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Posted Date: 26 May 2023

doi: 10.20944/preprints202305.1921.v1

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Article

Pre-Season ACL Risk Classification of Professional and Semi-Professional Football Players, via a Holistic Test-Battery

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Featured Application: Authors are encouraged to provide a concise description of the specific application or a potential application of the work. This section is not mandatory.

Abstract: The study aimed to identify football players at high risk (HR) for anterior cruciate ligament (ACL) injury via a four-test battery and assess possible factors affecting classification. Ninety-one professional and semi-professional athletes participated in a field-based preseason screening. Aknowledged inter-limb asymmetry limits for quadriceps and hamstrings isometric strength, and Single Leg Triple Hop for distance, in addition to the Landing Error Scoring System (LESS) comprised the test-battery. Additional assessment of hip adductors and core stability completed the global functional profile of the players. Sixty-one players were identified as HR and 30 as low-risk (LR) for ACL injury. Test-battery classified adequately 78,0% of them (Chi-square= 27,485 p=,000), identifying only 4 misclassified cases in the LR group, this low number being important for avoiding improper treatment of injury-prone athletes. All partcipants were considered healthy, and history of a previously rehabilitated injury did not interfere with the results. LESS seems to be the optimal criterion for classification and also the best predictor of both the initial grouping and the secondary one with the wrong vs correct classification cases. The proposed test-battery provides a promising option for field-based preseason ACL-risk assessment of football players and needs to be studied prospectively.

Keywords: ACL; screening; injury-risk; prevention; LESS; asymmetry; soccer

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1. Introduction

Anterior cruciate ligament (ACL) injury is one of the most dramatic injuries in football, resulting in knee pain and swelling, muscle atrophy, functional instability and at least six months of absence from participation, [1]. In the long term, ACL injury can be devastating for those failing to return to preinjury level of participation [2], while for those who return to participation, there is an even higher risk for a secondary ACL injury. Re-injury rates in young athletes (<25 years) who return to sports have been reported to reach 23% [3]. Furthermore, it is estimated that one-third of the injured athletes will develop post-traumatic knee osteoarthritis, compromising their quality of life in the future [4–6]. Since ACL rupture may be life-changing, apart form career threatening, the importance of efficient prevention is fundamental.

Although, ACL risk profile is multifactorial, inter-limb asymmetry has been associated with increased risk of both primary [7–10] and secondary ACL injury [11–13]. The passive tissues of the lower limbs are compromised when the impact forces are not equally distributed during landing due to biomechanical or postural control deficits between the two legs [11]. Abnormal asymmetrical landing biomechanics increase the risk of injury [14], as loads which are sustained by the strong leg, may endanger the weak side due to poor discipation capability [15].

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Pre-seasonal assessment (PA) has been recognized as mandatory for injury prevention, however, no clear guidelines are available at the moment [16]. Recently, regarding Return to Sport (RTS) after ACL reconstruction, it has been proposed the use of a battery of tests that evaluate the knee function in order to determine safe participation in pivoting sports [17]. An efficient RTS battery should include a combination of muscle strength tests, hop tests, and measures of quality of movement [18]. The main focus of researchers for the optimal PA, is to avoid costly and time consuming laboratory testing, enabling trainers and medical teams to apply low-cost, field-based screening tests, even in low budget teams without compromising the training plan. PA for injury risk-profiling with portable equipment like push dynamometers, in combination with field tests, could be useful for quick assessment of high numbers of athletes, easily repeatable through season. and [16]. Correct biomechanics during high impact landing are acknowledged as a key element for load management and injury prevention. Assessment of quality of movement is important to be included in PA, and the landing error scoring system (LESS) is considered a valid and reliable tool for the assessment of the athlete's landing pattern during a drop-jump task [19,20]. Regarding strength testing, Hand Held Dynamometry (HHD) is an appropriate method for use in clinical and field-based settings, with moderate to good reliability and validity [21].

The criteria used to discriminate between high and low-risk athletes are subjected to ongoing research,which aims to provide objective information,easily understood and applied to support decision-making process. For muscle strength and hop tests, a common limb symmetry index >90% is the most common acceptable criterion [17]. For the quality of movement when using the test Landing Error Scoring System, various cut-off scores have been suggested, with up to 6 errors indicating acceptable landing mechanics [20,22,23]. Apart from the one-dimentional open kinetic chain tests for muscle strength, hop performance and landing technique represent a global body function, connected to core stability [24–27].

For wide use in any location, functional tests to identify footballers prone to ACL injury, have to be low-cost and relative fast to perform, while at the same time they should ideally balance between simplicity for feasibility and enough complexity for adequate information. Test batteries have been suggested, including strength and hop tests [16,28], while others highlight the need to assess landing biomechanics more thoroughly. LESS has been developed to serve this requirement avoiding the use of sophisticated equipment for in-field assessment. A combination of the above approaches with key muscle strength, low limb functional performance and assessment of landing biomechanics may provide a sensitive tool for identifying ACL injury-prone players.

The main objective in this the current study was to identify professional/semi-professional football players at high risk for ACL injury based on a classification battery including quadriceps and hamstrings isometric dynamometry, the triple single hop test for distance and the Landing Error Scoring System (LESS). The Low-risk (LR) and High-risk (HR) groups were compared in terms of proportions of players with a) history of injury (general), b) injury history to the lower limbs, c) injury history to the knee. An additional objective of the study was to identify the functional and biomechanical variables that significantly predicted the injury group categorization. In the functional variables, apart, from the ones comprising the 4 criteria, other more global were added, including four that assess core stability and function. We also tested how accurate this criteria-battery classified players correctly into the 2 groups.

2. Materials and Methods

2.1. Study Design

This is a cross-sectional study based on the STROBE (Strengthening the reporting of observational studies in epidemiology) guidelines for cross-sectional studies [29]. In the last week of July to the first week of August 2022, a pre-screening examination was conducted on professional and semi-professional football players to identify possible risk factors for ACL injury. Testing took place at the training facilities of the teams with portable equipment, during the first two pre-season weeks. Data collection process is presented on Figure 1. Collected data included athletes'

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demographic and previous injury details, thigh-muscle strength, the Single Leg Triple Hop for Distance (SLTH) test and scoring of landing mechanics with LESS. Additional core stability tests were included for holistic body assessment. Specific details for each measurement methodology is provided below. The project was approved (ID 12126) by the institutional ethics committee of the University of Patras and is a part of the registered study protocol presented in the public database ClinicalTrials.gov (Identifier: NCT05430581).

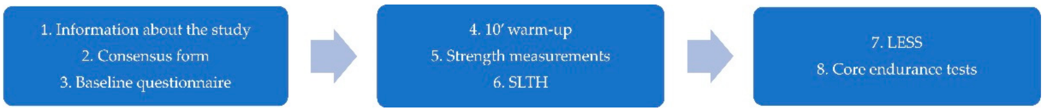

Figure 1. Data collection process.

2.2. Participants

Five football teams were examined, three of them at the professional Greek second division, the remaining being semi-professional, competing at the Greek third division, and the under-19 division. From the one hundred and fifteen players initially available for the examination, ninety-one football players eventually participated in the pre-screening examination. The rest were excluded due to recent history of injury, team schedule restrictions, and pain or instability induced incomplete measurements. Athletes eligible to participate in the study were free from injury or have been completely rehabilitated, had a professional work contract with their team, and participated in five to six training sessions per week in the previous season, depending on the game schedule. Fifty-seven have suffered a previous injury, eleven of them to their knee. Demographics are presented on Table 1.

Table 1. Participants' demographic characteristics.

	Mean ± SD
Weight	74.21 ± 7.90
Height	1.79 ± 0.06
BMI	23.19 ± 1.80
Starting Training Age	7.77 ± 3.03
Competitive playing experience years	4.00 ± 4.31
Training Hours/day	2.31 ± 0.63
Training days/week	5.64 ± 1.06
Games played the previous year	19.33 ± 9.92

2.3 Baseline Assessment

Each athlete initially completed a questionnaire concerning demographic, sports participation characteristics, and previous injury details [30]. Additionally, athletes filled out a specific injury questionnaire reporting the type of injury, the injured limb, the time of injury and the time lost from training and competition due to the injury.

2.4 Muscle Strength Testing

After completing the questionnaire, isometric tests for quadriceps, hamstrings, and abductors muscles, were performed using a HHD (MicroFET 2; Hoggan Scientific). The same examiner performed all strength tests. A previous systematic review [31] indicates that HHD has moderate to good reliability and validity compared with the "gold standard" isokinetic dynamometer. Participants after a warm-up including 2 trials of about 2 seconds of submaximal contraction. Then, three maximal 5-second trials were conducted, separated by a rest at least of 20 seconds. All tests were recorded in Newton, and the higher value was used for the calculation of the Limb-Symmetry-Index.

To assess knee extension strength, participants stood seated on a specific metal table with the back straight and hip, and knee angle at around 90 degrees of flexion. The participants kept their

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hands crossed on their chest. A physical therapist stabilized the thighs with his hands directly above the hip joint to prevent thigh movements during maximal quadriceps isometric contraction. A belt was placed just proximal to the malleolus and attached to a rigid frame. The HHD stabilized between the rigid frame and the belt. Participants were asked to contract their quadriceps maximally by trying to extend their tibia as forcefully as possible for five seconds. Hansen et al. [32] report that this testing configuration is a valid and reliable option for knee extensor strength testing. Figure 2a illustrates the configuration of the quadriceps muscle strength testing.

To assess the isometric hamstring strength, participants were placed in a prone position, with their feet off the bed. The examiner passively flexed the knee at a height equal to the athlete's foot length [21,33]. This position is approximately 30 degrees of knee flexion. Then, the examiner placed the dynamometer on the heel and asked the athlete to contract their hamstrings maximally by flexing their knee as forcefully as possible for five seconds. This is an often-mentioned technique in the literature in order to assess hamstrings strength using HHD [33,34]. Whiteley et al. [21] using HHD reported an excellent inter-rater reliability and a moderate to good correlation with isokinetic assessment.

Hip abductor strength was measured to complete the global assessment of the high muscles, according to the protocol by Thorborg et al. [35]. The athletes were in a side-lying position, with the testing hip on the upside in a neutral position. The opposite leg was flexed in the hip and knee at around 90 degrees (Figure 2c). The participants stabilized themselves by holding the examination table with their hands and the examiner stood behind each athlete. Then the examiner, with one hand, stabilized the participant's pelvis and, with the other hand, applied resistance holding the HHD to the contraction of the abductors. The HHD was placed 5 cm proximal to the lateral malleolus. Then the participants pushed against the dynamometer for 5 sec. This strength-testing configuration was choosen for the abductor muscles to minimize the pelvis's movement during the maximal contraction.

2.5. Single Leg Triple Hop for Distance (SLTH) test

After approximately five minute rest the SLTH test was performed.The SLTH test can highly discriminate strength and power deficits between the lower limbs [12,36,37] and show high test-retest reliability [36]. After muscle strength testing, athletes performed the STHD with shoes and arms free. Participants had up to 2 practice trials to familiarize themselves with the hop test. A hop trial was classified as successful when the athlete maintained a single-leg stance for around 2 seconds after landing without losing his balance, shuffling around the standing foot to maintain stability. Participants alternated their legs for each trial to prevent fatigue. Athletes had rest time about 10 seconds between hop trials and thus 20s between trials on the same leg. Three successful hop trials for each leg use used for analysis and no unsucceful trails were observed.

2.6. Landing Error Scoring System (LESS)

Subsequently we used LESS to identify possible landing errors that may increase the risk of ACL injury. The LESS performed after a five minute rest from the SLTH test. The LESS is a valid and reliable tool [19,20] that assesses the participant's landing pattern during a drop-jump task. The athletes jumped from a 30 cm box with both feet, landed at a distance equal to half of their height, and performed a maximum vertical jump. Beyond the information of the proper execution of the test, no other information was given regarding the proper landing technique. Athletes performed 1-2 trials for familiarization with the test, and then we recorded three successful jump-landing trials. No unssuccesful trials were onserved. Each athlete needed 2-3 minute to complete the test. Two conventional cameras (Panasonic HC-V770 and Sony HDR-CX625) capture the trials from the frontal and sagittal view. The recorded video of three successful trials is stored on a personal computer and analyzed using the Kinovea software (0.8.26 experimental version). We use the scoring form and the guidelines of Padua et al. [20] to evaluate the landing technique. The scoring form contains 15 rating items that evaluate knee, hip, and trunk flexion angles from the side view, and knee valgus, base of support width and toes position from the frontal view. The aforementioned items are rating at initial

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contact and maximum knee flexion. In addition, two questions contain the rater's subjective sense of the landing technique. The LESS total score can range from 0 to 17 [20]. The average LESS score from the three trials was used for statistical analysis. Athletes with a total LESS score >6 are considered to have a high risk landing pattern for ACL injury [20,38]. The same examiner rated all videos. The evaluator (NIL author) had clinical experience in sports injury assessment and rehabilitation and the proper use of the LESS scoring instrument [39,40]. Test-retest reliability was examined in a random subgroup of 37 players and proved to be excellent (ICC= .927, 95% CI= .859 - .982).

2.7. Core stability tests

Two symmetric and one bilateral core stability tests were applied, intercepted by 5 minute rest. The valid and reliable Prone Bridging test was used to assess the capability of the abdominal muscles for core stability [41]. Both lateral abdominal muscles were tested via the Side Bridging test, according to the protocol proposed by McGill et al. [42]. Finally, the Biering-Sorensen test was used as a valid test for back muscle endurance [43]. For each test, players were informed about the proper execution, and performed one trial for a few seconds, for failiarization. The time in seconds that athletes maintained the proper position was recorded. For the bilateral test, asymmetry index was calculated.

2.8. Statistical Analysis

We calculated asymmetry for quadriceps, hamstrings and abductor isometric strength, as well as for the core rerformance tests , regardless dominance (absolute asymmetry). Asymmetry (%) was calculated using the equation (Dominant leg – Non-Dominant leg)/Maximum (Dominant: Non-dominant)*100. For all between-groups comparisons, asymmetries were expressed in positive values regardless limb domimance. As previously proposed [17] we considered asymmetries >10% as critical for the risk for ACL injury. In addition, the criterion of 6 was used for the LESS test [38]. Athletes assessed with a LESS score >6 were categorized as having an at-risk landing technique. Athletes were categorized into Low Risk Group (LRG) and High Risk Group (HRG) based on quadriceps, hamstrings, and SLTH asymmetries (high-risk group >10%), in addition to the LESS score (high-risk group >6). Statistical analysis was conducted using the IBM SPSS (v.26). We used Chi-square test to compare the proportions of players with a) history of injury (general), b) history of injury to the lower limbs, c) history of knee injury, between LRG and HRG. The functional variables potentially contributing to group splitting were tested via binary logistic regression with dependent variable the grouping (LRG vs HRG risk). The same test was used to identify the possible predicting variables for those that the model considered initially placed in the opposite category. Discriminant analysis was used to investigate whether the original grouped cases were classified correctly. The significance level a=0,05 was used.

3. Results

Application of the battery-criteria resulted in the formation of the LRG N=30 and the HRG N=61. There were no significant differences to the proportions of previously injured payers into the LRG and HRG (Table 2). Binary logistic regression model included two predictors for Risk grouping, the LESS score and the prone bridge time (Table 3).

Table 2. This is a table. Tables should be placed in the main text near to the first time they are cited.

Injury percentage	General	Lower limb	Knee
LRG (N=30)	57,1%	32,1%	17,9%
HRG (N=61)	65,0%	30,0%	18,3%
Pearson Chi-Square	0.50 p= 0.48	0.10 p= 0.76	0.00 p= 0.96

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Table 3. Predictors for the categorical "ACL-Risk" variable (0=Low risk, 1=High risk).

	B	S.E.	Wald	df	Sig.	Exp(B)
LESS score	0.93	0.22	18.54	1.00	0.00	2.52
Prone Bridge	-0.01	0.00	4.65	1.00	0.03	0.99
Constant	-2.91	1.15	6.42	1.00	0.01	0.06

The criteria-battery classified 78,0% of original grouped cases correctly, which is statistical significant Chi-square= 27,485 p=,000. Regardint the categories it calssified succesflully 87,1% of cases in the LRG and 73,3% in the HRG. We isolated the 4 misplaced cases from the LRG and the 16 from the HRG in order to identify a possible different pattern in their 4 criteria. For this profiling, absolute asymmetry values were used to produce meaningful means (Table 4).

Table 4. The absolute values of percent asymmetry and LESS score for the 4 and 16 misclassified players, in the respective Low-risk and High-risk groups (mean ± SD).

	H strength	Q strength	SLTH	LESS
Low-risk, N=4	6.74 ± 3.65	3.99 ± 1.41	1.71 ± 1.28	5.83 ± 0.34
High-risk N=16	6.74 ± 5.53	8.47 ± 6.42	6.09 ± 4.49	4.69 ± 1.21

Observing the results we notice that for the four players for the Low risk category that were initially classified as High risk by the model, had a mean of errors in LESS score, close to the upper acceptable limit, while strength and functional symmetry percentages were low.

For the sixteen players initially placed in the High risk group and the model classified them as low risk players, their means of asymmetry as well as the mean of LESS were far below the criteria. They were initially considered as high risk because individual they had either only one clear asymmetry > 10% and the rest of the criteria were clearly passed (values way lower than the cutoffs), or they exceeded critical values in two criteria but only marginally.

Binary logistic regression model included two predictors for wrong grouping (players that were initially placed in the opposite group), the LESS score and the prone bridge time (Table 5).

Table 5. Predictors for the categorical "correct vs wrong initial placement" variable (0=Low risk, 1=High risk).

	B	S.E.	Wald	df	Sig.	Exp(B)
LESS score	-0.49	0.18	7.38	1.00	0.01	0.61
Prone Bridge	-0.01	0.01	6.06	1.00	0.01	0.99
Constant	3.51	1.31	7.15	1.00	0.01	33.51

4. Discussion

The main objective in the current study was to identify professional/semi-professional football players at high risk for ACL injury based on a classification battery of tests (four criteria). The critical values were based on the current consensous for inter-limb asymmetry (10%) and the upper limit of 6 landing errors as proposed for the LESS. Preseason screening of the professional/semiprofessional football players classified the majority of players at the high risk group for ACL injury. Only 30 of the 91 athletes met the four criteria and considered low-risk. Previous injuries which were considered healed, regardless location, did not interfere with the results, since proportions were very similar between the two risk-prediction groups. This can be explained on the basis that, players with incomplete rehabilitation, recent injuries, or those who failed to perform maximally due to pain or instability, were excluded in the study. Our results are in line with Markström et al. [45] who based on a battery of tests including hop tests and isometric strength tests found that 83% of the athletes with ACL reconstruction and 76% of the noninjured athletes failed to pass the criteria for symmetry

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of ≤10%. Thus, when formulating either prevention or rehabilitation programs, acceptable functional asymmetry should be considered without being tested, even among competitive athletes.

Enough evidence supports the use of battery of tests for ACL injury risk assessment [16,17]. Hollistic body functionality is also connected to ACL protective mechanisms and all recent prevention programs try to restore correct landing biomechanics [46]. LESS is a tool that assesses the latter considering trunk mechanics as well [7]. In addition, injury prognostic tools should be easy to perform in any non-laboratory location, without expensive and too sophisticated equipment, while at the same time maintaining high standards of reliability and external validity. Therefore, we considered that a battery coprising of isometric testing of the major antagonistic thigh muscle groups, a functional test of multiple jumps and a more global-technically oriented test would create a meaningful tool to enhance the ACL injury predictive potential in soccer.

The most important predictor variable for risk categorization was the LESS score, followed by the prone bridge test. This finding highlights the importance of an holistic approache during preseason screening for ACL injury risk. Total LESS score is derived from 17 different scores assessing separate variables of landing technique after a drop jump. This obviously depends on the global body potential to provide correct limb alignment and efficient force dissipation. We considered this test as a necessary supplement to the triple hop test. The bridge test was among the supplementary tests we selected, to structure a more holistic functional profile of the players. It assessed the endurance of the frontal trunk and lower limb muscles while stabilizing the trunk in a high leverage position. Core stability has drawn attention for its connection to functional performance and injury prevention [25,26,41]. A stable core provides the basis for the effective load transmission between body segments and especially during hoping or high velocity cutting, it keeps torques produced by the torso to safe limits. Failing to control the trunk during dynamic high-energy maneouvres, often occurring in football, would let the upper body to sway excessively, and put the knee under ACL injury-predisposing stress [27]. From a variety of core stability tests [51], we selected two symmetrical endurance tests [52] for the flexors and extensors and one performed unilaterally from both sides, to ensure a complete multi-dimentional muscle assessment of the thoracic spine, the lumbopelvic hip complex, and the abdomen. We included a hip abductors strength test, which seem to be correlated with non-contact lower limb injury [53]. Most of the functional variables we introduced, did not play a role in group separation. This might imply that other tests could be tested in future studies. Despite that, the finding that LESS was a significant predictor of group separation suggests that a more technique-focusing assessment of unilateral landing is fundamental for a propre pre-season ACL injury risk screening.

Muscle fatigue has been suggested that alters landing biomechanics predisposing the lower limb to ACL injuries [54–57]. Performance in muscle endurance tests reflects the athlete's ability to resist fatigue and this was the reason for inclusion of these tests in the PA [27]. It might be useful to include such tests within the criteria for risk-level classification of athletes, however, muscle endurance has not been studied as ACL injury predictor enough to provide cut-off values, as it applies for thigh muscle strength and hop tests. In the present study, the frontal core muscle endurance performance was a separating variable between high and low-risk players indicating a direction for future investigation.

It appears that the tested battery of criteria significantly classified players and could be useful for preseason ACL-risk assessment of football players. It was not directly tested for its injury predictive potential, but the criterion in every single factor was the most widely accepted. Discriminant analysis showed that the overall successful classification was very high. It is important that our test-battery placed players into the Low-risk group with higher accuracy than in the High-risk goup. Only four players were misplaced in this category. Should the opposite occurred, a higher number of them would be falsely considered safe for exposure to unrestricted participation in football, with increased chance to get injured. A higher proportion of players were misplaced into the High-risk category, which is a possible error towards the safe side, accompanied by extra attention in those who might not need it. A question is raised regarding the approach to prevent these misclasifications. Observation of these particular cases, since the low number would not provide safe statistics, shows that the key variable for further consideration is the LESS score. For the four players that were initially considered safe, but in fact, the may need a closer attention, we notice that their mean functional asymmetries were low, while the LESS score marginally missed the upper limit of six mistakes (5.83). On the contrary, those who enterd the High-risk group but possibly belong to the other group had a mean of low LESS scores (4.69). This suggests that a cut-off point of LESS = 5 might lead to an even better risk prediction.

This study was cross sectional and assessed players via a composite tool, comprising of separately acknowledged tests, however, not having been evaluated prospectively. This remains to be examined via a prospective study to identify the predictive accuracy of this tool. A higher number of participants would be required for this, and in addition, this assessment should be updated through the season, as values might change with accumulated training, fatigue and micro-injuries. Continuous screening through the season has been proposed for ACL injury prevention [49]. In reality, no model is expected to be entirely sensitive for high injury risk classification of players, since the neuromechanics of the dynamic unpredicted maneouvres in contact, cutting and twisting sports can not be assessed in detail. To make things worse, an endless list of intrinsic and extrinsic factors influence players' profiles. Scientists ought to constantly seek for additional factors, in order to improve understanding of the causal relationships predisposing for ACL injury [47], thus producing sensitive and specific prognostic tools.

5. Conclusions

The screening battery of four criteria, comprising of asymmetries to the thigh muscle strength, the triple single leg hop for distance and the Landing Error Scoring System , appeared to classify efficiently football players into the high risk for ACL injury. Additional holistic assessment was conducted and LESS and the prone-bridge test were significant predictors for risk-group classification indicating the importance of global body functionality for players screening. It is imperative to test this tool prospectively to identify its actual predictive strength.

Author Contributions: "Conceptualization, C.T., N.L., S.X. and E.T.; methodology, S.X, K.F., M.T. and E.T.; validation, C.T., and N.L.; formal analysis, E.T.; investigation, C.T., and N.L.; data curation, C.T., and N.L.; writing—original draft preparation, C.T., N.L., S.X. and E.T.; writing—review and editing, M.T. and K.F.; visualization, C.T., and N.L.; supervision, S.X. and E.T.; project administration, S.X. and E.T. All authors have read and agreed to the published version of the manuscript."

Funding: "This research received no external funding"

Institutional Review Board Statement: "The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee of the University of Patras -Greece (ID 12126) and is a part of the registered study protocol presented in the public database ClinicalTrials.gov (Identifier: NCT05430581).

Informed Consent Statement: "Informed consent was obtained from all subjects involved in the study."

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy of professional football players' performance and injury-history information.

Conflicts of Interest: "The authors declare no conflict of interest."

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