©Journal of Sports Science and Medicine (2020) **19**, 204-212
http://www.jssm.org

Research article

Monitoring External Training Loads and Neuromuscular Performance for Division I Basketball Players over the Preseason

Aaron D. Heishman [1,2]✉, Bryce D. Daub [2], Ryan M. Miller [1], Eduardo D. S. Freitas [1] and Michael G. Bemben [1]

[1] Department of Health and Exercise Science, University of Oklahoma, Norman, Oklahoma, USA
[2] Department of Athletics, Basketball Strength and Performance, University of Oklahoma, Norman, Oklahoma, USA

Abstract

Limited research has paralleled concomitant changes in external training load (eTL) and countermovement jump (CMJ) performance. Therefore, this investigation characterized eTL and CMJ performance changes across preseason training in Division 1 male collegiate basketball athletes, while examining the influence of position (Guard vs. Forward/Center) and scholarship status (Scholarship = S vs. Walk-on = WO). During 22 practices, eTL was monitored in 14 male athletes, with weekly CMJs performed to quantify neuromuscular performance (Jump Height [JH], Flight Time:Contraction Time [FT:CT], Reactive Strength Index Modified [RSI_{Mod}]). PlayerLoad per minute was significantly higher during W1 and W2 (5.4 ± 1.3au and 5.3 ± 1.2au, respectively; $p < 0.05$) compared to subsequent weeks, but no additional differences in eTL parameters across time were observed. Scholarship athletes displayed greater PlayerLoad (S = 777.1 ± 35.6, WO = 530.1 ± 56.20; Inertial Movement Analysis (IMA) IMA_High (S = 70.9 ± 15.2, WO = 41.3 ± 15.2); IMA_Medium (S = 159.9 ± 30.7, WO = 92.7 ± 30.6); and IMA_Low (S = 700.6 ± 105.1, WO = 405 ± 105.0;) ($p < 0.05$), with no observed differences in eTL by position. Moderate decreases in FT:CT and RSI_{Mod} paralleled increased eTL. Significant increases in practice intensity (W1 and W2) did not impact CMJ performance, suggesting athletes could cope with the prescribed training loads. However, moderate perturbations in FT:CT and RSI_{Mod} paralleled the weeks with intensified training. Cumulatively, scholarship status appears to influence eTL while player position does not.

Key words: Athlete monitoring, athlete performance, countermovement jump, fatigue, team sport.

Introduction

Athlete monitoring strategies are used to understand imposed training loads, and to evaluate an athlete's response to training stimuli. Monitoring strategies can be useful in optimizing an athlete's performance by determining their position on the recovery-adaptation continuum following training exposures, managing training loads to mitigate injury risk, as well as establishing quantitative parameters to guide return-to-play and return-to-performance protocols following an injury (Halson, 2014; Bourdon et al., 2017; Dunlop et al., 2019; Taberner et., 2019). Monitoring external training load (eTL) refers to the assessment of mechanical or locomotive work completed by the athlete and provides sport performance coaches with an objective measure of work performed during training, as well as games (Halson, 2014; Heishman et al., 2018a; 2018b; Fox et al., 2018; Svilar et al., 2018a; 2018b). Wearable microsensors, known as inertial measurement units (IMUs) offer a practical and convenient option to quantify eTL in indoor team sports, such as basketball (Holme, 2015; Fox et al., 2017).

IMUs have been used to characterize eTL among basketball athletes during both practice and competition, with PlayerLoad™ (PL) frequently reported as the key workload variable (Scanlan et al., 2014; Schelling and Torres, 2016; Aoki et al., 2017; Heishman et al., 2017; 2018a; 2018b; Peterson and Quiggle, 2017; Fox et al., 2018; Svilar et al., 2018a; 2018b). PL is a vector of magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the 3 orthogonal planes, divided by the scaling factor 100 and expressed in arbitrary units (au) (Barrett et al., 2014; Heishman et al., 2018a; 2018b). The computation of PL includes the summation of load vectors in all 3 orthogonal planes (mediolateral, anteroposterior, and vertical), however laboratory evidence suggests the vertical component of PL contributes 50-60% of load accumulation, while the mediolateral and anteroposterior components only contribute 20-25% of load accumulation during PL analysis (Barrett et al., 2014). Field-based analyses have identified strong correlations between PL and total distance traveled, suggesting the sensitivity of PL to running based activity, likely resulting from increased vertical accelerations from ground reaction forces during the gate cycle (Cormack et al., 2013; Barrett et al., 2014; Polgaze et al., 2015). McLean et al. (2018) speculated that an abundance of vertical acceleration data may mask smaller increases in mediolateral and anteroposterior vector activity, which may be pertinent to the sensitivity of eTL quantification. Moreover, it may be speculated that the large vertical component of basketball play (Schelling and Torres, 2016; Stojanović et al., 2018) could exacerbate the suppression of small increases in mediolateral and anteroposterior movements, such as increases associated with change-of-direction (CoD) activity. These findings have spawned contemporary interests among practitioners to determine alternative strategies for quantifying cumulative movement, such as 2-Demensional PL (PL^{2D}), that only includes the mediolateral and anteroposterior movements, as well as the evaluation of the each individual PL vector, however these analysis have yet to be performed in basketball.

In addition to quantitating work performed during training, some athlete monitoring strategies are used to evaluate the response of the athlete to the training imposed. The countermovement jump (CMJ) is commonly used to

Received: 02 October 2019 / Accepted: 16 December 2019 / Published (online): 24 February 2020

evaluate neuromuscular readiness and performance in sport (Aoki et al., 2017; Rowell et al., 2017; Heishman et al., 2018a; 2018b; Ferioli et al., 2018) and may provide insight regarding the capacity of an athlete to recover from training. Interestingly, previous research has reported increases (Aoki et al., 2017) and decreases in CMJ height over the preseason among professional basketball players, (Ferioli et al., 2018) decreases in collegiate players, (Heishman et al., 2017) while semi-professional athletes have revealed no change (Ferioli et al., 2018). These results may reflect the level of play or varying levels of eTL, which often go unquantified. Previous basketball literature has evaluated changes in CMJ height, while evidence from alternative sports suggests that different force-time characteristics may accentuate fatigue by identifying compensations in movement strategy to achieve the desired gross output (Cormack et al., 2008; Gathercole et al., 2015; Rowell et al., 2017). Of note, Flight Time to Contraction Time Ratio (FT:CT) evaluates the athletes' jumping strategy and has recently been established as a reliable variable in collegiate basketball players (Heishman et al., 2018a; 2018b; 2019). Additionally, Reactive Strength Index Modified (RSI_{Mod}), derived from dividing contraction time (CT) by jump height, provides an index of explosiveness (Kipp et al., 2016), and may also be a useful parameter to quantify changes in performance (McMahon et al., 2018; Heishman et al., 2019). Therefore, coupling eTL with resultant changes in CMJ performance may allude to the dose-response relationship of training. Although an acute inverse relationship between eTL and subsequent CMJ performance has been established (Heishman et al., 2018a; 2018b; Cruz et al., 2018), no data exists paralleling eTL with CMJ performance in basketball athletes.

Limited data exist identifying the influence of player position on eTL in collegiate basketball players. Similarly, no data exist examining the impact of a player's scholarship status, which alludes to their role on the team, on eTL. Furthermore, a paucity of literature is available relating eTL parameters with subsequent changes in CMJ performance parameters. Therefore, the purpose of the present study was to 1) characterize the average eTL per session; 2) examine differences in the average eTL per session each week; and 3) explore changes in CMJ performance across the 5 weeks of preseason training phase in NCAA Division I basketball athletes. Subsequent analyses examined the influence of position and academic status on eTL. It was hypothesized that the average eTL per session would be similar across training weeks and that there would be a decrease in the neuromuscular performance indices of jump height, FT:CT, and RSI_{mod} across the preseason.

Methods

Subjects

Fourteen male (age = 19.7 ± 1.0 years, height = 1.98 ± 0.07 m, body mass = 94.7 ± 6.2 kg) NCAA Division I collegiate basketball players were included in this study. Participants were categorized into position groups consisting of forwards/centers (n = 7) or guards (n = 7) determined by the basketball coaching staff. Players were classified by academic status as either a scholarship or non-scholarship (Walk-on) athlete (Scholarship: n = 10; Walk-on: n = 4) and were active squad members of the University of Oklahoma's Men's Basketball team. This research was approved by the Institutional Review Board of the University of Oklahoma and all participants provided written, informed consent before participating in the study.

Design

In a prospective observational study design, eTL was measured during 22 basketball practice sessions over the course of a 5-week preseason training phase. In addition, weekly measurements of neuromuscular performance were assessed using the CMJ, performed just prior to the start of each strength training session. Subjects performed 1 CMJ assessment prior to the start of the preseason (Pre) and then 1 CMJ assessment per week, following a day off from training, except for Weeks 2 and 3, where CMJ testing was performed in 2 separate sessions due to the logistics of strength training scheduling requiring a portion of the team to come 2 days after an off day. A detailed schedule is provided in Figure 1.

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Week 1	**OFF**	*Practice*	*Practice*	*Practice*	**OFF**	CMJ (1) *Practice*	*Practice*
Week 2	**OFF**	*Practice*	*Practice*	**OFF**	CMJ (2) *Practice*	CMJ (2) *Practice*	**OFF**
Week 3	**OFF**	*Practice*	*Practice*	*Practice*	**OFF**	CMJ (3) *Practice*	CMJ (3) *Practice*
Week 4	**OFF**	*Practice*	*Practice*	*Practice*	**OFF**	CMJ (4) *Practice*	**OFF**
Week 5	**OFF**	*Practice*	*Practice*	*Practice*	*Practice*	**OFF**	**OFF**
Week 6	**OFF**	CMJ (5)					

Figure 1. The schedule of practice, off-days, and CMJ assessments performed during the preseason. Practice = Team practice where external training load was monitored and practice always occurred following CMJ assessments. CMJ = countermovement jump assessment, followed by the (number) to identify the assessment, which always occurred prior to the start of strength training sessions; OFF = scheduled off day with no organized team training.

Procedures

External Training Load (eTL) Monitoring: Subjects wore the Catapult Sport OptimEye T6 IMU system (Catapult Innovations, Melborne, VIC, Australia) comprised of a triaxial accelerometer, gyroscope, and magnetometer, sampling at a rate of 100Hz, in a supportive harness positioned between the scapulae. Subjects wore the same IMU and supportive garment during each practice(McLean et al., 2018) and eTL monitoring started when athletes took the floor for pre-practice warm-ups and ended when they left the floor at the conclusion of practice. Once starting practice, all players remained in the respective drill and were not 'interchanged' or substituted, even if they were not the primary participant in the drill as previous literature has suggested substitution can artificially inflate training load intensities (Fox et al., 2018).

All data were analyzed via the Catapult Sport software (Openfield, Catapult, Innovations, Melborne, VIC, Australia) which applies specific algorithms to transform the input of raw inertial data captured during athlete movement into meaningful and standardized output variables used to quantitate the movement experienced. These variables can be classified into two types of variables, "workload variables" and "event detection variables" (Holme, 2015). The workload variables included PL, PL^{2D} which only includes the accelerometer data from the mediolateral and anteroposterior planes of movement, and individual PL^{1D} accumulated in the anteroposterior ($PL^{1D\text{-}FWD}$), mediolateral ($PL^{1D\text{-}SIDE}$), and vertical ($PL^{1D\text{-}UP}$) planes of movement. PL/min divides the PL accumulated by time, providing an intensity index.

Inertial Movement Analysis™ (IMA™) values defined as an instant one-step movement effort or micromovement and is expressed as count data (ct) (Holme, 2015; Spangler et al., 2018; Ward et al., 2018). These distinct acceleration micro-movement events occur during sudden explosive movements, such as accelerations, decelerations, and CoD movements, common among team sport play (Holme, 2015; Spangler et al., 2018; Ward et al., 2018). IMA™ events are detected using proprietary algorithms within the manufacturer software during post-session data analysis generated. IMA™ events are quantified by coupling triaxial accelerometer and triaxial gyroscope data to form a non-gravitational vector and use advanced Kalman filtering algorithms to detect and quantify the frequency of micro-movements experienced during sport play (Holme, 2015). An IMA™ event is detected with the application of polynomial smoothing curves between the start and end point of the accelerative events (Holme, 2015; Spangler et al., 2018). The magnitude of an event (IMA™ Magnitude) is subsequently computed by summing the accelerations under the polynomial curve, measured in terms of delta-velocity, a unit of impulse ($m \cdot s^{-1}$).

The key IMA™ variables were as follows: IMA_Low = Low Intensity (1.5-2.5$m \cdot s^{-1}$) IMA™ events; IMA_Medium = Medium Intensity (2.5-3.5$m \cdot s^{-1}$) IMA™ events; and IMA_High = High Intensity (>3.5$m \cdot s^{-1}$) IMA™ events. Additionally, the total number of jump events were combined, as previous literature has outlined the limited sensitivity of the IMU to detect differences in jump heights (Spangler et al., 2018), therefore Jumps = Total number of IMA™ Jump events (including High, Medium, and Low Intensities).

Neuromuscular Fatigue and Performance Assessment: In accordance with previously described methods, (Heishman et al., 2018a; 2018b) following a standardized warm-up and prior to the start of a strength training session, participants performed 3 CMJs on the ForceDecks FD4000 Dual Force Platforms hardware (ForceDecks, London, UK), with a sample rate of 1000Hz.

Subjects started in the tall standing position, with feet placed hip width to shoulder width apart and hands akimbo. Participants then dropped into a self-selected countermovement depth followed by a maximal effort CMJ landing in an athletic position on the force platforms. Subjects reset to the starting position after each jump, and the procedure was completed for 3 jumps. If the subject removed their hands from their hips at any point or exhibited excessive knee or hip flexion once airborne, the jump was ruled invalid and repeated.

ForceDecks software (ForceDecks, London, UK) was used to analyze each CMJ, and the variables of interest were: FT:CT (the ratio of flight time to contraction time), RSI_{Mod} (calculated as jump height divided by contraction time), and JH (computed by the flight time method) (Heishman et al., 2018a; 2018b; 2019). CMJ tests were performed during the same time of day over the course of the preseason, (Heishman et al., 2017) and the average of the 3 CMJs was utilized for analysis.

Statistical analysis

All data are reported as means ± SD unless stated otherwise. Statistical analyses were performed using SPSS statistical software with an a priori significance level set at $p \leq 0.05$. Initially, data normality was confirmed using the descriptive and graphical information supplemented by Shapiro-Wilk test statistic. A 3-way (Week [W] x Position x Academic) Repeated Measures Analyses of Variance with Bonferroni post hoc analysis was used to examine differences in the average eTL per session each week and differences in the CMJ variables. Effects sizes (Cohen's *d*) were calculated and interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80) (Cohen, 1992).

Results

Average eTL per session

$PL^{1D\text{-}UP}$, $PL^{1D\text{-}SIDE}$, and $PL^{1D\text{-}FWD}$ contributed 43.7 ± 1.8%, 28.7 ± 1.7%, and 27.3 ± 1.5%, respectively, to PL. The results of the average training load per session each week are outlined in Table 1.

There were no significant differences in the average PL, PL^{2D}, $PL^{1D\text{-}FWD}$, $PL^{1D\text{-}SIDE}$, $PL^{1D\text{-}UP}$ per session each week ($p > 0.05$). As outlined in Figure 2, there was a significant ($p < 0.001$) main effect for average PL/min per session, with further analyses revealing significant increases during W1 compared to W3 ($p = 0.002$, $d = 0.46$), W4 ($p = 0.05$, $d = 0.60$), and W5 ($p = 0.015$, $d = 0.72$), and significant increases in W2 compared to W5 ($p = 0.035$, $d = 0.66$). No significant differences were observed for IMA_Low ($p = 0.163$), or IMA_High ($p = 0.430$), but IMA_Medium presented a significant main effect (p = 0.041) for differences across weeks, however further analyses revealed no significant differences between weeks (p > 0.05).

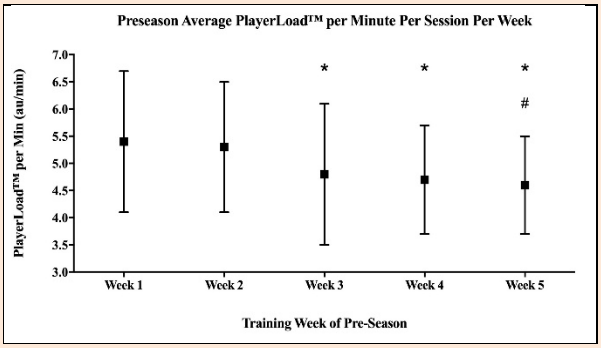

Figure 2. Differences in the average PlayerLoad™ per minute (PL/min) per session across the 5 weeks of preseason. * = Significantly different than Week 1, $p < 0.05$; # = Significantly different from Week 1, $p \leq 0.05$

Position differences in eTL

There were no significant Position*Week interactions and no significant differences in the average PL (p = 0.883), PL/min (p = 0.830), PL^{2D} (p = 0.794), $PL^{1D\text{-}FWD}$ (p = 0.825), $PL^{1D\text{-}SIDE}$ (p = 0.761), $PL^{1D\text{-}UP}$ (p = 0.852), IMA_Low (p = 0.361), IMA_Medium (p = 0.780), IMA_High (p = 0.780), or Jumps (p = 0.692) per session each week between positions (Table 2). However, a medium effect (*d* = 0.51) for differences in IMA_Low and a small effect (*d* = 0.22) for differences in Jumps between positions were observed but the remaining variables displayed trivial effects (*d* < 0.2).

Academic status differences in eTL

Significant Academic*Week interactions were observed for PL (p = 0.042), $PL^{1D\text{-}SIDE}$ (p = 0.020), and $PL^{1D\text{-}UP}$ (p = 0.036). Further analyses revealed significantly greater average PL per session for Scholarship athletes during W1 (Scholarships = 841.9 ± 46.0, Walk-ons = 544.4 ± 72.8; p = 0.005), W3 (Scholarships = 792.4 ± 46.5, Walk-ons = 447.6 ± 73.5; p = 0.002), W4 (Scholarships = 721.5 ± 39.3, Walk-ons = 548 ± 62.2; p = 0.036), and W5 (Scholarships = 759.8 ± 23.6, Walk-ons = 526.2 ± 37.3; p < 0.001). Scholarship athletes experienced significantly greater $PL^{1D\text{-}SIDE}$ per session during W1 (Scholarships = 342.7 ± 20.1, Walk-ons = 218.8 ± 31.8; p = 0.007), W3 (Scholarships = 321.64 ± 20.2, Walk-ons = 180.2 ± 32.0; p = 0.002), and W5 (Scholarships = 308.5 ± 12.23, Walk-ons = 206.4 ± 19.3; p = 0.001). Scholarship athletes also experienced greater $PL^{1D\text{-}UP}$ per session during W1 (Scholarships = 545.5 ± 29.5, Walk-ons = 351.6 ± 46.6; p = 0.004), W2 (Scholarships = 499.3 ± 30.0, Walk-ons = 375.8 ± 47.5; p = 0.048), W3 (Scholarships = 514.3 ± 30.5, Walk-ons = 285.5 ± 48.3; p = 0.002), and W5 (Scholarships = 496.0 ± 15.4, Walk-ons = 339.2 ± 24.3; p < 0.001).

As outlined in Figure 3 and Figure 4, there was a significant main effect for differences between Scholarship and Walk-on athletes per session for: PL (p = 0.003, *d* = 2.2), PL/min (p = 0.002, *d* = 2.3), PL^{2D} (p = 0.005, *d* =2.0), $PL^{1D\text{-}FWD}$ (p = 0.005, *d* =2.0), $PL^{1D\text{-}SIDE}$ (p = 0.007, *d* = 1.9), $PL^{1D\text{-}UP}$ (p = 0.003, *d* = 2.2), IMA_Low (p < 0.001, *d* = 2.8), IMA_Medium (p = 0.003, *d* = 2.2), IMA_High (p = 0.003, *d* = 1.9), and Jumps (p = 0.001, *d* = 2.6).

Table 1. Average external training load per session each week.

Variable	Week 1	Week 2	Week 3	Week 4	Week 5	p-value
PL (au)	756.9 ± 197.5	716.8 ± 167.2	693.9 ± 214.6	671.9 ± 144.6	693 ± 130.9	0.083
PL^{2D} (au)	491.1 ± 131.1	465.7 ± 112.2	451.4 ± 139.3	428.7 ± 97.2	447.7 ± 86.6	0.085
$PL^{1D\text{-}FWD}$ (au)	307.3 ± 84.4	290.9 ± 73.7	281.5 ± 90.5	267.7 ± 64.8	279.4 ± 60.6	0.065
$PL^{1D\text{-}SIDE}$ (au)	318.5 ± 83.9	302.2 ± 70.8	293.6 ± 88.1	278.3 ± 60.6	290.7 ± 52.1	0.108
$PL^{1D\text{-}UP}$ (au)	490.1 ± 127.7	464.0 ± 108.1	448.9 ± 141.8	423.2 ± 96.8	451.2 ± 87.1	0.054
IMA_High (cts)	65.2 ± 24.5	64.9 ± 22.8	62.9 ± 25.8	57.7 ± 10.8	61.6 ± 20.3	0.430
IMA_Medium (cts)	152.8 ± 54.2	145.1 ± 45.5	140.2 ± 53.5	129.8 ± 36.1	135.5 ± 41.2	0.041
IMA_Low (cts)	667.3 ± 220.7	615.4 ± 169.4	615.4 ± 227.8	596.1 ± 151.3	587.1 ± 155.8	0.163
Jumps (cts)	112 ± 41.5	106.3 ± 42.5	104.2 ± 43.2	101.3 ± 38.7	92.6 ± 36.5	0.056

PL = PlayerLoad™; PL^{2D} = 2-Demensional PlayerLoad™; $PL^{1D\text{-}FWD}$ = 1-Demensional PlayerLoad™ Forwards; $PL^{1D\text{-}SIDE}$ = 1-Demensional PlayerLoad™ Side; $PL^{1D\text{-}UP}$ = 1-Demensional PlayerLoad™ Up; IMA_High = High Intensity (>3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™; IMA_Medium = Medium Intensity (2.5 to 3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™; IMA_Low = Low Intensity (1.5 to 2.5 $m \cdot s^{-1}$) Inertial Movement Analysis™; Jumps = Total number of Jumps, including High, Medium, and Low Intensity; au = arbitrary units; cts = counts; statistical significance set at $p < 0.05$.

Table 2. Positional difference in external training load. Values are means ± SD.

Variable	Guards	Forwards/Centers	p-value	Cohen's *d*
PL (au)	713.1 ± 164.6	699.9 ± 164.6	0.883	0.08
PL/min (au)	5.0 ± 1.1	4.9 ± 1.1	0.830	0.12
PL^{2D} (au)	464.6 ± 108	449.2 ± 108.0	0.794	0.14
$PL^{1D\text{-}FWD}$ (au)	289.7 ± 72.2	281 ± 72.2	0.825	0.10
$PL^{1D\text{-}SIDE}$ (au)	302.2 ± 66.9	291.1 ± 66.9	0.761	0.17
$PL^{1D\text{-}UP}$ (au)	460.9 ± 106.6	450.1 ± 106.6	0.852	0.10
IMA_High (cts)	67.8 ± 20.1	57.1 ± 20.1	0.339	0.52
IMA_Medium (ct)	144.0 ± 44.7	137.3 ± 44.7	0.780	0.15
IMA_Low (cts)	572.6 ± 172	659.9 ± 172	0.361	0.51
Jumps (cts)	99.1 ± 38.8	107.5 ± 38.8	0.692	0.22

PL = PlayerLoad™; PL^{2D} = 2-Demensional PlayerLoad™; $PL^{1D\text{-}FWD}$ = 1-Demensional PlayerLoad™ Forwards; $PL^{1D\text{-}SIDE}$ (au) = 1-Demensional PlayerLoad™ Side; $PL^{1D\text{-}UP}$ = 1-Demensional PlayerLoad™ Up; IMA_High = High Intensity (>3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™; IMA_Medium = Medium Intensity (2.5 to 3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™; IMA_Low = Low Intensity (1.5 to 2.5 $m \cdot s^{-1}$) Inertial Movement Analysis™; Jumps = Total number of Jumps, including High, Medium, and Low Intensity; au = arbitrary units; cts = counts; statistical significance set at $p \leq 0.05$.

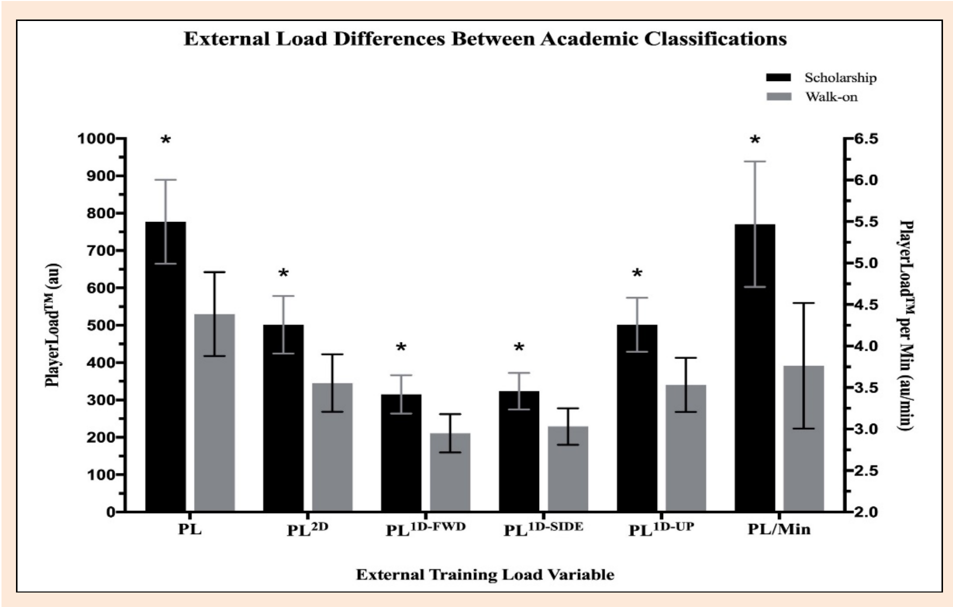

Figure 3. Comparing PlayerLoad™ (PL) eTL variables between Scholarship and Walk-on Athletes. eTL = external training load; PL = Total PlayerLoad™; PL^{2D} = 2-Demensional PlayerLoad™; $PL^{1D\text{-}FWD}$ = anterior-posterior PlayerLoad™; $PL^{1D\text{-}SIDE}$ = medio-lateral PlayerLoad™; $PL^{1D\text{-}Up}$ = vertical PlayerLoad™; PL/Min = PlayerLoad™ per minute; au = arbitrary units; * = significantly different between groups, $p \leq 0.05$. All differences exhibited a large effect (Cohen's $d > 1.0$).

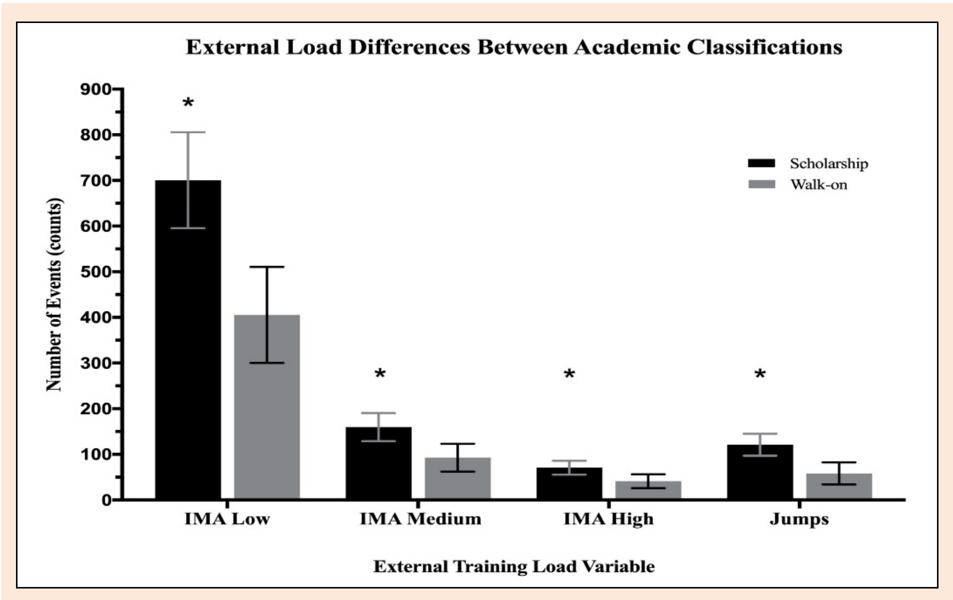

Figure 4. Comparing Inertial Movement Analysis™ (IMA) between Scholarship and Walk-on athletes. IMA Low = Low Intensity (1.5 to 2.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA Medium = Medium Intensity (2.5 to 3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; and IMA High = High Intensity (>3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; Jumps = Total number of Inertial Movement Analysis™ Jump events (including High, Medium, and Low Intensities); * = significantly different between groups, $p \leq 0.05$. All differences exhibited a large effect (Cohen's $d > 1.0$).

Neuromuscular performance

There were no significant Position*Week or Academic*Week interactions among any of the neuromuscular performance parameters. As outlined in Figure 5, there were no significant differences in FT:CT, RSI_{Mod}, or JH across the 5 weeks of preseason. Interestingly, decreases in FT:CT demonstrated a small effect (d = 0.25) from Pre- to W1, while the increase in FT:CT from W2-W3 and W3-W4 showed medium effects (d = 0.55 and 0.61, respectively). Similarly, changes in RSI_{Mod} demonstrated small effects from Pre- to W1 (d = 0.42), W2-W3 (d = 0.42), W3-W4 (d = 0.35), and W4-W5 (d = 0.46).

There was a significant main effect for differences between positions for JH (Forward/Center = 34.6 ± 0.36, Guards = 42.6 ± 0.36, $p < 0.001$), but no significant positional differences in FT:CT (Forward/Center = 0.685 ± 0.13, Guards = 0.72 ± 0.13, $p = 0.495$) or RSI_{Mod} (Forward/Center = 0.45 ± 0.13, Guards = 0.52 ± 0.13, $p = 0.092$).

Discussion

The present study was designed to 1) characterize the average eTL per session across each week of the preseason;

2) examine differences in the average eTL; 3) evaluate the influence of position and academic status on eTL; and 4) examine changes in neuromuscular performance across the 5 weeks of preseason. The main findings of the present study were 1) the characterization of eTL in NCAA Division I basketball players during the preseason training phase; 2) no significant positional differences were observed in eTL; 3) $PL^{1D\text{-}UP}$ contributed less to total PL accumulation during basketball play, while $PL^{1D\text{-}FWD}$ and $PL^{1D\text{-}SIDE}$ each demonstrated a 2-7% greater contribution to total PL compared to the previously reported data on linear running; 4) significant differences in eTL between key players and role players during the preseason training period; and 5) there appeared to be a moderate effect of decreases in FT:CT and RSI_{Mod} with increases in PlayerLoad/min, however jump height remained unchanged.

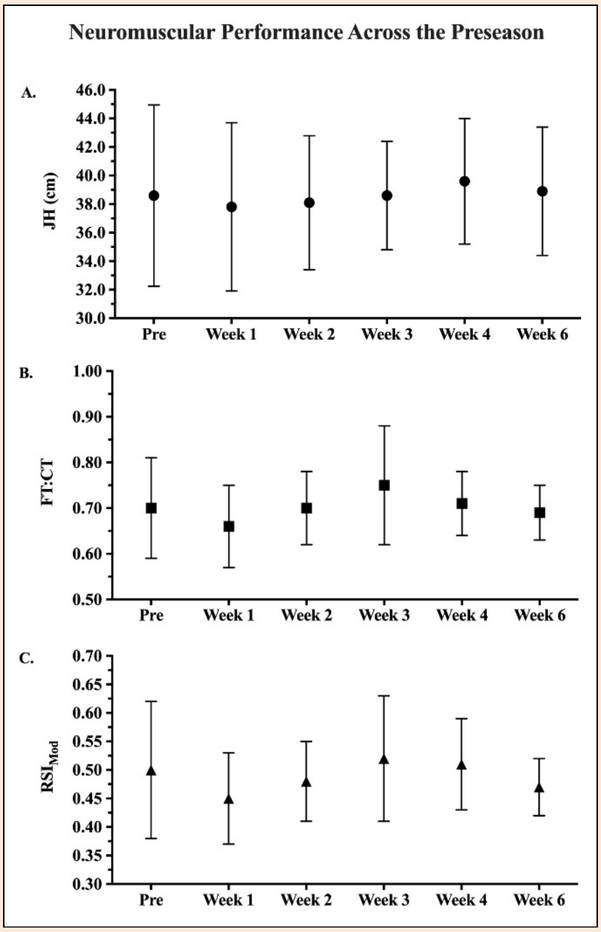

Figure 5. Changes in Neuromuscular Performance during the Countermovement Jump Across the Preseason. JH = Jump Height; FT:CT = Flight Time to Contraction Time; RSImod = Reactive Strength Index Modified.

This is the first study to provide a comprehensive eTL profile for collegiate men's basketball players during the preseason training period, which includes the commonly reported PL and PL/min values, but also including IMA™ data. The present study observed greater values for PL than previously reported in collegiate basketball athletes during the preseason (Heishman et al., 2017; 2018a; 2018b) and professional athletes, (Svilar et al., 2018a; 2018b) but more similar to PL and PL/min values seen in semi-professional (Fox et al., 2018). While limited data exists surrounding the IMA™ events in basketball play, the total jumps per session in the present study were approximately 2-3 times greater in addition to total IMA™ events nearly 2 times higher than those previously reported (Svilar et al., 2018a; 2018b). Differences observed in eTL characteristics likely related to the types of drills and activities included in the basketball sessions, which is largely dependent on the sport coaches and their perspective on the needs of the technical and tactical improvements of team, as well as other factors such as the style of play of the team. In addition, it should be mentioned that there is possibility for differences to arise through the use of different IMU hardware throughout the literature. In addition to the use of different manufactures, there is always potential for differences within manufacturer products, with previous much of literature using Catapult Innovations S5 units, while the present study utilized Catapult Innovation T6 devices. Although utilizing the same hardware, a comparison between the two units has yet to be published. All of these factors make the comparison of absolute eTL values between research challenging.

There were no significant differences in eTL variables per week of practice across the preseason, except for increases in PL/min during the first 2 weeks of the preseason. The significant elevation in intensity likely reflects the players' and coach's excitement for the new training phase and upcoming season, as well as the later stages of the training phase leading into competition where practices included more instructional time learning tactical strategies, often occurring at lower intensities.

The present study provides evidence that $PL^{1D\text{-}UP}$ contributes 5-15% less to total PL accumulation during basketball activity, compared to laboratory-based studies of linear running activities (Barrett et al., 2014). $PL^{1D\text{-}FWD}$ and $PL^{1D\text{-}SIDE}$ each demonstrated a 2-7% greater contribution to total PL compared to the previously reported running data on linear running (Barrett et al., 2014). These findings are likely due to the large lateral component and intermittent play of basketball requiring frequent accelerations and decelerations (Stojanović et al., 2018). These movements produce more horizontal and fewer vertical ground reaction forces than top-end speed running (Nagahara et al., 2018) that may be achieved in outdoor sports with large areas of play (Cormack et al., 2013; Ward et al., 2018). These findings may suggest the vertical component of basketball activity plays a smaller role in masking minor increases in the mediolateral and anteroposterior vector activity than that experienced in other sports (McLean et al., 2018).

Although positional differences in training load is evident in a variety of sports and are thought to be crucial for improving the individualization of the training program (Aughey and Varley, 2013; Ward et al., 2018), the present study observed no positional differences for eTL (Staunton et al., 2018). Similarly, Staunton et al. (2018) reported few position-specific differences in the exercise dose, average intensity, or the proportion of time spent in each intensity zone during training between front-court and backcourt players within a women's professional team. Alternatively, previous literature has demonstrated higher acceleration loads for guards, which may be due to smaller players having a lower body mass that can be accelerated with less applied force and tactical principles of the game position bigger players closer to the basket and incorporate a smaller playing zone for their actions, while smaller players travel more distance during gameplay (Schelling and Torres, 2016). Additionally, Svilar et al. (2018a; 2018b) reported key eTL variables were position-dependent; however, their statistical approach limits the generalizability of their findings, and may reflect more to the style of play within their team. Therefore, the lack of difference observed in the present study may be attributed to the team's style of play or player profiles. Specifically, the present study included several hybrids (or "stretch four") players that are versatile enough to play around the basket and the perimeter. Further, training phase may contribute to the lack of differences between positions, as the preseason practice strategy differs from that during the season.

These data present a novel finding revealing significant increases, with large effects, in eTL among Scholarship athletes, and ultimately suggests that coaches may need to consider academic differences and player roles when managing eTL. This observation is important as eTL differences may require supplemental training to maintain physical fitness, and be useful for managing training loads, or guiding return-to-play and return-to-performance protocols. The current stratification approach (academics) was used since the player's roles had not been established during the preseason and misclassification would likely compromise the analysis. Therefore, future research may stratify players considering game-minutes played or team role. Additionally, future literature should explore the eTL disparities during the season since it can be speculated that Walk-on eTL may increase during the competitive phase, as they often relieve scholarship/key players to manage fatigue and may have increased training loads from scout team responsibilities.

To our knowledge, this is the first study to couple quantitative eTL with changes in neuromuscular performance among basketball players. The present study provides conflicting results compared to previous observations reporting no significant differences in JH across the preseason, whereas previous literature has reported increases (Aoki et al., 2017) and decreases (Heishman et al., 2017; Cruz et al., 2018). Similarly, Ferloi et al. (2018) observed no change in JH over the course of the preseason, thus the maintenance of JH across the preseason may suggest that the athletes were able to adequately recover from the prescribed eTL. Therefore, different observations regarding changes in JH over intensive training periods may relate the eTL imposed, but also may be associated with the athlete's physical capacities and fitness level to with-stand the imposed volumes and intensities of training.

Although there were no significant differences in FT:CT or RSI_{Mod} observed over the duration of the preseason in the present study, there was a moderate effect for decreases in FT:CT and RSI_{Mod} following the first 2 weeks of training, which paralleled a significantly greater PL/min. Therefore, JH may not be sensitive enough to detect alterations in eTL parameters, but changes in movement strategy (FT:CT or RSI_{Mod}) appear to be altered to achieve the gross jump output of JH following intensified bouts of training. These findings support the utility of FT:CT outlined in previous work that has acutely observed substantial reductions in FT:CT following both training and game play (Cormack et al., 2008; Rowell et al., 2017).

The present study has limitations that warrant discussion. First, there was no control of individual work outside of organized team practice, which could influence total eTL and fatigue. Secondly, all players did not jump on the same day due to the logistical challenges when scheduling training session in the collegiate setting (e.g., academic class schedules), however this could have influenced the interpretation of the results. Finally, it may be more practically useful to practitioners if athletes were stratified into groups of key players, rotational players, and developmental players. Due to the training phase the researchers could not definitively delineate each players role in the forthcoming season, however this should be a consideration in future work.

Conclusion

While there were significant increases in practice intensity during W1 and W2 of the preseason, no significant differences manifested in neuromuscular performance indices, suggesting athletes were able to cope with the prescribed training loads. However, there appeared to be small perturbations in FT:CT and RSI_{Mod} following the weeks with intensified training. Scholarship athletes displayed significantly greater eTL variables when compared to Walk-on athletes, but eTL was not affected by position.

The present study provides valuable insight for performance practitioners, characterizing the eTL profile during practice in a cohort of NCAA Division I basketball players. The significant increases in eTL parameters for Scholarship athletes suggests coaches may need to monitor and manage these athletes with different strategies to maintain fitness and for guiding return-to-play and return-to-performance protocols following injury. Additionally, the lack of positional differences suggests that coaches may not need to stratify teams by position in load monitoring strategies, however coaches should examine the differences among their squad individually, as they may vary depending upon style of play and player personnel. Finally, the present study suggests JH may lack the sensitivity to detect alterations in eTL, while FT:CT and RSI_{Mod} may be more useful in monitoring neuromuscular performance, as athletes may modify their movement strategy to achieve a desired JH.

Acknowledgements

The authors would like to thank Mr. Brady Brown and Mr. Keldon Peak for their assistance with this project. Additionally, the authors thank the Basketball Programs at the University of Oklahoma for their continued support of research directed at enhancing athlete performance, while also improving overall student-athlete welfare. Finally, the authors would also like to thank all of the student-athletes that graciously volunteered their time to enroll and participate in this study. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare.

References

Aoki, M. S., Ronda, L. T., Marcelino, P. R., Drago, G., Carling, C., Bradley, P. S. and Moreira, A. (2017) Monitoring training loads in professional basketball players engaged in a periodized training program. *Journal of Strength and Conditioning Research* **31(2)**, 348–358.

Aughey, R. J. and Varley, M. C. (2013) Acceleration profiles in elite Australian soccer. *International Journal of Sports Medicine* **34(3)**, 34-39.

Barrett, S., Midgley, A. and Lovell, R. (2014) PlayerLoad^{TM}: reliability, convergent validity, and influence of unit position during treadmill running. *International Journal of Sports Physiology & Performance* **9(6)**, 945-952.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T.J., Coutts, A.J., Burgess, D.J., Gregson, W. and Cable, N. T. (2017) Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance* **12(Suppl 2)**, 2161–2170.

Cohen, J. (1992) A power primer. *Psychological Bulletin* **112(1),** 155.

Cormack, S., Mooney, M., Morgan, W. and McGuigan, M. (2013) Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. *International Journal of Sports Physiology and Performance* **8(4)**, 373–378.

Cormack, S., Newton, R. and McGuigan, M. (2008) Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance* **3(3)**, 359–374.

Cruz, I. de F., Pereira, L. A., Kobal, R., Kitamura, K., Cedra, C., Loturco, I. and Cal Abad, C. C. (2018) Perceived training load and jumping responses following nine weeks of a competitive period in young female basketball players. *PeerJ* **6(July)**, e5225.

Dunlop, G., Ardern, C. L., Andersen, T. E., Lewin, C., Dupont, G., Ashworth, B., Gary O'Driscoll, Andrew Rolls, Susan Brown and McCall, A. (2019) Return-to-Play Practices Following Hamstring Injury: A Worldwide Survey of 131 Premier League Football Teams. *Sports Medicine* **(2)**, 1-12.

Ferioli, D., Bosio, A., Bilsborough, J. C., Torre, A. La, Tornaghi, M. and Rampinini, E. (2018) The Preparation Period in Basketball: Training Load and Neuromuscular Adaptations. *International Journal of Sports Physiology and Performance* **(January)**, 1–28.

Fox, J. L., Scanlan, A. T. and Stanton, R. (2017) A Review of Player Monitoring Approaches in Basketball: Current Trends and Future Directions. *Journal of Strength and Conditioning Research* **31(7)**, 2021–2029.

Fox, J. L., Stanton, R. and Scanlan, A. T. (2018) A Comparison of Training and Competition Demands in Semiprofessional Male Basketball Players. *Research Quarterly for Exercise and Sport* **89(1)**, 103–111.

Gathercole, R., Sporer, B. and Stellingwerff, T. (2015) Countermovement Jump Performance with Increased Training Loads in Elite Female Rugby Athletes. *International Journal of Sports Medicine* **36(9)**, 722–728.

Halson, S. L. (2014) Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine* **44**, 139–147.

Heishman, A., Brown, B., Daub, B., Miller, R., Freitas, E. D. S. and Bemben, M. (2019) The Influence of Countermovement Jump Protocol on Reactive Strength Index Modified and Flight Time: Contraction Time in Collegiate Basketball Players. *Sports* **7(2)**, 37.

Heishman, A., Curtis, M., Saliba, E., Hornett, R., Malin, S. and Weltman, A. (2018a) Non-Invasive Assessment of Internal and External Player Load. *Journal of Strength and Conditioning Research* **32(5)**, 1280-1287.

Heishman, A. D., Curtis, M. A., Saliba, E. N., Hornett, R. J., Malin, S. K. and Weltman, A. L. (2017) Comparing performance during morning vs. afternoon training sessions in intercollediate basketball players. *Journal of Strength and Conditioning Research* **31(6)**, 1557–1562.

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., Frantz, B. A. and Bemben, M. G. (2018b) Countermovement Jump Reliability Performed With and Without an Arm Swing in NCAA Division 1 Intercollegiate Basketball Players. *Journal of Strength and Conditioning Research* **34(2)**, 546-558.

Holme, B. (2015) *Wearable microsensor technology to measure physical activity demands in handball.* (Master's thesis), Norwegian School of Sport Sciences, Olso. 55.

Kipp, K., Kiely, M. T. and Geiser, C. F. (2016) Reactive strength index modified is a valid measure of explosiveness in collegiate female volleyball players. *Journal of Strength and Conditioning Research* **30(5)**, 1341–1347.

McLean, B. D., Cummins, C., Conlan, G., Duthie, G. and Coutts, A. J. (2018) The Fit Matters: Influence of Accelerometer Fitting and Training Drill Demands on Load Measures in Rugby League Players. *International Journal of Sports Physiology and Performance* **Epub(Epub)**, 1–24.

McMahon, J., Lake, J. and Comfort, P. (2018) Reliability of and Relationship between Flight Time to Contraction Time Ratio and Reactive Strength Index Modified. *Sports* **6(3)**, 81.

Nagahara, R., Mizutani, M., Matsuo, A., Kanehisa, H. and Fukunaga, T. (2018) Association of Sprint Performance With Ground Reaction Forces During Acceleration and Maximal Speed Phases in a Single Sprint. *Journal of Applied Biomechanics* **34(2)**, 104–110.

Peterson, K. D. and Quiggle, G. T. (2017) Tensiomyographical responses to accelerometer loads in female collegiate basketball players. *Journal of Sports Sciences* **35(23)**, 2334–2341.

Polgaze, T., Dawson, B., Hiscock, D. and Peeling, P. (2015) A comparative analysis of acceleromter and time motion data in elite mens hockey training and competition. *International Journal of Sports Physiology and Performance* **(2)**, 1–44.

Rowell, A. E., Aughey, R. J., Hopkins, W. G., Stewart, A. M. and Cormack, S. J. (2017) Identification of Sensitive Measures of Recovery After External Load From Football Match Play. *International Journal of Sports Physiology and Performance* **12(7)**, 969–976.

Scanlan, A. T., Wen, N., Tucker, P. S. and Dalbo, V. J. (2014) The relationship between internal and external training load models during basketball training. *Journal of Strength and Conditioning Research* **28(9)**, 2397–2405.

Schelling, X. and Torres, L. (2016) Accelerometer load profiles for basketball-specific drills in elite players. *Journal of Sports Science and Medicine* **15(4)**, 585–591.

Spangler, R., Rantalainen, T., Gastin, P. B. and Wundersitz, D. (2018) Inertial Sensors are a Valid Tool to Detect and Consistently Quantify Jumping. *International Journal of Sports Medicine* **39(10)**, 802-808.

Staunton, C., Wundersitz, D., Gordon, B., Custovic, E., Stanger, J. and Kingsley, M. (2018) The Effect of Match Schedule on Accelerometry-Derived Exercise Dose during Training Sessions throughout a Competitive Basketball Season. *Sports* **6(3)**, 69.

Stojanović, E., Stojiljković, N., Scanlan, A. T., Dalbo, V. J., Berkelmans, D. M. and Milanović, Z. (2018) The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. *Sports Medicine* **48(1)**, 111–135.

Svilar, L., Castellano, J. and Jukic, I. (2018a) Load Monitoring System in Top-Level Basketball Team: Relationship Between External and Internal Training Load. *Kinesiology* **501**, 25–33.

Svilar, L., Castellano, J., Jukic, I. and Casamichana, D. (2018b) Positional Differences in Elite Basketball: Selecting Appropriate Training-Load Measures. *International Journal of Sports Physiology and Performance* **13(7)**, 947–952.

Taberner, M., Allen, T. and Cohen, D. D. (2019) Progressing rehabilitation after injury: consider the "control-chaos continuum". *British Journal of Sports Medicine* **53(18)**, 1132-1136.

Ward, P. A., Ramsden, S., Coutts, A. J., Hulton, A. T. and Drust, B. (2018) Positional Differences in Running and Nonrunning Activities During Elite American Football Training. *Journal of Strength and Conditioning Research* **32(7)**, 2072–2084.

Key points

- Characterization of external training loads in NCAA Division I basketball players.
- No significant differences were observed between the guard and forward/center positions.
- PlayerLoad ($PL^{1D\text{-}UP}$) contributed less to total PlayerLoad accumulation during basketball play, while $PL^{1D\text{-}FWD}$ and $PL^{1D\text{-}SIDE}$ each demonstrated a 2-7% greater contribution to total PL compared to the previously reported running data on linear running.
- Significant differences in external training loads between key players and role players during the preseason training period.
- There appeared to be a moderate effect of decrease in FT:CT and RSI_{Mod} with increase in PlayerLoad/min, however jump height remains unchanged.

AUTHOR BIOGRAPHY

Aaron D. HEISHMAN
Employment
Assistant Director of Basketball Performance and Sport Scientist, University of Oklahoma, Ok, USA
Degree
M.Ed.; PhD Candidate
Research interests
Athlete performance, athlete monitoring, basketball performance, performance training, neuromuscular performance, and neuromuscular fatigue
E-mail: aaronheishman@ou.edu

Bryce D. DAUB
Employment
Director of Basketball Performance, University of Oklahoma, Ok, USA
Degree
M.S.
Research interests
Athlete performance, basketball performance, cognitive fatigue, fatigue and recovery in athletes, neuromuscular performance and perception of effort
E-mail: bdaub@ou.edu

Ryan M. MILLER
Employment
Graduate Assistant, Department of Health and Exercise Science, University of Oklahoma, Ok, USA
Degree
M.S.; PhD Candidate
Research interests
Neuromuscular performance, Aging, Women's health, Resistance training, and Clinical populations
E-mail: ryanmiller1@ou.edu

Eduardo D. S. FREITAS
Employment
Graduate Assistant, Department of Health and Exercise Science, University of Oklahoma, Ok, USA
Degree
M.S.; PhD Candidate
Research interests
Neuromuscular physiology, Bioenergetics and Metabolism, Perceptual Responses to Resistance Training, Resistance Training, Blood Flow Restriction Training, Clinical Populations.
E-mail: eduardofreitas@ou.edu

Michael G. BEMBEN
Employment
Department Chair, Department of Health and Exercise Science, University of Oklahoma, Ok, USA
Degree
PhD
Research interests
Neuromuscular performance, Aging, Body composition assessment, and Potentiation of muscle hypertrophy
E-mail: mgbemben@ou.edu

✉ **Aaron D. Heishman**
Department of Health and Exercise Science, University of Oklahoma, Norman, Oklahoma, USA