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Difference in Internal and External Workloads between Non-Injured and Injured Groups in Collegiate Female Soccer Players

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ABSTRACT

Background: Effects of internal and external workloads (IL, EL) on lower limb soft-tissue injuries (LLSTI) risk in male soccer players has been described, the relationships remain unclear in collegiate female (soccer players. Objective: The purpose was to examine the mean difference in IL and EL in LLSTI between non-injured and injured groups (N-IG and IG). **Method:** 20 collegiate female soccer players (age: 19.2±1.2years; height: 168.2±7.3cm; body mass: 41.0±17.9kg) were included for 14 week competitive season. IL included average heart rate (Avg-HR) and high heart rate zone. EL included total distance, average speed (Avg-Spd), and high-speed running distance. Injuries were counted if (a) they were LLSTI and muscular/ligamentous strains or tears and tendon problems, and (b) the players missed more than one match or training session. Acute (7-day simple average) and chronic (21-day simple average) IL and EL were calculated in the IG while the mean of acute (7-day) and chronic (21-day) IL and EL were computed in the NIG. Acute Chronic Workload Ratio (ACWR) was calculated as the ratio of acute and chronic IL and EL. **Results:** Seven LLSTI occurred over 14 weeks. The acute Avg-HR and ACWR of Avg-Spd were significantly higher in the IG than the N-IG ($p=0.001$ and 0.024). IL and EL in the IG were placed below or above the mean of the N-IG. **Conclusion:** LLSTI might occur at high and low workloads in collegiate female soccer players. This may support the use of micro-technology to monitor workload based on individual player's threshold to reduce LLSTI.

Key words: Soccer, Athletic Injuries, Physiology, Wearable Electronic Device

INTRODUCTION

Soccer is the world's most popular sport (Kunz, 2007) and is played by all genders and ages at a variety of competitive levels. A soccer team consists of 11 players who play on fields of 90 to 120 meters in length and 45 to 90 meters in width for 90 minutes. Soccer match-play consists of repeated and prolonged sprints combined with jogging, jumping, kicking, heading, and changing directions. In National Collegiate Athletic Association (NCAA) Division I female soccer in North America, players participate in approximately 20 to 25 matches over a 12 to 14 week season. This requires appropriate rest between matches to be allocated to maintain physical performance and minimize the risk of injuries (Andersson et al., 2008; Rollo, Impellizzeri, Zago, & Iaia, 2014).

Advances in technology help to reduce the risk of injury in competitive soccer through workload monitoring (Bowen, Gross, Gimpel, & Li, 2017; Buchheit et al., 2013; de Hoyo et al., 2016; Ehrmann, Duncan, Sindhusake, Franzsen, & Greene, 2016; Owen et al., 2015). Wearable micro-technology devices such as heart rate (HR) monitors and global positioning system (GPS) units quantify session workloads during training and match-play. Workloads are characterized into two categories: internal load (IL) and external load (EL) (Bourdon et al., 2017; Vanrenterghem, Nedergaard, Robinson, & Drust, 2017). IL represents biological responses to external loads or stresses (i.e., average heart rate (HR) and oxygen consumptions), while EL is derived from players' physical movements (i.e., GPS and acceleration-derived variables).

Currently, monitoring and manipulating athlete's workloads based on data produced by wearable devices during sessions play a vital role in minimizing the risk of injuries in soccer (Bowen et al., 2017; Cormie, McBride, & McCaulley, 2008; Ehrmann et al., 2016). Monitoring an athlete's workloads can quantity IL and EL achieved, so sport scientists may be able to manage training plans to maintain or improve sport performance across a competitive season. For maintaining sports performance and minimizing

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the risk of injuries, the theory of acute to chronic workload ratio (ACWR) is commonly used to accumulate IL and EL with the lowest likelihood of injuries (Bourdon et al., 2017; Gabbett, 2017). The ACWR is commonly calculated with both EL and IL variables (i.e., running variables, heart rate variables or the ratings of perceived exertion) (Carey et al., 2016; Hulin et al., 2016; Malone et al., 2017; Malone et al., 2017). Based on the evidence from previous literature (Bowen et al., 2017; Carey et al., 2016; Ehrmann et al., 2016; Gabbett & Ullah. 2012; Owen et al., 2015; Malone et al., 2018), the lowest risk of injury in ACWR would range from 0.8 to 1.3. High acute (i.e., three to seven days) and chronic (three to six weeks) workload have been shown to be associated with a higher likelihood of injuries. For example, Bowen et al. (2017) showed that GPS derived higher workloads were significantly correlated with non-contact injuries in soccer players.

Although previous literature has shown effects of IL and EL on the risk of non-contact injuries (Bowen et al., 2017; Ehrmann et al., 2016; Owen et al., 2015) and lower limb soft-tissue injuries (LLSTI) (Gabbett & Ullah. 2012) in male athletes, the relationships between IL or EL and injuries remains unclear in NCAA female soccer. Additionally, a consensus does not exist on which variables have the highest predictive value of injury in female athletes. It is not known if the same variables are applicable to female athletes. Therefore, the purpose of this study was to examine the mean difference in internal and external loads in LLSTI between non-injured and injured groups of collegiate female soccer players.

METHODS

Participants and Study Design

Twenty NCAA Division I female soccer players from a single team were included in this study (age: 19.2 ± 1.2 years; height: 168.2 ± 7.3 cm; body mass: 41.0 ± 17.9 kg). Required sample size was calculated from previous data in the literature (Ehrman et al., 2016) using G*power 3.1 (Faul et al. 2007). An a priori, one-way ANOVA with desired power (1- β) set at .80, a large effect size of .60, and alpha of 0.5 yields a target sample size of 24. Most collegiate soccer teams have a roster of 30 or more players thus providing a convenience sample. To be eligible for the study, players were (a) outfielders (defenders, midfielders, or forwards) on the team's roster. Players were excluded if they sustained an injury before the season started. Unfortunately five players had to be excluded due to previous injury. Four players on the roster were goalkeepers and thus excluded leaving 20 eligible players.

An observational retrospective cohort design was utilized to analyze previously captured IL, EL, and injury data from a single collegiate season. All data utilized in the study was retrospectively retrieved and analyzed after the conclusion of the season. This was done so that data collected, injury classification, resulting care, and medical decision making would be free of study influence. This study was conducted in 2017 using a completed 14 week competitive season. Players completed 52 training sessions and 22 matches over this period. The players trained 5 to 8 times per week typically for 1 to 2 hours in the morning (from 9 am to noon), and 1 to 2 matches composed of two 45 minute periods with a 15 minute half time intermission. Per NCAA by-laws, all players received at least one day off from physical activity (i.e., skill training, match, and weight training) per week. Data recording in training session started from the beginning of warm-up through the end of the recovery session while the data in a match included warm-up, through the kick-off whistle until the final whistle or when a player was substituted (Eharmann et al., 2016). If a match went into overtime, the extra time was added into the match data. Training and match data were collected and downloaded at the end of each session. During the retrospective analysis, players were divided into two groups: injured and non-injured. The injured group included players that suffered LLSTI and missed at least one full training or match. LLSTI were defined as muscular/ligamentous strains or tears and tendon problems. Upper limb injuries were not counted in this study due to the low rate of injuries in collegiate soccer outfielders (Goodman, Etzel, Raducha, & Owens, 2018). All experimental procedures were approved by and met the guidelines established by the Human Subjects Review Committee at Arizona State University.

Measures

Internal loads were measured by a heart rate monitor (Polar Team 2, Polar Electro OY, Kempele, Finland). The monitor recorded heart rate every 5 seconds. HR data were automatically synchronized with the GPS unit through the Bluetooth when the HR monitor and the GPS unit were worn. The HR data were downloaded to GPS analytic software (Openfield, Catapult Innovation, Melbourne, Australia). The team strength and conditioning coach dampened the electrodes on a chest strap and connected HR monitors to the straps at least 10 minutes before training or match started. Players were taught how to properly wear the HR monitors by placing the strap and monitor over the xiphoid process. As variables of interests, IL included average HR (Avg-HR; beats/min), maximum HR (beats/min), and high HR zones (High HR zone; min ≥ 85% of HRmax). HR max was predicted using 220-age of individual players (Fox, Naughton, & Haskell, 1971).

GPS derived ELs were measured by a 10 Hz GPS unit (Optimeye S5, Catapult Innovation, Melbourne, Australia). Players were instructed to turn these units on and off by the team strength and conditioning coach. The GPS units were worn for every training session and every match for the entire season. GPS units were positioned between the shoulder blades within a vest. Each unit's data were transferred into an analytic software program (Openfield, Catapult Innovation software). GPS derived measures of workload included total distance (m), average speed (Avg-Spd; m/min), and high-speed running distances (HSR; m). HSR was calculated as the distances covered at ≥60% of GPS derived maximum velocity.

To be counted as an injury, three criteria had to be met (Ehrmann et al., 2016): First, the team athletic trainer diagnosed injury as a LLSTI. Second, injuries were muscular/ligamentous strains or tears and tendon problems (Gabbett & Ullah, 2012). Finally, the player missed at least one whole training session or one match after a soft-tissue injury occurred. Severity of injury was not considered.

Data Analysis

Acute (7-day simple average) and chronic (21-day simple average) IL and EL were calculated in the injured group. Also, the mean of acute (7-day) and chronic (21-day) IL and EL in the non-injured were obtained (Carey et al., 2017). Coupled Acute Chronic Workload Ratio (ACWR) was defined as the ratio of acute and chronic IL and EL. Because of the brevity of the collegiate soccer season compared to other traditional soccer seasons, the chronic period was set at 3 weeks.

Statistical Analysis

SPSS version 24.0 (IBM Corporation, New York, USA) was employed for statistical analysis. Initially, a one-way ANOVA was to be performed to compare mean differences, however due to uneven group distribution a Kruskal-Wallis test was used due to non-parametric sample sizes. Mean differences of IL (Avg-HR and H-HR zone) and EL (total distance, Avg-speed, and HSR) between non-injured and injured groups were analyzed this way. Alpha was set at 0.05 for statistically significant differences. Data were expressed as mean ± standard deviation (SD).

RESULTS

Anthropometric characteristics in the non-injured and injured group is described in Table 1. Seven LLSTI occurred during the 2017 season. Four of them were non-contact injuries while the remaining were contact injuries. The most frequent injury was muscle strain on hamstrings in this study, followed by medial collateral ligament sprain. One injury occurred on the third day of the season, therefore ACWR analysis was not performed for the injury (participant ID 7). No player suffered a second injury during the season.

Global Positioning System and Heart Rate Workloads

Acute and chronic workloads and ACWR are described in Table 2. In acute workloads, significant deference was observed in Avg-HR by 8.9 beats/min between the non-injured and injured groups with a mean rank of 13 and 7 for non-injured and injured players, respectively (H(1)=5.8414, p<.001). The other acute workloads were not significantly different between the groups (high HR zone, H(1)= 2.3878, p=.11; total distance, H(1)=2.388, p=.12; Avg-Spd, H(1)= 1.6087, p=.60; HSR, H(1)=1.1453, p=.29). No mean difference was found between the non-injured and the injured group's chronic workloads with a mean rank of 13 and 6 for non-injured and injured players, (Avg-HR; H(1)=.76923, p=.32; high HR zone, H(1)=.93077, p=.37; total distance, H(1)=.277, p=.60; Avg-Spd, H(1)=.12308, p=.76; HSR, H(1)= 1.1077, p=.23). In Avg-Spd, the ACWR in the injured group was significantly higher than the non-injured by 0.07 with a mean rank of 13 and 6 for non-injured and injured players, respectively (H(1)=5.119, p=.024). No significant differences were shown in the other ACWR variables (Ave-HR, H(1)=1.646, p=.20; high HR zone, H(1)=1.406, p=.69; total distance, H(1)= 5.2275, p=.056; HSR, H(1)=.157, p=.69). Figure 1, and 2 described the individual ACWR of TLs in the all participants. Table 3 highlights the individual IL and EL in the injured group. The ACWR of IL and EL in the injured players were located below or above the mean of the non-injured group.

Table 1. Mean (±SD) in the non-injured and injured groups

Group	Injured (n=7)	Non-Injured (n=13)
Age (Years old)	19.6±1.3	18.8±1.2
Height (cm)	174.2±7.0	167.5±5.5
Weight (kg)	65.1±3.5	63.9±4.01
BMI (kg/m2)	21.9±1.3	22.9±0.6

DISCUSSION

The primary findings were (a) the acute Avg-HR in the injured group was statistically higher than the non-injured group, (b) ACWR of Avg-Spd in the injured group was statistically higher than the non-injured group, by 0.07, and (c) the injured group sustained injury when the workloads were extremely high or low compared to the mean of the non-injured group.

The acute Avg-HR in the injured group was significantly higher than the non-injured group by 8.9 b/min. As described by Vanrenterghem and Robinson (Vanrenterghem et al., 2017), HR is indicative of the response to workloads in the cardiovascular system. Thus, during the seven days before injuries, the injured group completed training and matches at a relatively higher intensity than the non-injured group. These findings agree with Owen et al. (Owen et al., 2015) who reported that the injury risk significantly increased in a match when professional soccer players spent longer durations at or above 90% of HRmax (odds ratio = 1.87; p=0.02). Based on the findings of this study and the evidence from previous research (Owen et al., 2015; Schneider et al., 2018), it appears that monitoring athletes for acute changes in Avg-HR during training or matches may provide insight into those players at risk for LLSTI.

Regarding ACWR, Avg-Spd in the injured group was higher than the non-injured group. When ACWR is above 1.0, acute workloads are higher than chronic workloads, which indicates that players are exposed to increased overall and intensive stress on their bodies. According to Vanrenterghem and Robinson (Vanrenterghem et al., 2017), Avg-Spd is associated with the training intensity of EL, so Avg-Spd represents energy consumption. These findings are in agreement with Ehrman et al. (2016) who indicated that the injured players showed significantly higher weekly Avg-Spd in Australian soccer players. Although the numbers of LLSTI

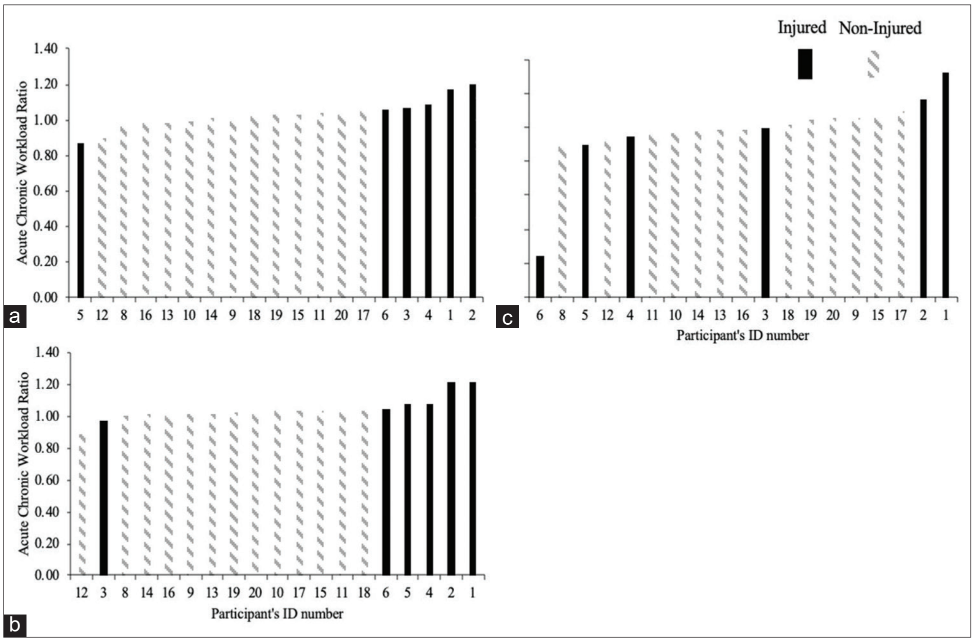

Figure 1. Individual Acute Chronic Workload Ratio of total distance (a), average speed, (b) and high-speed running distance (c). Participant ID 7 was eliminated because the player sustained the third day of the season.

Table 2. Mean (±SD) internal and external loads in the non-injured and injured groups

Items	Acute workload		*p*	Chronic workload		*p*	Acute cronic workload ratio		*p*
	Non-Injured (n=13)	Injured (n=7)		Non-Injured (n=13)	Injured (n=6)		Non-injured (n=13)	Injured (n=6)	
Average HR (beats/min)	143.8±5.0	152.7±5.6	**0.01**	143.7±7.4	147.0±3.7	0.32	1.01±0.04	1.04±0.05	0.20
High HR zone (min)	20.3±6.7	26.1±8.5	0.11	20.0±7.1	23.0±5.3	0.37	1.00±0.06	1.20±0.35	0.69
Total distance (m)	4613.7±1035.2	5182.5±1506.2	0.12	4514.7±1083.4	4978.1±1122.4	0.60	0.99±0.03	1.08±0.12	0.056
Average speed (m/min)	56.4±5.6	58.1±8.7	0.60	55.7±5.5	54.7±7.1	0.76	1.03±0.06	1.10±0.10	**0.02**
HSR (m)	35.7±20.4	47.5±28.2	0.29	33.9±19.7	46.5±22.5	0.23	1.00±0.04	0.93±0.37	0.69

HR: Heart rate. High HR Zone: HR zone ≥85% of HR max. HSR: High speed running distances. Chronic workloads and Acute Chronic Workload Ratio in participant ID 7 were not calculated because the player sustained the injury on the third day of the season. Bold: $p<0.05$.

(seven injuries) were quite limited in this study, ACWR in Avg-Spd might be indicative of the risk of LLSTI.

The injured players were characterized into two types of workloads: either very high workload (ACWR>1.4) or very low workload (ACWR<0.8) groups (Figure 1 and Figure 2). Bourdon et al. (2017) recently stated that with regard to injury, there is an ACWR "sweet spot" that ranges from about 0.8 to 1.3. When the ACWR is above 1.0, players are exposed to more overall and intensive workloads on their bodies. The majority of the injured players (Participant's ID1, ID2, ID3, and ID4) had higher acute IL or EL values than the overall acute mean workloads of the non-injured group while no significant mean differences were observed in chronic IL and EL. Therefore, it appears that cumulative high acute workloads are present when LLSTI occurred. However, ACWR of IL and/or EL in the rest of the injured players (Participant's ID5 and ID6) was 0.1 to 0.2 lower than the group mean of the injured players. For those players, the injuries occurred in the beginning of the season at a period within which the body is adapting to increased TLs. Previous literature indicated that very high acute workload, chronic workload, and ACWR would exponentially increase the risk of injuries (Bowen et al., 2017; Rogalski, Dawson, Heasman, & Gabbett, 2013). Thus, similar to previous literature (Bowen et al., 2017; Rogalski, Dawson, Heasman, & Gabbett, 2013), it was anticipated that both very high ACWR with high acute workload would increase injury risk.

Presently, no consensus exists about how very low workload accumulation may affect injury risk. Very low acute and chronic workload accumulations have been shown to be a risk factor for sustaining an injury. In this study, the two injured players (Participant's ID5 and ID6) were placed at 0.8 of ACWR (Figure 1 and 2). Similar to these findings, Harrison and Johnston (2017) revealed that in Australian Football League players, those with the lowest workload accumulation (1,250 AU per week) had the highest rate of injuries.

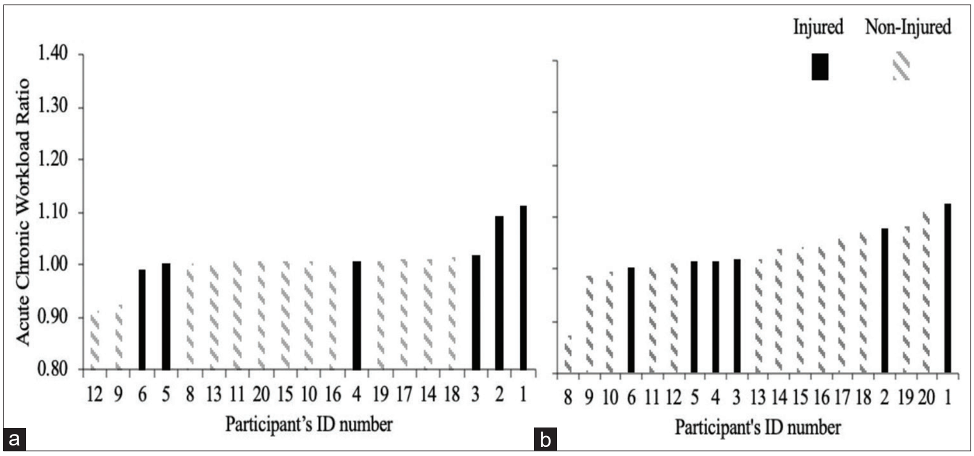

Figure 2. Individual Acute Chronic Workload Ratio of average heart rate (a) and high heart rate zone (b). Participant ID 7 was eliminated because the player sustained the third day of the season.

Table 3. Summary of internal and external workloads in the injured group

Participant ID	1	2	3	4	5	6	7	Mean±SD
Acute Workload								
Average HR (beats/min)	163.7	152.6	146.8	153.3	148.4	149.7	154.6	152.7±5.6
High HR zone (min)	33.5	36.3	25.5	23.4	32.3	13.4	18.0	26.1±8.5
Total distance (m)	5933.0	6087.3	6011.1	6238.1	5904.7	2409.0	3694.4	5182.5±1506.2
Average Speed (m/min)	57.4	68.8	54.1	63.0	67.7	49.3	46.6	58.1±8.7
HSR(m)	69.9	92.3	47.2	47.2	32.5	2.8	40.7	47.5±28.2
Chronic Workload								
Average HR (beats/min)	147.0	139.8	148.0	150.5	148.1	148.5		147±3.7
High HR zone (min)	19.2	25.6	21.2	28.5	28.0	15.4		23.0±5.3
Total distance (m)	5054.1	5084.6	5626.4	5755.3	5582.0	2766.1		4978.1±1122.4
Average Speed (m/min)	47.2	56.6	55.6	58.3	64.8	45.9		54.7±7.1
HSR(m)	52.8	79.4	52.9	47.6	34.4	11.7		46.5±22.5
ACWR								
Average HR	1.11	1.09	0.99	1.02	1.00	1.01		1.04±0.05
High HR zone	1.75	1.42	1.20	0.82	1.16	0.87		1.20±0.35
Total distance	1.17	1.20	1.07	1.08	1.06	0.87		1.08±0.12
Average Speed	1.22	1.22	0.97	1.08	1.04	1.07		1.10±0.10
HSR	1.32	1.16	0.89	0.99	0.94	0.24		0.93±0.37

HT: Heart rate. High HR Zone: HR zone ≥ 85% of HR max. HSR: High speed running distances. ACWR: Acute Chronic Workload Ratio. Chronic workloads and ACWR in Participant ID 7 were not calculated because the player sustained the injury on the third day of the season.

Additionally, Malone et al. (2018) reported that the risk of injury loss was the lowest in professional soccer players when the ACWR in the session ratings of perceived exertion ranged from 1.0 to 1.25. Although the number of injuries was quite limited in this study, it raises the possibility that acute underloading of IL and/or EL might increase the risk of injuries as well as overloading.

One of the strengths of this study is that it is the first to examine the mean differences in IL and EL between injured and non-injured groups of female collegiate soccer players. Although the numbers of the injuries in this study were quite limited, the data may provide sports scientists with the importance of workload management not to sustain injuries in female soccer players. Also, this study re-introduced HR as a potential physiological variable for injury prevention research in sport. The study by Owen et al. (2015) only indicated the impact of HR variables on total injury incidence per 1000 hours of training and matches. Therefore, this study might re-emphasize the importance of HR monitors to minimize the risk of LLSTI in soccer athletes.

There were four main limitations in this study. First, this study only looked at the responses to IL and EL from one team of 20 female collegiate soccer players for 14 weeks. The size of the data set for the limited period is not generalizable to other female soccer teams. Future studies should increase the length of data collection or incorporate more players or teams to increase statistical power via increased exposures, and therefore quantity of injuries. Second, playing position differences were not considered for the risk of LLSTI. Physical demands in female soccer players vary across playing position because different playing patterns (i.e., total distances traveled, HSR, and sprint frequency) (Di Salvo et al., 2010), so the position differences could affect the results in this research. Third, menstrual history or status of the players was not controlled for. According to Lebrun, McKenzie, Prior, and Taution (1995), menstrual cycle negatively affects aerobic performance. Finally, no measure of biological and mechanical workload was included in this study. Future research should include performance tests (i.e., isometric strength test and jump performance tests) as part of ongoing athlete monitoring programs to assess biomechanical status prior to match play.

CONCLUSION

In conclusion, this study indicated that mean acute Avg-HR and ACWR of Avg-Spd were significantly higher in the injured group than the non-injured group. Additionally, IL and EL in the injured players were placed below or above the mean of the non-injured group. The findings might support that LLSTI occur at both high and low workloads in collegiate female soccer players. Every athlete has a different capacity to endure workloads without injury, so it is not possible to identify a single predictor or threshold value of IL and EL for injury in athletes. Therefore, this study might support that monitoring workloads using micro-technology should be carefully conducted based on each individual player's threshold to reduce the risk of soft-tissue injuries.

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