Relationship of Pre-Season Strength Asymmetries, Flexibility, and Aerobic Capacity with In-Season Lower Body Injuries in Soccer Players

Original Scientific Paper

Injuries in Soccer Players

Koulla Parpa[1] and Marcos Michaelides[1]

[1]University of Central Lancashire - Cyprus Campus, University Avenue 12-14, 7080 Pyla, Cyprus

Corresponding author:

Koulla Parpa

UCLan University of Cyprus

Department of Sport and Exercise Science

University Avenue 12-14, 7080 Pyla

kparpa@uclan.ac.uk

Word count: 3000

Abstract word count: 249

Number of Tables: 3

Number of Figures: 2

Abstract

The present study aimed to assess the differences in pre-season knee strength asymmetries, flexibility, and aerobic capacity of soccer players that sustained lower-body injuries during the in-season period compared to those that did not have a lower-body injury. A secondary purpose was to compare the aforementioned parameters between the players that sustained a knee ligament injury and hamstring strain. One hundred and thirty-three division 1 soccer players participated in the study. Fitness testing was conducted at the end of the pre-season period, and the players were followed for a total of 20 games. The anthropometric, lower body strength, flexibility and aerobic capacity parameters were compared between the players that sustained hamstring strains and knee ligament injuries and those that did not sustain any injuries. Results indicated that injured players were significantly older and less flexible than non-injured players ($p<0.05$). Additionally, injured players appeared significantly weaker on the right and left quadriceps and hamstring muscles ($p<0.05$). Furthermore, injured players had significantly greater asymmetries for the hamstrings muscle ($p<0.05$) and significantly lower VO2max values and running time than the non-injured players ($p<0.05$). Lastly, a significant difference between the players that sustained a hamstring injury compared to those who sustained a knee injury was indicated in right hamstring strength, right side ratio, and hamstring asymmetries ($p<0.05$). Our findings suggest that off- and pre-season interventions should be tailored toward increasing aerobic fitness and lower body strength and flexibility while minimizing strength asymmetries and imbalances to reduce in-season injury risk.

Keywords: *bilateral asymmetries, strength imbalances, flexibility, aerobic fitness, soccer*

Introduction

Professional soccer is generally known to be associated with a relatively high injury rate (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001). Research indicated that the total injury incidence in professional soccer players ranges from 2.48 (Ekstrand, Hagglund & Walden, 2011) to 9.4 injuries per 1000 hours of exposure (Walden, Hagglund, & Ekstrand, 2005). More specifically, the injury rate during competition ranges from 8.7 to 65.9 injuries per 1000 hours of exposure, whereas the injury incidence during training is between 1.37 to 5.8 injuries per 1000 hours of exposure (Ekstrand, Hagglund, & Walden, 2011, Eirale, Hamilton, Bisciotti, Grantham & Chalabi, 2012). Furthermore, an analysis of 6030 injuries in soccer players indicated that the majority of injuries were classified as strains (37%) and sprains (19%), with the lower extremity being the site of 87% of the reported injuries (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001). Additionally, research affirmed that soccer injuries are associated with the players' age, exercise load, professional level, and pre-season training status (Dauty & Collon, 2011; Clemente et al., 2017a; Clemente et al., 2017b; Eliakim, Doron, Meckel, Nemet, & Eliakim, 2018; Nobari et al., 2021).

It is imperative to identify the modifiable risk factors in order to prevent time-loss due to soccer-related injuries and maintain soccer players' health and safety. For over a decade, investigators have examined the effect of specific factors on fatigue (Clemente et al., 2017a; Clemente et al., 2017b; Nobari et al., 2021; Nobari, Fani, Pardos-Mainer, & Pérez-Gómez, 2021) and soccer-related injuries with an ultimate goal to prevent them. In this regard, it is debatable whether it is possible to use screening tests to determine who is at an increased risk for a sports injury. Nonetheless, research indicated that a combination of tests during the pre-season period that identify bilateral and ipsilateral isokinetic asymmetries and mixed rations could potentially predict the likelihood of hamstring injury in professional soccer players during the competitive season (Dauty, Menu, Fouasson-Chailloux, Ferréol, & Dubois, 2016). Furthermore, it was demonstrated that lower pre-season isokinetic hamstring strength and a lower hamstring-to-quadriceps ratio increase the risk of acute hamstring strain injury during the in-season period (Lee, Mok, Chan, Yung, & Chan, 2018). Concurrently, if the asymmetry between the knee extensors exceeds 10%, it increases the risk of musculoskeletal injuries by 16 times and ligament and meniscus injuries by up to 28 times (Liporaci, Saad, Grossi, & Riberto, 2019). Moreover, if a strength imbalance is over 10% in the knee flexors, the risk of injury increases by 12 times. Notably, soccer players have shown differences in strength and flexibility between the dominant and non-dominant limbs, which may be due to the technical elements that involve one-sided activities such as kicking, tackling and passing, performed during the games and training (Rahnama, Lees, & Bambaecichi, 2005). Research also indicated that long-term participation in soccer leads to the development of various degrees and modes of functional asymmetry (Fousekis, Tsepis, & Vagenas, 2010). While the aforementioned studies indicated an association between the forces generated at slow isokinetic speeds and lower limb injury incidence, slow-velocity strength production alone might not fully represent the forces generated during a soccer game. Notwithstanding, the rationale for assessing lower-body isokinetic strength and imbalances remains, although it must be acknowledged that the risk of injury is multi-factorial (Hughes, Sergeant, Parkes, & Callaghan, 2017).

In addition to the aforementioned factors, studies in various groups indicated that aerobic fitness might be a recognized risk factor for injury (Watson, Brickson, Brooks, & Dunn, 2017; Eliakim, Doron, Meckel, Nemet, & Eliakim, 2018). Research on female teenage soccer players demonstrated that a higher level of pre-season aerobic fitness is related to a lower risk of injury and sickness throughout the season, suggesting that the off-season training program should be tailored towards increasing aerobic fitness, which may aid in injury and illness prevention (Watson, Brickson, Brooks, & Dunn, 2017). Additionally, research indicated that improvements in VO2 max during the pre-season training period were significantly lower among injured soccer players than non-injured players, while the fitness characteristics at the beginning of pre-season training were not significantly different between the two groups (Eliakim, Doron, Meckel, Nemet, & Eliakim, 2018).

Pre-season soccer training aims to prepare the players mentally and physically to withstand the demands associated with the training and competition during the in-season. Unlike other sports, soccer is characterized by a shorter pre-season training period and a longer in-season period, especially when teams participate in international games (Francioni et al., 2016). Thus, the pre-season period is characterized by a high training load compared to the in-season period (Francioni et al., 2016). Therefore, a careful strategic periodization is required for the players to increase their aerobic capacity and strength and reduce possible asymmetries, which may result in injuries during the in-season period.

The present study aimed to assess the differences in pre-season intra- and inter-limb strength knee asymmetry, flexibility, and aerobic capacity of soccer players that sustained lower-body non-contact injuries during the in-season period compared to those that did not have a lower-body injury. The study's secondary purpose was to compare the aforementioned parameters between the players that sustained a knee ligament injury and hamstring strain.

Methods

Participants

A total of one hundred and thirty-three division 1 soccer players (n=133, age 25.51 ± 5.59 years, height 179.9±17 cm) participated in the study. Fitness testing was conducted at the end of the pre-season period, and the players were followed for a total of 20 games (from Aug 20, 2021, to Feb 5, 2022). The initial sample included 155 players, but only 133 met the inclusion criteria. Players diagnosed with COVID-19 within two months before the collection of data were excluded from the study. Furthermore, players with a previous lower-body injury within the last six months or those that had an injury during the pre-season training period were excluded from the study. Additionally, players with contact injuries or injuries other than hamstring strains (grade 2 and up) and knee ligament injuries were also excluded. The injuries were included only when they were clinically diagnosed and resulted in an absence from training or competition of at least seven days. Only injuries classified as moderate (8–28 days of absence) and major (more than 28 days of absence) were included in this study (Hägglund, Waldén, Bahr, & Ekstrand, 2005). Therefore, the study included the players that sustained hamstring strains (grade 2 and up) and knee ligament injuries and those that did not sustain any injuries. Participants and the medical team of the five participating teams were asked to report any injury that occurred during a soccer game or training and resulted in the athletes' inability to continue participating. In addition, they were asked to provide the date of the injury, the body part involved, and the mechanism.

Procedures and data collection

Players were advised to abstain from any activity the days before testing, and measurements were obtained between 9:00 am and 14:00 on two different days to avoid potential fatigue from subsequent testing. Testing was part of the professional team's seasonal plan to examine the players' readiness at the end of the pre-season period, but players' participation in this study was completely voluntary. Each player was briefed on the procedures and signed an informed consent before data collection. Ethical guidelines were followed according to the Helsinki Declaration's ethical standards, and the University's ethics committee board (reference number STEMH 541) approved the study.

Anthropometric measurements

A wall stadiometer (Leicester; Tanita, Japan) was used to measure the players' stature, while a leg-to-leg bioelectrical impedance analyzer (BC418MA; Tanita) was utilized to measure body composition. Before the measurements were obtained, all players were instructed to follow the standard BIA (bioelectrical impedance analysis) guidelines (Kyle et al., 2004).

Sit and reach test

A sit and reach box was used to assess the flexibility of the lower back and hamstring muscles according to methods described by previous investigators (Russell, 1980). Players removed their shoes and placed the soles of their feet against the box while their knees were fully extended. They were instructed to avoid fast and jerky movements while leaning forward with their hands on top of each other and palms facing downwards. They performed two practice trials, and the third trial was recorded to the nearest cm.

Lower body strength

The isokinetic knee strength was assessed utilizing the Humac Norm and Rehabilitation device (CSMI, Stoughton, MA, USA) according to the methods described by previous investigators (Parpa & Michaelides, 2020). Before the isokinetic testing, players had a 5-min self-paced warm-up on a mechanically braked cycle ergometer (Monark 894 E Peak Bike, Weight Ergometer, Sweden). Once the players were appropriately positioned on the device, they performed five sub-maximal repetitions of concentric knee flexion and extension for familiarization purposes. The isokinetic testing included three maximal concentric flexion and extension repetitions at an angle speed of 60°/sec.

Cardiopulmonary exercise testing

The players completed an incremental maximal cardiopulmonary exercise testing until they reached exhaustion on a treadmill (h/p/Cosmos Quasar med, H-P-Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany). The players were tested utilizing the modified Heck incremental maximal protocol, which was previously validated for its reliability to test soccer players (Santos-Silva, Fonseca, Castro, & Greve, 2007; Parpa & Michaelides, 2022). A breath-by-breath analysis was performed on the Cosmed Quark CPET (Rome, Italy) system while laboratory conditions were kept constant (temperature 22±1ºC and relative humidity at 50%). The test came to an end when the participant reached volitional fatigue or when there was no variation among the VO2 levels while the workload increased. The VO2max was detected following filtering the results to identify the highest value for an average of 10 seconds. The ventilatory threshold and respiratory compensation point were determined using different criteria. The ventilatory threshold was determined through the V-Slope method and was verified at the nadir of the VE/V̇ O2 curve. The respiratory compensation point was determined at the nadir of the VE/V̇ CO2 curve.

Statistics

SPSS 26.0 for Windows (SPSS Inc., Chicago) was utilized to analyze the results. The homogeneity of variance and normality assumptions were verified using Brown and Forsythe's and Shapiro-Wilk tests, respectively. Means and Standard Deviations were calculated for all the parameters. Means were compared using an independent samples t-test. Cohen's d was calculated to determine the effect size. Effect sizes were interpreted as small (0.2-0.4), medium (0.5-0.7) and large (0.8-1.4) (Cohen, 1988). For the statistical analyses, significance was accepted at $p<0.05$.

Results

The anthropometric and body composition parameters are presented in table 1. Following the twenty in-season games, 37 players suffered either a hamstring strain (n=20) or knee ligament injury (n=17).

Table 1. Demographic Characteristics of injured and non-injured players.

Note.*p<0.05; CI: confidence interval

	Injured		Non-Injured		95% CI for the difference
	n	Mean±SD	n	Mean±SD	Lower Upper
Age (years)	37	27.08±6.32*	96	24.91±5.19	-4.29-(-0.062)
Height (cm)	37	175.02±29.98*	96	181.79±6.94	0.34-13.20
Weight (kg)	37	74.72±6.89*	96	78.29±7.22	0.84-6.30
Fat % BIA	37	10.61±3.32	96	10.57±2.94	-1.21-1.13

It should be noted that 16 out of the 20 hamstring injuries and 14 out of the 17 knee ligament injuries occurred during a competitive game. Results indicated that injured players were significantly older [t(131)=-2.036, d= 0.375, p<0.05], while at the same time, they were significantly shorter [t(131)=-2.084, d=0.32, p<0.05] and lighter than non-injured players [t(131)=-2.59, d=0.51, p<0.05] (Table 1).

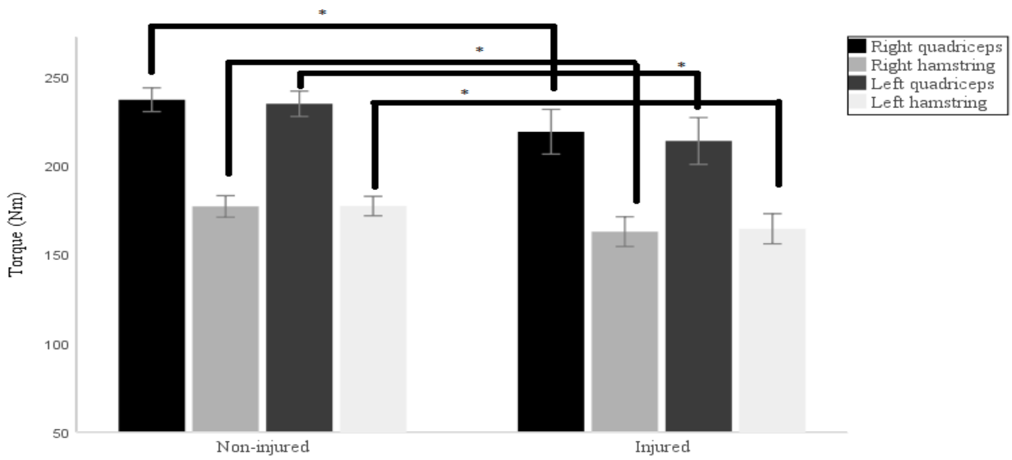
Table 2. Flexibility and lower body strength parameters of injured and non-injured players.

Note. *p<0.05; CI: confidence interval

	Injured		Non-Injured		95% CI for the difference
	n	Mean±SD	n	Mean±SD	Lower Upper
Flexibility (cm)	37	31.41±9.76*	96	38.52±6.69	4.18-10.04
Right quadriceps 60^0/sec	37	218.81±37.68*	96	236.77±33.01	4.81-31.11
Right hamstring 60^0/sec	37	162.68±25.02*	96	176.83±29.86	3.21-25.11
Ratio	37	74.86±12.59	96	74.83±8.84	-3.87-3.80
Left quadriceps 60^0/sec	37	213.62±39.43*	96	234.50±35.08	6.97-34.79
Left hamstring 60^0/sec	37	164.30±25.42*	96	177.06±26.86	2.63-22.90
Ratio	37	78.03±11.66	96	76.10±9.91	-5.91-2.07
quadriceps asymmetry	37	8.32±6.37	96	6.94±5.48	-3.58-0.81
Hamstrings asymmetry	37	10.43±7.14*	96	5.53±4.18	-6.88-(-2.92)

Furthermore, the examination of flexibility indicated that injured players were significantly less flexible [t(131)=-4.79, d=0.85, p<0.05] than non-injured players (Table 2). Additionally, considering lower body strength parameters, injured players appeared to be significantly weaker on both right and left quadriceps and hamstring muscles (p<0.05) compared to non-injured (Table 2, Figure 1).

Figure 1. Lower body strength of injured and non-injured players



Note *p<0.05

Considering muscle asymmetries, injured players had significantly [t(131)= 4.90, d=0.84, p<0.05] greater bilateral difference for the hamstrings muscle compared to non-injured players (Table 2). Furthermore, results indicated significantly lower VO2max values [t(131)=4.64, d= 0.95, p<0.05] and running time [t(131)=5.44, d=1.07, p<0.05] for the injured players compared to the non-injured players (Table 3, Figure 2). Concurrently, VO2 values at ventilatory (VT) threshold [t(131)=2.43, p<0.05] and respiratory compensation point (RC) [t(131)=3.85, p<0.05] were significantly lower for the injured players (Table 3).

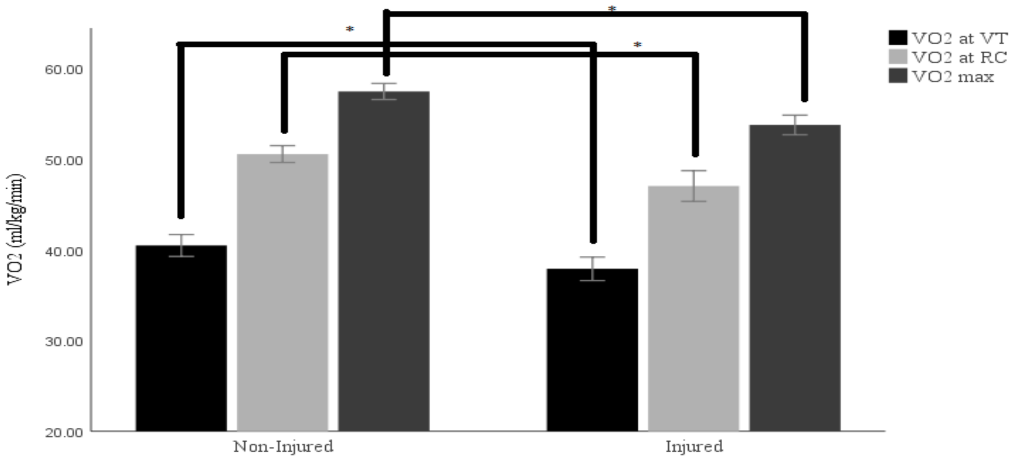
Table 3. Aerobic capacity of injured and non-injured players.

	Injured		Non-Injured		95% CI for the difference	
	n	Mean±SD	n	Mean	Lower	Upper
VO2max (ml/kg/min)	37	53.77±3.24*	96	57.46±4.39	2.12-5.26	
Running time (min)	37	15.84±1.51*	96	17.55±1.68	1.09-2.34	

VO2 at VT (ml/kg/min)	37	37.91±3.88*	96	40.49±5.97	0.83-4.33
VO2 at RC (ml/kg/min)	37	47.04±5.08*	96	50.56±4.59	1.71-5.33

Note. *p<0.05; CI: confidence interval; VO2max: maximal oxygen uptake; VO2 at VT: oxygen uptake at ventilatory threshold; VO2 at RC: oxygen uptake at respiratory compensation point.

Figure 2. Oxygen consumption at ventilatory threshold (VO2 at VT), at respiratory compensation point (VO2 at RC) and VO2max of injured and non-injured players



Note *p<0.05

Concerning the aforementioned parameters based on the type of the injury, results indicated that the players who sustained hamstring injuries were not significantly different in aerobic performance, flexibility or anthropometric characteristics compared to those that sustained a knee injury. On the contrary, a significant difference between the two groups was indicated in right hamstring strength [t(35)=2.92, p<0.05], right side ratio [t(35)=4.43, p<0.05], and hamstring asymmetries [t(35)=-2.73, p<0.05]. A borderline significant difference was also indicated in the left hamstring strength between the two groups [t(35)=1.96, p=0.07]. More specifically, hamstring asymmetry was 13.13±7.6 for the players that sustained a hamstring injury, while it was 7.24±5.09 for the players that sustained a knee ligament injury. Furthermore, players who sustained a hamstring injury had significantly weaker right hamstring muscles (152.60±24.70 Nm) than those who sustained a knee ligament injury (174.53±20.20 Nm).

Discussion

The present study aimed to examine the differences in pre-season intra- and inter-limb strength knee asymmetry, flexibility, and aerobic capacity of soccer players that sustained lower-body non-contact injuries during the in-season period compared to those that did not have any lower-body injuries. After twenty in-season games, twenty players suffered a hamstring strain, and seventeen players suffered a non-contact knee ligament injury. Results indicated that injured players were significantly older and less flexible than non-injured players. Additionally, injured players appeared to be significantly weaker on both right and left quadriceps and hamstring muscles and had greater bilateral differences for the hamstrings muscle than non-injured players. Furthermore, results indicated significantly lower VO2max values and running time for the injured players than for non-injured players. Lastly, the players who sustained a hamstring injury were significantly weaker on the hamstring muscles and had significantly greater hamstring asymmetries than those who sustained a knee ligament injury. Whilst these results should not be a surprise, these data clearly show that injured players were significantly weaker, had greater imbalances and had significantly lower physical fitness and flexibility at the beginning of the season, which might have contributed to the development of lower-body injuries.

The role of muscle strength, imbalances and flexibility are particularly interesting because these are modifiable risk factors and potential points of engagement for hamstring injury prevention. Research indicated that a mixed ratio of less than 0.8, an ipsilateral ratio of less than 0.47, and a bilateral ratio of less than 0.85 were the most predictive of a hamstring injury (Dauty, Menu, Fouasson-Chailloux, Ferréol, & Dubois, 2016). In addition, the ipsilateral ratio of less than 0.47 allowed the prediction of the severity of the hamstring injury (Dauty, Menu, Fouasson-Chailloux, Ferréol, & Dubois, 2016). In our study, the ratios of injured and non-inured players were within normal values and did not indicate any risk when the injured players were analyzed as one group. However, when the players were compared based on the type of injury they sustained, it was demonstrated that those who sustained a hamstring injury had a mean ratio of 68, while those who sustained a knee ligament injury had a mean ratio 82.94.

This finding supports that those ratios may be predictive of a hamstring injury, as indicated by other research as well (Lee, Mok, Chan, Yung, & Chan, 2018), rather than a knee ligament injury. Furthermore, the hamstring asymmetry of the injured group was over 10% which is in agreement with other studies (Liporaci, Saad, Grossi, & Riberto, 2019). More specifically, research demonstrated that a strength imbalance of over 10% in the knee flexors increases the risk of injury by 12 times (Liporaci, Saad, Grossi, & Riberto, 2019). In our study, when the injured players were analyzed based on the injury they sustained, it was indicated that hamstring asymmetry was 13.13±7.6 for the players that sustained a hamstring injury, while it was 7.24±5.09 for the players who sustained a knee ligament injury. This finding further supports that hamstring imbalances of over 10% may predict hamstring injuries rather than knee ligament injuries. On the contrary, other studies (Izovska et al., 2019) suggested that those imbalances in the flexors of the knee may predominantly be associated with the rapture of the anterior cruciate ligament and other parts of the knee. Of note is that no strength asymmetry between the knee extensors was presented in the injured and non-injured group.

Considering lower body strength and flexibility, our results align with other studies indicating that lower pre-season isokinetic hamstring strength increases the risk of acute hamstring strain injury during the in-season period (Wan, Qu, Garrett, Liu, & Yu, 2017). Our results demonstrated that injured players were significantly weaker in the quadriceps and hamstring muscles than non-injured players. Furthermore, while no significant differences were demonstrated between the players who sustained hamstring injuries and knee ligament injuries in the strength of the quadriceps, the hamstring injured group had significantly weaker right hamstring muscles (152.60±24.70 Nm) compared to those that sustained a knee ligament injury (174.53±20.20 Nm). Concurrently, our findings indicated that injured players had significantly lower flexibility assessed by the sit and reach test than non-inured players. Flexibility was not significantly different among the players that sustained a hamstring injury or knee ligament injury. These results align with previous investigators who indicated that in sports that involve sprinting, athletes with good hamstring flexibility have lower peak hamstring muscle strains than athletes with poor hamstring flexibility. In contrast, other studies suggest that hamstring flexibility cannot be used to predict a hamstring injury accurately (Gabbe, Finch, Bennell, & Wajswelner, 2005). Notably, there is conflicting evidence that older age, increased quadriceps peak torque, hamstring flexibility and strength imbalances increase the risk of a hamstring injury (Freckleton & Pizzari, 2013). The differences in the methodology utilized by the different studies might have contributed to these conflicting results. Nevertheless, lower hamstring flexibility should not be ignored as it may turn into a risk factor, especially when combined with other risk factors such as strength and asymmetries.

In addition to the aforementioned risk factors, research affirms that aerobic fitness might be a recognized risk factor for injury (Watson, Brickson, Brooks, & Dunn, 2017; Eliakim, Doron, Meckel, Nemet, & Eliakim, 2018). Our results indicated that injured players had significantly lower VO2max values and running time on the treadmill than the non-injured players. Concurrently, the injured players' VO2 values at the ventilatory threshold and respiratory compensation point were significantly lower. These results are in agreement with previous studies that demonstrated a negative association between pre-season aerobic fitness and injury risk throughout the season (Watson, Brickson, Brooks, & Dunn, 2017). In addition, research indicated that lower improvements in VO2max during the pre-season training are associated with higher injury rates during the in-season period (Eliakim, Doron, Meckel, Nemet, & Eliakim, 2018).

To our knowledge, this is the first study that evaluated lower body strength, asymmetries, flexibility and aerobic performance as risk factors for injuries in soccer players. Together, our findings suggest that off, and pre-season interventions should be tailored toward increasing aerobic fitness, lower body strength and flexibility while minimizing strength asymmetries and imbalances (especially in the hamstring muscles) in order to reduce in-season injury risk.

Limitations

Despite the significant findings, this study comes with several limitations. First, the injuries were not specified based on the players' playing position, which could be linked with different muscle strength profiles. Furthermore, hamstring injuries should have been separated into the stretch-type and sprint-type hamstring injuries. In addition, extrinsic factors such as the quality of the soccer field, insufficient warm-up, and differences in the training load of the participating teams could not be controlled.

References

Clemente, F. M., Mendes, M., Nikolaidis, P. T., Calvete, F., Carriço, S., & Owen, A. L. (2017a). Internal training load and its longitudinal relationship with seasonal player wellness in elite professional soccer. *Physiology and Behavior,* 179, 262–267.

Clemente, F. M., Nikolaidis, P. T., van der Linden, C. M. I., & Silva, B. (2017b). Effects of small-sided soccer games on internal and external load and lower limb power: a pilot study in collegiate players. *Human Mov*ement, 18(1), 50–57.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY: Routledge Academic.

Dauty, M., & Collon, S. (2011). Incidence of injuries in French professional soccer players. *International Journal of Sports Medicine*, 32(12), 965–969.

Dauty, M., Menu, P., Fouasson-Chailloux, A., Ferréol, S., & Dubois, C. (2016). Prediction of hamstring injury in professional soccer players by isokinetic measurements. *Muscle, Ligaments,and Tendons Journal,* 6(1), 116-123.

Eirale, C., Hamilton, B., Bisciotti, G., Grantham, J., & Chalabi, H. (2012). Injury epidemiology in a national football team of the Middle East. *Scandinavian Journal* of *Medicine* & *Science* in *Sports,* 22(3), 323–329.

Ekstrand, J., Hagglund, M., & Walden, M. (2011). Epidemiology of muscle injuries in professional football (soccer). *American Journal of Sports Medicine*, 39(6), 1226–1232.

Eliakim, E., Doron, O., Meckel, Y., Nemet, D., & Eliakim, A. (2018). Pre-season fitness level and injury rate in professional soccer—A prospective study. *Sports Medicine International Open*, 2(3), E84-E90.

Fousekis, K., Tsepis, E., & Vagenas, G. (2010). Lower limb strength in professional soccer players: profile, asymmetry, and training age. *Journal of sports science & medicine,* 9(3), 364–373.

Francioni, F. M., Figueiredo, A. J., Lupo, C., Conte, D., Capranica, L., & Tessitore, A. (2016). Pre-season strategies of Italian first league soccer clubs in relation to their championship ranking: A five-year analysis. *Journal of Human Kinetics*, 50, 145–155.

Freckleton, G., & Pizzari, T. (2014). Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. British Journal of Sports Medicine, 47(6), 351-358.

Gabbe, B. J., Finch, C. F., Bennell, K. L., & Wajswelner, H. (2005). Risk factors for hamstring injuries in community level Australian football. *British Journal of Sports Medicine*, 39(2), 106-110.

Hägglund, M., Waldén, M., Bahr, R., & Ekstrand, J. (2005). Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *British Journal of Sports Medicine,* 39(6), 340–346.

Hawkins, R. D., Hulse, M. A., Wilkinson, C., Hodson, A., & Gibson, M. (2001). The association football medical research programme: an audit of injuries in professional football. *British journal of sports medicine,* 35(1), 43–47.

Hughes, T., Sergeant, J. C., Parkes, M. J., & Callaghan, M. J. (2017). Prognostic factors for specific lower extremity and spinal musculoskeletal injuries identified through medical screening and training load monitoring in professional football (soccer): a systematic review. *BMJ Open Sport & Exercise Medicine,* 3(1), e000263.

Izovska, J., Mikic, M., Dragijsky, M., Zahalka, F., Bujnovsky, D., & Hank, M. (2019). Pre-season bilateral strength asymmetries of professional soccer players and relationship with non-contact injury of lower limb in the season. *Sport Mont,* 17(2), 107-110.

Kyle, U. G., Bosaeus, I., De Lorenzo, A., Deurenberg, P., Elia, M., Gómez JM, ….. Pichard, C. (2004). Composition of the ESPEN Working Group. Bioelectrical impedance analysis--part I: review of principles and methods. *Clinical Nutrition,* 23(5), 1226-1243.

Lee, J.W., Mok, K. M., Chan, H. C., Yung, P. S., & Chan, K. M. (2018). Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: A prospective study of 146 professional players. *Journal of Science and Medicine in Sport,* 21(8), 789–793.

Liporaci, R. F., Saad, M., Grossi, D. B., & Riberto, M. (2019). Clinical features and isokinetic parameters in assessing injury risk in elite football players. *International Journal of Sports Medicine*, 40(14), 903–908.

Nobari, H., Alves, A. R., Haghighi, H., Clemente, F. M., Carlos-Vivas, J., Pérez-Gómez, J., & Ardigò, L. P. (2021). Association between Training Load and Well-Being Measures in Young Soccer Players during a Season. *International Journal of Environmental Research and Public Health,* 18(9), 4451.

Nobari, H., Fani, M., Pardos-Mainer, E., & Pérez-Gómez, J. (2021). Fluctuations in Well-Being Based on Position in Elite Young Soccer Players during a Full Season. *Healthcare (Basel, Switzerland),* 9(5), 586.

Nobari, H., Mainer-Pardos, E., Denche Zamorano, A., Bowman, T. G., Clemente, F. M., & Pérez-Gómez, J. (2021). Sprint Variables Are Associated with the Odds Ratios of Non-Contact Injuries in Professional Soccer Players. *International Journal of Environmental Research and Public Health*, 18(19), 10417.

Parpa, K., & Michaelides, M. A. (2020). The Effect of Transition Period on Performance Parameters in Elite Female Soccer Players. *International Journal of Sports Medicine,* 41(8), 528-532.

Parpa, K., & Michaelides, M. A. (2022). Maximal Aerobic Power Using the Modified Heck Protocol: Prediction Models. *International Journal of Sports Medicine.* doi: 10.1055/a-1749-5829. Epub ahead of print.

Rahnama, N., Lees, A., & Bambaecichi, E. (2005). Comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. *Ergonomics,* 48(11-14), 1568-1575.

Russell, R. P. (1980). *American Alliance for Health, Physical Education, Recreation and Dance: Health-Related Physical Fitness Test Manual.* Reston, VA: American Alliance for Health, Physical Education, Recreation and Dance.

Santos-Silva, P. R., Fonseca, A.J., Castro, A. W., Greve, J. M., & Hernandez, A. J. (2007). Reproducibility of maximum aerobic power (VO2max) among soccer players using a modified heck protocol. *Clinics (Sao Paulo),* 62(4), 391–396.

Walden, M., Hagglund, M., & Ekstrand, J. (2005). UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. *British Journal of Sports Medicine*, 39(8), 542–546.

Wan, X., Qu, F., Garrett, W. E., Liu, H., & Yu, B. (2017). The effect of hamstring flexibility on peak hamstring muscle strain in sprinting. *Journal of sport and health science*, *6*(3), 283–289.

Watson, A., Brickson, S., Brooks, M. A., & Dunn, W. (2017). Pre-season Aerobic Fitness Predicts In-Season Injury and Illness in Female Youth Athletes. *Orthopaedic journal of sports medicine,* 5(9), 2325967117726976.