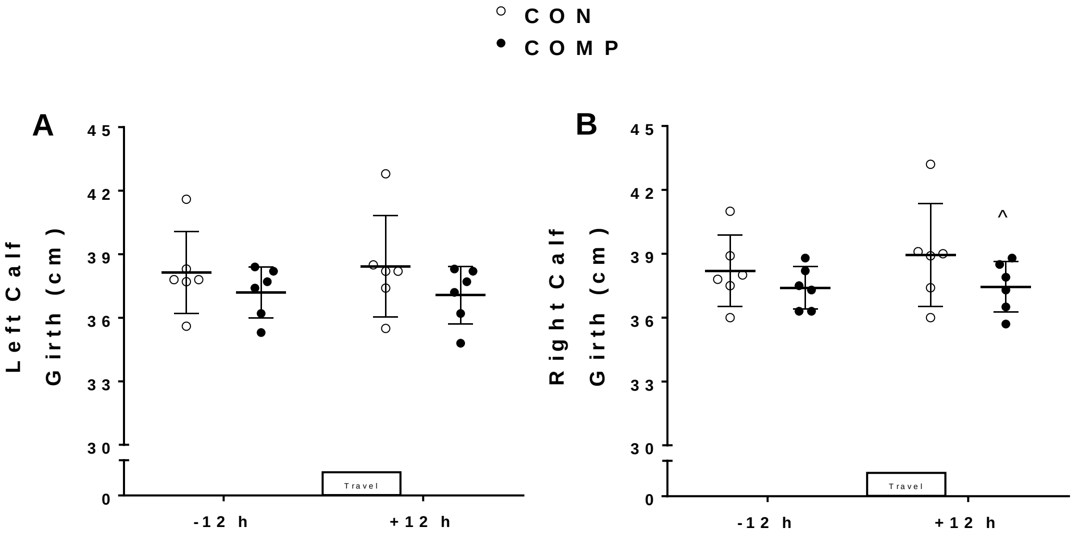

Figure 5: Markers of coagulation and fibrinolysis for the control (CON) and compression (COMP) conditions, before (-12 h) and after (+12 h) travel. Markers were Tissue Factor (A), Tissue Factor Pathway Inhibitor (B), Thrombin-Antithrombin Complex (C), and D-Dimer (D). All data are presented as mean ± SD.

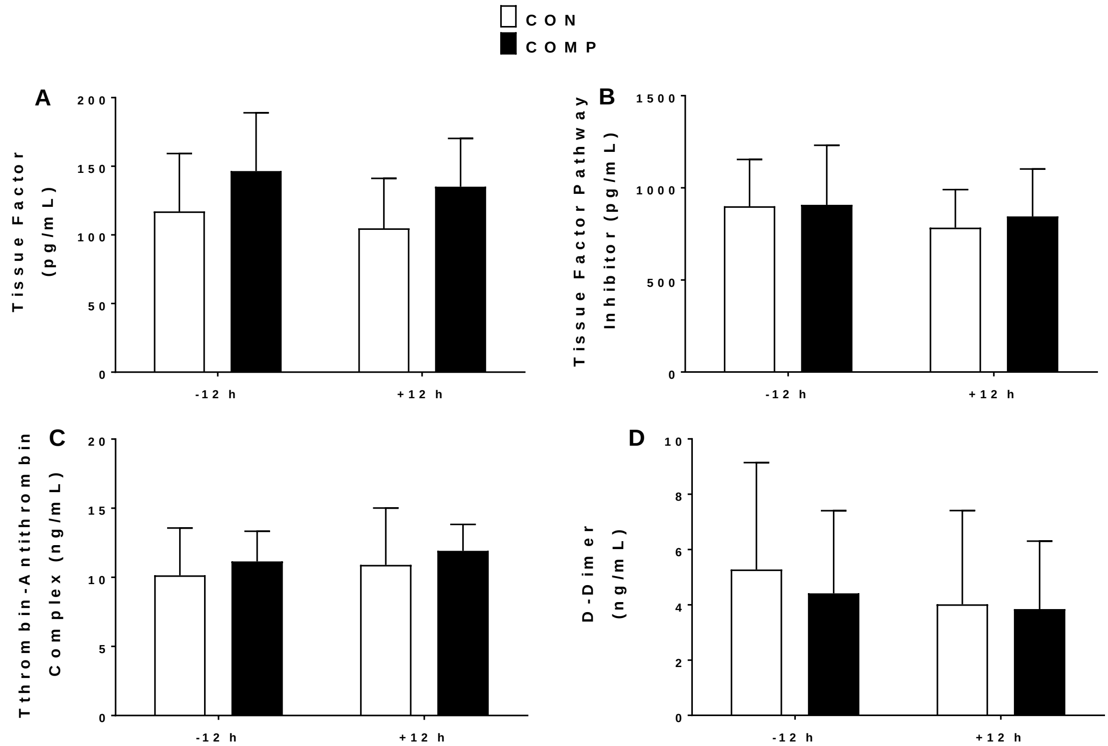

Table 1: Subjective ratings of jet lag, alertness, mood, fatigue, muscle soreness, motivation, and overall health from the jet lag questionnaire (JLQ).

	Time Point			
	-12 h	**+6.5 h**	**+9 h**	**+12 h**
Jet Lag				
CON	0.2 ± 0.2	1.5 ± 2.0	1.7 ± 1.7	4.1 ± 2.6*
COMP	0.1 ± 0.2	1.1 ± 1.8	2.7 ± 2.5	4.4 ± 2.6*
Alertness				
CON	3.5 ± 2.1	3.8 ± 2.6	5.7 ± 3.2	5.5 ± 2.2
COMP	4.9 ± 1.6	4.0 ± 2.4	4.8 ± 1.8#	5.9 ± 1.4
Mood				
CON	1.8 ± 1.6	2.1 ± 2.2	2.6 ± 1.9	3.0 ± 3.0
COMP	2.2 ± 2.2	1.5 ± 2.1	1.9 ± 2.2	2.9 ± 2.7
Fatigue				
CON	5.1 ± 2.5	5.3 ± 2.2	5.2 ± 1.8	6.2 ± 1.7
COMP	6.1 ± 1.6	4.6 ± 2.1#	5.1 ± 1.5	6.6 ± 1.4
Muscle Soreness				
CON	5.6 ± 2.6	5.5 ± 1.6	5.6 ± 2.2	4.7 ± 2.5
COMP	5.6 ± 1.7	4.4 ± 1.6#	3.9 ± 2.4#	4.7 ± 1.9
Motivation				
CON	4.4 ± 2.4	4.3 ± 1.4	4.6 ± 1.6	4.5 ± 2.3
COMP	4.6 ± 2.6	4.7 ± 2.2	4.4 ± 1.8	5.7 ± 3.0
Overall Health				
CON	1.8 ± 1.2	1.7 ± 2.0	2.5 ± 1.9	2.4 ± 2.1
COMP	1.5 ± 0.8	2.6 ± 2.1#	2.3 ± 1.9	2.8 ± 2.3

Values are arbitrary units from 0-10 on a visual analogue scale, presented as mean ± SD. Time points are before travel (-12 h), 6.5 h into travel (+6.5 h), 9 h into travel (+9 h), and post-travel (+12 h). * Significantly different to baseline ($P < 0.05$). # Moderate effect (ES = 0.6-1.2) as compared with CON.