DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
SPORT SCIENCES
2018

Arnhild Bakken

The benefits of periodic health evaluation in professional football

A focus on musculoskeletal screening

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Change is hard at first, messy in the middle and gorgeous at the end.

Robin Sharma

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Arnhild Bakken

Oslo, February 2018

List of papers

This thesis is based on the following original research papers, which are referred to in the text by their Roman numerals:

I. Health conditions detected in a comprehensive periodic health evaluation of 558 professional football players. Br J Sports Med 2016 Sep; 50(18):1142-50. doi:10.1136/bjsports-2015-095829. Epub 2016 Mar 24.

II. Muscle strength is a poor screening test for predicting lower extremity injuries in professional male soccer: A 2-year prospective cohort study. Am J Sports Med, Accepted 28 November 2017

III. The functional movement test 9+ is a poor screening test for lower extremity injuries in professional male football players: a 2-year prospective cohort study. Br J Sports Med 2017, May 16. doi: 10.1136/bjsports-2016-097307. [Epub ahead of print]

IV. Interseason variability of a functional movement test, the 9+ screening battery, in professional male football players. Br J Sports Med 2017 Jul; 51 (14): 1081-1086. doi:10.1136/bjsports-2016-096570. Epub 2016 Sep 6.

Abbreviations

ACL	Anterior cruciate ligament
AUC	Area under the curve
BMI	Body mass index
CI	Confidence Interval
IOC	International Olympic Committee
ECG	Electrocardiography
FIFA	Fédération Internationale de Football Association
FEV	Forced expiratory volume
FEV_1	Forced expiratory volume in one second
FEV_1/FVC	Forced expiratory volume in one second and forced vital capacity ratio
FMS	Functional movement screen
HR	Hazard ratio
ICC	Interclass correlation coefficient
MDC	Minimal detectable change
OR	Odds ratio
PCMA	Pre-competition medical assessment
PEF	Peak Expiratory flow
PHE	Periodic health evaluation
QSL	Qatar Stars League
ROC	Receiver operating characteristic
SCD	Sudden cardiac death
SEM	Standard error of measurement
UEFA	Union of European Football Association

Summary

Introduction

Injury and illness are common in professional football, causing substantial morbidity, and may have potentially negative long-term health consequences on the player. A periodic health evaluation (PHE) or screening examination is a widely used method to detect and manage health problems which may influence the athlete's ability to train or compete. It is also used as a method to identify the athlete at risk with a view to implementing targeted prevention measures. FIFA encourages all football teams at the elite level to complete the football-specific Pre-Competition Medical Assessment (PCMA), which includes a comprehensive cardiovascular, general medical and musculoskeletal assessment. However, there has been limited research into the effectiveness of PHE, with the efficacy of PHE in detecting serious risk factors and health conditions being questioned. The overall aim of this thesis was to investigate the benefits of PHE in professional football with a focus on the musculoskeletal screening.

Methods

All professional male football players eligible to compete in the Qatar Stars League (QSL) were invited to participate in this research project as they presented for their annual pre-season PHE at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar during the 2013/14 and 2014/15 football seasons. The PHE consisted of history, a comprehensive general medical screening including laboratory blood tests, cardiovascular screening with 12-lead ECG and echocardiography and a comprehensive musculoskeletal screening. The test battery aimed to identify potential biomechanical and anatomical risk factors for lower extremity injuries; it included hip and thigh muscle strength tests and a functional movement test, the 9+ test. In addition, all players were monitored prospectively for time-loss injuries and exposure in match and training during the 2013/14 and 2014/15 football seasons through the Aspetar Injury and Illness Surveillance Program. In paper I, we described the prevalence of musculoskeletal and medical conditions detected on a PHE of 558 football players who completed the PHE during the 2013/14 or 2014/15 seasons. In Papers II and III, we investigated the value of the two most utilised screening tests in professional football, muscle strength testing and the 9+ test, in predicting lower extremity injury. In paper IV, we assessed the season-to-season variability of the 9+ test among 220 players who had 9+ test results for both PHE seasons.

Main Results

The PHE detected at least one health condition in 95.5% of players (n=533), and this was mainly due to a high prevalence of players with Vitamin D deficiency or insufficiency (≤30 ng/mL) (n=499, 89.4%). Musculoskeletal examination detected a musculoskeletal condition requiring follow-up (e.g. physiotherapy, prevention programmes) in 32.3% of players. Cardiovascular screening required 8.6% of the players to undergo further investigations, mainly because of anomalies on ECG and echocardiography. However, only a few of the health conditions impacted on clearance for participation in football. For players who completed all the muscle strength tests and the subsequent injury registration (n=369), 206 of these sustained 538 injuries. Of the 20 strength variables examined, we found a weak significant association between quadriceps concentric peak torque at 300^0/ s (HR 1.005, 95% CI: 1.00 to; P=.037) and lower extremity injury, and quadriceps concentric peak torque at 60^0/ s (HR 1.004, 95% CI: 1.00 to 1.01; P=.026) and overuse lower extremity injury in multivariate analysis. However, the sensitivity and sensibility analysis indicated poor predictive ability (area under the curve [AUC], 0.46 and 0.45, respectively) (Paper II). In paper III, 362 players, and 203 sustained 526 injuries, completed the 9+ test and injury registration. There was no association between the 9+ total score and the risk of lower extremity injury, even after adjusting for other risk factors in a multivariate analysis (HR 1.01, 95% CI 0.98 to 1.04, p=0.37). The sensitivity and sensibility analysis found no cut-off point that distinguished injured from non-injured players (AUC = 0.48). In paper IV, we found a significant increase in the mean total score of 1.6 points (95% CI 1.0 to 2.2, p<0.001) between two consecutive seasons. However, the variability (ICC 0.24, 95% CI 0.11 to 0.36) and the measurement error (SEM, 3.0-3.4 points) and minimal detectable change (MDC= 8.7 points) was large, irrespective of whether the player had sustained an injury or not.

Perspectives

The PHE detects current health conditions, which are believed to be relevant for health and performance upon treatment or further investigations may be instigated. In the case of musculoskeletal screening, our results suggest it has limited (or no) value as a method of identifying the athlete at risk of future lower extremity injury because of the low predictive ability of the screening tests. We found only a weak association between isokinetic quadriceps concentric strength and lower extremity injury, but these associations were too small to identify the player at risk for injury. Furthermore, we found that the 9+ test was not associated with risk of lower extremity injury and performed no better than chance to distinguish injured from uninjured players, partly because of the high variability (measurement error) of the 9+ test.

Sammendrag på norsk

Introduksjon

Skader og sykdom er vanlig blant elitefotballspillere, og som kan føre til betydelig sykelighet og kan ha potensielle negative langsiktige helsekonsekvenser for spilleren/utøveren. Standardisert helseundersøkelse (PHE) eller screening er en kjent metode for å avdekke og behandle helseplager som kan hindre deltakelse i trening og/eller konkurranse. Screening blir også benyttet for å identifisere risikofaktorer for fremtidig skade og sykdom slik at disse kan forebygges. FIFA oppfordrer alle fotballklubber på elitenivå til å helseundersøke spillere med en standardisert fotball helseundersøkelse (PCMA) som inkluderer en omfattende generell medisinsk undersøkelse, hjertescreeening og en muskel-og skjelett undersøkelse. Det er imidlertid lite dokumentasjon på effekten av screening, noe den Internasjonale Olympiske Komité har etterlyst for å kunne vurdere om dette er en nyttig metode for å ivareta utøvernes helse.

Det overordnende målet med denne avhandlingen var å øke vår kunnskap om hvilke fordeler det er å utføre standardisert helseundersøkelse av elitefotballspillere med fokus på muskel-og skjelettscreening.

Metode

Alle mannlige elitefotballspillere som var kvalifisert til å spille i Qatar Stars League (QSL) utførte en omfattende helseundersøkelse (PHE) i forkant av fotballsesongene 2013/14 og 2014/15 på Aspetar Orthopedic and Sports Medicine Hospital i Doha, Qatar. PHE besto av anamnese, en generell medisinsk screening som inkluderte laboratoriske blodprøver, hjertescreening med 12-ledet EKG og ekkokardiografi, og en omfattende muskel– og skjelettscreening. Testbatteriet var rettet mot kjente risikofaktorer for underekstremitetsskader og inkluderte hofte og lår muskelstyrketester og en funksjonell beveglighetstest, 9+ test. I tillegg ble alle skader i trening og kamp registrert prospektivt gjennom Aspetar skade - og sykdomsregistering gjennom hver av fotballsesongene 2013/14 og 2014/15. I artikkel I undersøkte vi prevalensen av helseplager (medisinske og muskel-og skjelettplager), avdekket gjennom screening, av 558 fotballspillere som utførte PHE i forkant av fotballsesongene 2013/14 eller 2014/15. I artikkel II og III undersøkte vi verdien av de to mest benyttete screeningtestene i mannlig elitefotball, muskelstyrketesting og 9+ test, til å predikere underekstremitetsskader. I artikkel IV evaluerte vi sesong-til-sesong variasjonen av 9+ testen av 220 spillere som hadde 9+ testresultater for begge PHE-sesongene.

Hoved resultater

Helseundersøkelsen (PHE) avdekket minst en helseplage hos 95.5% av spillerne (n=533), og dette var hovedsakelig på grunn av en høy prevalens av spillere med Vitamin D mangel (≤30 ng/ml) (n=499, 89.4%). Muskel-og skjelettundersøkselsen avdekket plager hos 32.3% av spillerne. Skadeforebyggende tiltak i klubben var det hyppigste tiltaket igangsatt for muskel- og skjelettplagene. Hjertescreeningen førte til videre undersøkelser av 8.6% av spillerne, de fleste på grunn av uregelmessigheter på EKG og/eller ekkokardiografi. Det var bare et fåtall av disse helseplagene som fikk konsekvenser for deltakelse i fotball. For spillere som fullførte alle muskelstyrketestene og den påfølgende skaderegistreringen (n = 369), hadde 206 av disse en eller flere underekstremitetsskader i løpe av de 2 sesongene (n=538). Av de 20 styrkevariablene som ble undersøkt, fant vi en svak signifikant sammenheng mellom konsentrisk quadricepsstyrke ved 300°/ s (HR 1.005, 95% CI: 1.00-1.01; P = .037) og underekstremitetsskader, og konsentrisk quadricepsstyrke ved 60°/ s (HR 1.004, 95% CI: 1.00-1.01; P = .026) og belastningsskader i multivariate analyser. Sensitivitets-og spesifisitetsanalyser viste at de signifikante styrkevariablene er lite treffsikre til å identifisere spillere med høy risiko for skade (areal under kurven [AUC]; 0.46 til 0.45) (Artikkel II). I Artikkel III, var det 362 spillere, hvorav 203 hadde 526 underekstremitetsskader, som fullførte 9+ testen og skaderegistreringen. Det var ingen sammenheng mellom 9+ total skåre og risiko for underekstremitetsskade, selv etter justering for andre risikofaktorer i en multivariat analyse (HR 1.01, 95% CI 0.98 til 1.04, p = 0.37). Sensitivitets-og spesifistetsanalyser viste at det ikke var noen cut-off punkt som kunne skille skadet spillere fra ikke-skadet spillere (AUC = 0,48). I Artikkel IV fant vi en signifikant forbedring i 9+ totalskåre på 1,6 poeng fra sesong 1 til sesong 2 (95% CI 1.0-2.2, p <0,001), men variasjonen var høy (ICC 0.24, 95% CI 0.11 til 0.36). 9+ testen viste stor målefeil (SEM, 3.0-3.4 poeng) og en endring på minst 8 poeng var nødvendig for å representere en ekte endring i 9+ test skåre fra sesong til sesong. Denne endringen var uavhengig av om spilleren hadde en skade eller ikke.

Konklusjon

Denne avhandlingen viser at en standardisert helseundersøkelse (PHE) er en nyttig metode for å avdekke en rekke helseplager, som man tror kan være relevant for utøverens helse og prestasjon, hvor behandling eller videre oppfølging kan bli initiert. For muskel- og skjelettscreeningen viser resultatene fra denne avhandlingen at den har begrenset (eller ingen) verdi som en metode for å identifisere spilleren som er i risiko for underekstremitetsskade på grunn av den lave prediktive evne til screeningtestene. Vi fant bare en svak sammenheng mellom isokinetisk konsentrisk quadricepsstyrke og underekstremitetsskader, men disse assosiasjonene var for små til å identifisere spillere med høy risiko for skade. Videre fant vi at 9+-testen ikke var forbundet med risiko for underekstremitetsskader og ikke var bedre enn 50/50 prosent sjanse til å skille skadet spiller fra ikke-skadet spiller. Dette var delvis på grunn av høy variasjon (målefeil) av 9+-testen.

Introduction

Professional sport, including football, is well-known for its high physical demands with a high risk of injury, illness, and potentially also negative long-term health consequences.[74, 78, 147] Protection of the health of the athlete should be of utmost importance for sports authorities.[64, 68, 219] A periodic health evaluation (PHE) or a pre-participation examination (PPE) (screening) is widely used to identify the athlete at risk of future injury and illnesses.[154] The main purpose of PHE is to screen for injuries or medical conditions that may place an athlete at risk for safe participation. It includes a comprehensive assessment of the athlete's current medical and musculoskeletal health status and risk of future disease or injury.[154]

Various forms of PHE have been performed for many years. They may vary from a short general health examination to a day-long comprehensive assessment that may include an electrocardiogram (ECG) and echocardiography, as well as an extensive general medical and musculoskeletal assessment.[72, 102, 106, 206] In 2009, the International Olympic Committee (IOC) and the Fédération Internationale de Football Association (FIFA) released guidelines on PHE of elite athletes to set a standard for effective testing to assist in early detection of potential health (medical) and injury risk.[72, 154]

While the PHE is recommended by FIFA and the IOC, and a pre-season screening, is claimed to be an integral element in sport injury and health prevention,[72, 154] there is little evidence of its effectiveness.[163, 251] Considerations such as cost (economic and time), possibilities of significant findings, and impact of these are frequently discussed.[23, 104, 154, 165] Therefore, the IOC, in its 2009 consensus statement on PHE of elite athletes, recommended further research evaluation of the PHE. In particular, the statement concluded that large-scale population-based studies were needed to evaluate the components of musculoskeletal history and examination that can be used to identify athletes at risk, intervene and change outcome.[154]

Background

The purpose of screening

Screening, in its broad and traditional sense, is a strategy used in a population to identify unrecognised disease in individuals without signs or symptoms of that disease.[154] The aim is to identify pathological conditions early, thus enabling earlier intervention and management to reduce future morbidity and mortality.[154] Public health screening programmes include infant screening programs. For example the successful screening program for phenylketonuria (Følling's disease),[2] a condition leading to severe brain function abnormalities unless patients follow a prescribed dietary interventions from birth.

Cancer screening is a major focus of modern public health; breast cancer screening with mammography, cervical cancer with the Pap smear to examine changes on cells, and prostate cancer screening with the prostate specific antigen blood test. Although screening programmes may lead to an earlier diagnosis, not all programmes are beneficial. The value of current programmes for prostate and breast cancer screening on total or cause-specific mortality is debated widely and vigorously.[129, 144]

The WHO published the Wilson-Jungner criteria for appraising a screening programme in 1968,[250] and 50 years later they remain highly relevant for public health and for this thesis. The 10 criteria are:

(1) the condition being screened for should be an important health problem (how common is the condition? How serious is the condition?)

(2) the natural history of the condition should be well understood

(3) there should be detectable early stage

(4) treatment at an early stage should be of more benefit than at a later stage

(5) suitable tests are available to detect disease in the early stage

(6) the test should be acceptable

(7) intervals for repeating the test should be determined

(8) adequate health service provision should be made for the extra clinical workload resulting from screening

(9) the risks, both physical and psychological, should be less than the benefits

(10) the costs should be balanced against the benefits.

These fundamental principles for screening also apply to the sport. The criteria for screening the athletes should be that: (1) the health conditions and injuries should be sufficiently common to warrant the screening efforts; (2) tests to distinguish athletes at risk from healthy athletes should be available; (3) restriction of sports activity should significantly reduce the risk of medical conditions and injuries; (4) early treatment should alter the natural course of the disease or injury and decrease mortality; and (5) the screening programme should be cost effective.[52] However, these criteria have never been employed systematically to examine the benefits of athlete screening, except perhaps for cardiovascular screening.[12]

The PHE may also serve other purposes than the identification of individual occult health problems or injury risk. It may help the clinician determine whether an athlete is medically suitable to engage in a particular sport, ensuring that established disease or injury is managed appropriately. It represents an opportunity to review medications and supplements, and for the athlete to establish a relationship with team medical personnel. It may also serve as a baseline to measure how the athlete's characteristics change over time.[23, 154]

Periodic health evaluation (PHE) screening program

Medical screening

Cardiovascular examination

Screening for an underlying cardiovascular condition that may place an athlete at risk for sudden cardiac death (SCD) has received wide attention in the literature and is a topic of hot debate.[18, 51] Although SCD in athletes is rare, it is the most devastating sport-related event. The incidence of SCD in young athletes (<35 years of age) is between 0.3-3.6 per 100 000 persons per year,[31] with a higher rate in males (five times higher than females).[31, 118] The tragedy for families and the considerable media attention such incidents attract, is followed by calls for action to prevent future occurrences.[18]

Almost all SCD occur in individuals with pre-existing cardiac abnormalities. A variety of mostly hereditary, structural, or electrical cardiac disorders are associated with SCD in athletes; hypertrophic cardiomyopathy (HCM) is the most common underlying cause of SCD.[31, 229] HCM is more common in black athletes (0.24% vs 0.10% in Caucasian population) and therefore the incidence of HCM-related SCD is higher in black athletes.[31, 118] Congenital coronary artery anomalies, arrhythmogenic right ventricular cardiomyopathy (ARVC), myocarditis, long/short QT syndrome and Wolff-Parkinson-White syndrome (WPW) are other underlying causes of SCD,[31, 229] and SCD during exercise is often the first manifestation of disease.[234]

Cardiovascular screening has traditionally consisted of a history and a physical examination. Including 12-lead electrocardiography (ECG) in addition to history and a physical examination has been suggested to significantly improve the ability to detect certain underlying arrhythmias such as congenital accessory pathways, ion channelopathies (e.g. long QT syndrome) and WPW.[211, 234]

Including ECG as a prerequisite for participating in sport occurred following a large 25-year Italian prospective study.[50] A mandatory screening program reduced the annual incidence of SCD by 89%, while the rate for non-athletic population of the same age remained unchanged.[50] The argument for including ECG to the cardiovascular examination was that detecting a condition that was potentially lethal in sport (e.g. HCM) and restricting sports activity would save lives.[50, 52] Considerable controversy persists regarding the value of cardiovascular evaluation and the inclusion of a 12-lead ECG in the screening protocol with opposing recommendations from the US and Europe.[52, 53, 159] The European Society of Cardiology (ESC) recommends ECG to be part of the examinations based on the result of the aforementioned Italian study from 2006,[50] while the American Heart Association does not support such recommendations owing to the difficulty in correctly differentiating physiological adaptation from inherited or congenital cardiac pathology, in particularly in different ethnicity groups (i.e. black athletes).[234] Also, the fact the incidence of SCD in the US (0.90/100 000 person years) where there is no mandatory screening, is no different from recently data on SCD from Italy (0.4/100 000 person years) challenges the benefit of including ECG in the screening exam.[211, 234] Experts argue that the remarkably high incidence at the start of the Italian study (3.6/100 000 person years) might represent mere random variation. It is possible the apparent mortality reduction observed in the Italian study (3.6/100 000 person years in 1979 to 0.4/100 000 in 2004) is related to large year-to-year variation than the results of screening with ECG.[158, 220]

Experts note that ECG cannot detect all disorders that predispose to SCD, particularly those with anomalous coronary artery origins or premature atherosclerotic coronary disease (predominantly, but not only athletes >35 years of age). Given that screening cannot with 100% certainty rule out those not suspected with a cardiovascular disease, the implications of false-positive test results (inappropriately suspecting disease in healthy people) needs to be considered.[211, 234] They may lead to unnecessary secondary evaluations (follow-up investigations to confirm or refute the presence of a serious cardiac disorder) or unwarranted restriction or disqualifications from sporting activity.[52]

To address the issue of the high false-positive ECGs, a widely accepted ECG interpretation guidelines, the Seattle Criteria, was produced in 2012.[69] The new criteria have reduced the rate of falsely abnormal ECG markedly (17 to 4% and 29 to 11%) in a population of high-level athletes, while still identifying all athletes with cardiac pathology.[21, 22, 34] Furthermore, the new criteria account for ethnic variations in the ECG, such as anterior T-wave inversion (commonly observed in up to 13% of black athletes[194]), and this helps to further reduce the false-positive rates.[205] Despite major advances in interpretation of the ECG in athletes with the more stringent Seattle criteria, the false-positive rate among the most experienced physicians is still 5% for white athletes and 10% for black athletes.[211] Furthermore, a recent study from Norway has raised a concern of false-*negatives* ECGs.[20] In a retrospective 8-year follow-up study of 604 Norwegian professional football players, screened with ECG and echocardiography prior to the 2008 football season, more than 1 in 100 players with negative screening results experienced severe cardiovascular incidents (including three sudden arrests) during the follow-up period. However, no SCDs were reported.[20] The Seattle criteria was recently revised in a consensus meeting in February 2015 with the aim to improve and develop clear guide to the proper evaluation of ECG abnormalities in athletes based on the new and emerging research on ECG interpretation.[70] Future studies will prove if these new revised criteria will improve the false positives and negatives.

Echocardiography is the primary modality for further examination following an abnormal ECG finding as it is superior for the diagnose of HCM.[156, 204] It is also considered the most practical method for detecting structural cardiac defects such as anomalous coronary arteries, aortic root dilatation or mild cardiomyopathy.[211] The use of echocardiography as a routine screening tool is debatable when cost is a consideration. Whether inclusion of echocardiography will identify even more athletes at risk of SCD, and only those at risk, is questionable.[51, 72, 133] The debate whether to include ECG and echocardiography in the cardiovascular screening is still ongoing, and it is for the relevant sports authorities to decide what to or if to include cardiovascular screening.[52, 87, 154, 160]

FIFA addressed the overall issue of cardiac screening in sport by developing a standardised Pre-Competition Medical Screening (PCMA) prior to the 2006 FIFA World Cup. This comprehensive approach by FIFA may have been influenced, or at least accelerated, by one catastrophic event that occurred in front of a massive international television audience. Cameroonian player, Marc Vivien Foé, collapsed and died on June 26, during the 2003 FIFA

Confederations Cup.[142] The PCMA comprises of a player's personal and family medical history, a focused comprehensive physical examination, a 12-lead resting ECG, and if and when necessary echocardiogram.[142] The PCMA is aimed to detect the majority of genetically based potentially fatal cardiac abnormalities in football players.[142] FIFA and UEFA have mandated players to complete the PCMA including 12-lead ECG and echocardiography for some FIFA and UEFA competitions, and encourage all players competing in various national leagues around the world to complete the PCMA.

These international recommendations have been adopted by the Qatar Football Association (QFA) for all football players who compete in the Qatar Stars League (QSL), the professional first division of football in Qatar. Thus, all the players included in this thesis were required to complete an annual pre-season PHE including the requirement of the PCMA cardiovascular examination (i.e including ECG and echocardiography). Although the major focus of this project was to assess the benefits of musculoskeletal screening, in Paper I, we assessed the prevalence of all health conditions (medical as well as musculoskeletal) detected on a PHE. The ECG were interpreted according to the 2012 Seattle criteria as this project was conducted prior to the release of the new refined 2017 Seattle criteria.[70]

General medical examination

Cardiovascular conditions are not the only medical conditions that may warrant regular screening investigations. Sport physicians who regularly perform medical assessments on elite athletes, as well as other members of the medical team involved with the care of the elite athlete, commonly encounter health problems that are of non-cardiovascular nature and non-injury related. Studies investigating athlete presentation at Olympic Games have reported that non-injury related and non-cardiovascular conditions represented more than 50 % of all consultations. [42, 63, 246] Similarly, in a prospective study on illnesses of male elite football players, a player had a mean of 2.5 illness symptoms per season, and approximately 20% of these resulted in absence from training or match play.[191] Following these results, half of the players will experience a time-loss illness period each season. Recent studies from international tournaments and football leagues in Europe have reported an illness incidence from 1.5 to 16.5 per 1000 player-days, with most players with a time-loss illness episode able to return to play within three days.[25, 73, 225] Symptoms from the upper respiratory - and gastrointestinal tract are the most common causes of illness,[25, 32, 73, 85, 225] but other common conditions reported include respiratory illness (including exercise-induced bronchospasm), urological conditions, iron deficiency, allergies, infections, skin disorders, and oral health problems. [27, 73, 85, 86, 154, 197] Therefore, it seems that conditions in systems other than the cardiovascular are sufficiently common to warrant the screening effort (Wilson-Jungner criterion 1).

Although these conditions are common in elite athletes, they have not received much attention in the PHE or in the literature. Hence, there is limited evidence to support which conditions should be included in a PHE.[88] The IOC consensus statement provided evidence and recommendations for general medical screening.[154] However, for a PHE to be effective, the characteristics of the population and sport in question should be taken into consideration.[89] FIFA encourages all players to complete the FIFA PCMA, which in addition to a cardiovascular examination includes a comprehensive general medical screening with laboratory blood tests and urine test (these tests are mandatory for clubs involved in UEFA competitions) believed to identify conditions common and specific to the football populations.[72, 92, 232] The data collected during the annual PHE of professional football players in Qatar provided an opportunity to assess the prevalence of general medical conditions detected on a PHE in footballers in the current project (Paper I).

Musculoskeletal screening

Musculoskeletal problems or injuries are common in many sports, and is the most common reason leading to restriction of sport activities. Injuries may have substantial short-term and possible also long-term consequences for individuals and for society in general.[68, 147, 166] Time lost from participation from sport, reduced physical performance, and possibly early retirement from sport may affect the success of the athletes, teams and organisations.[75, 76, 112] Furthermore, their treatment involves direct and indirect costs on individuals, employers and health care systems.[58, 125, 241]

The fundamental principles for screening outlined in the Wilson-Jungner criteria, should be no different in the musculoskeletal screening. The purpose is to prevent the athlete for future injury and to detect any current conditions that would make sports participation unsafe, giving specific consideration to the sport for which the athlete is being screened, and to facilitate prevention programs.[45]

For a musculoskeletal screening to be able to serve its purposes, the musculoskeletal screening components should be tailored to the sport in question. Each sport has its distinct injury pattern and this pattern needs to be carefully considered when designing a program. For example, in football the FIFA PCMA focuses on musculoskeletal screening of the lower extremity,[72] especially tailored towards hamstring, groin, knee and ankle injuries whereas, in handball, volleyball and other upper extremity sport the musculoskeletal screening would be tailored to identify risk factors for shoulder injuries.

Key components of any PHE are a detailed history and a focused physical examination. Consequently, obtaining a thorough history of current and previous musculoskeletal injuries as well as any current pain or symptoms is a fundamental component of a musculoskeletal PHE.[39, 126, 154, 155, 240] Medical history alone has revealed 88% of all abnormal findings and 58% of the reasons cited activity restriction.[188] Athletes with a history of previous injury or symptoms indicating reduced function are a group with an increased injury risk that should be targeted for a physical examination and with specific prevention programmes addressing their deficits.[154]

The purpose of the physical examination in addition to detect or confirm any current injury or symptoms, is also to detect any underlying potential risk of an injury in the asymptomatic athlete with no history of previous injury or reported symptoms specific to the sport in question.[104, 154, 164] According to the consensus statement on PHE by the IOC and FIFA, the musculoskeletal examination should focus on any movement restriction, muscle strength deficits, flexibility or laxity deficits particular for the sport being screened for.[72, 154] In paper I, we aimed to assess whether a PHE comprising a targeted history and physical examination can detect musculoskeletal conditions (current problems or risk factors) upon which prevention measures can be instigated.

To date, no musculoskeletal screening program has proven the value of such a program in improving the outcomes regarding morbidity and future injury risk of athletes.[188, 251] A significant challenge to musculoskeletal screening is that there is limited evidence to prescribe specific tests to identify the asymptomatic, the apparently healthy athlete. The ability of such test to identify the athlete who is at risk for a sports injury (predictive value) is for the most part unknown.[154] The following section will review the challenges when developing a musculoskeletal screening programme to identify the athlete at risk of injury.

Musculoskeletal screening programme

The main aim of screening is to be able to prevent future injuries. Prevention depends on identifying possible risk factors that may contribute to an athlete's susceptibility to injury. The objective is early intervention (i.e prevention measures) to minimise the risk factors before injury happens (Wilson-Jungner criteria 2-4).[170]

How to identify and prevent injuries

The classical approach to sports injury prevention research is described by van Mechelen's four-step sequence of research on prevention of sports injuries.[239] The first step of the model is to determine the extent of the problem, including the incidence and severity of the problem. This step is the foundation for targeting the PHE to the injury pattern of the sport in question. The second step is to identify the risk factors and injury mechanisms that play a part in the occurrence of sports injuries (injury causation). The third step is to develop and implement injury prevention measures, and the fourth step is to evaluate the effectiveness of the prevention programs in reducing the injury rate (Figure 1).[239]

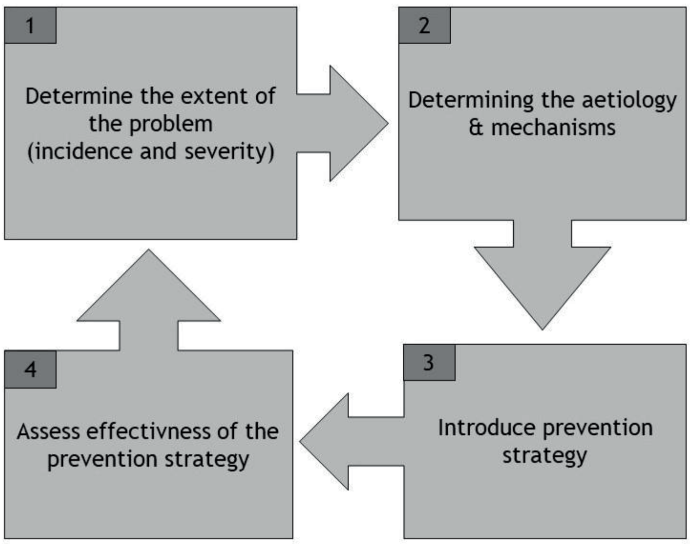


Figure 1. The 4-step sequence of injury prevention research in sports (adapted from van Mechelen et al., 1992)[239]

Injury risk screening

As outlined in the second step of the injury prevention model, understanding the risk factors and mechanisms (injury causes) for an injury is necessary to develop targeted prevention programmes. Injury causation is likely a complex interaction of multifactorial factors, and Meeuwisse[170] developed a model, later modified and expanded by Bahr & Krosshaug,[15] to take into account the aetiology and chain of events that lead to injury (Figure 2). This model explains why a particular athlete may be at risk in a given situation (risk factors) and how injuries occur (mechanisms of injury).

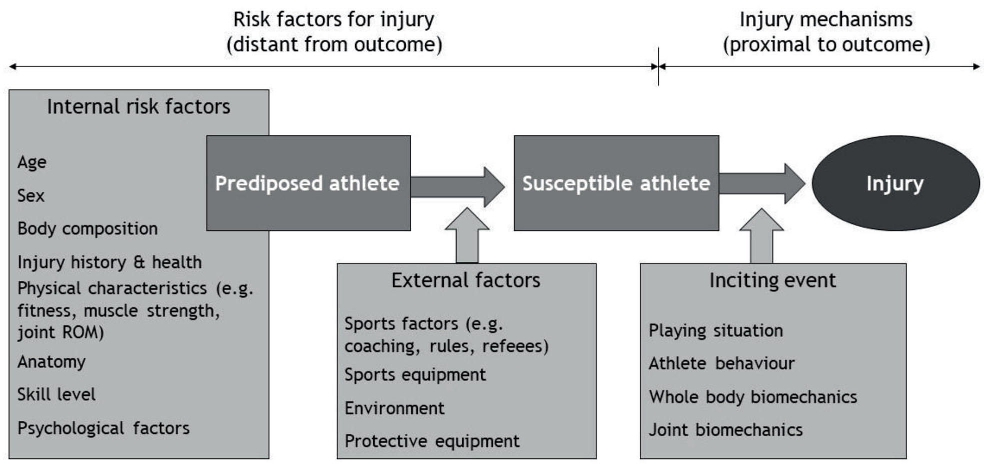
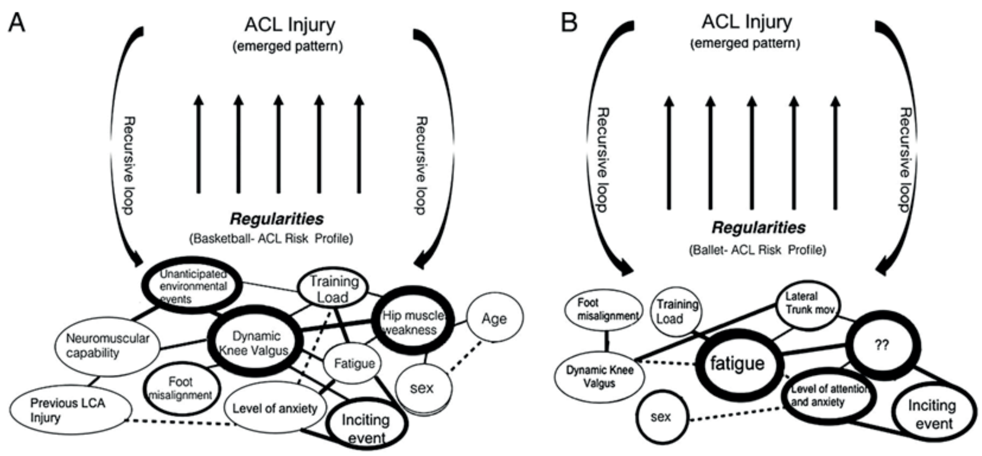


Figure 2. A comprehensive model of injury causation (adapted from Bahr and Krosshaug, 2005)[15]

Risk factors are typically separated into those internal (intrinsic; individual) and those external (extrinsic) to the athlete, traditionally classified as intrinsic or extrinsic risk factors.[14, 170] The intrinsic risk factors may predispose an athlete to injury, while extrinsic risk factors that athletes may be exposed to when they participate in training or competition, such as turf type, weather or type of shoe, may contribute further to the athlete being susceptible to injury. However, these factors are usually distant from the time of injury and rarely sufficient as a cause of injury alone.[170] According to the model of Meeuwisse[170] and Bahr & Krosshaug,[15] an inciting event is necessary to cause an injury.

These models have been developed further highlighting that the athlete's exposure to risk factors is not a static event. Meeuwisse et al[171] suggested in a later model that an athlete's risks are dynamic and there may be changes in susceptibility to injury as the athlete participates and adapts to the environment or potential injury situation with or without sustaining an injury. An athlete's exposure to a potential inciting event can produce adaptations in an athlete's intrinsic risk factors and alter their predisposition to injury.[171] Recently, Bittencourt et al[24] proposed a conceptual model describing the complexity of the injury causation. In this model, the multifactorial and complex nature of sports injuries are described as interactions among "the web of determinants" (factors; such as biomechanical, training characteristics, psychological and physiological) which may mediate/moderate each other to produce an emergent behaviour (injury) (Figure 3). According to this model, small changes in a few determinants may lead to large and sometimes unexpected consequences and some variables may have stronger interactions than others on injury risk. To plan an effective prevention intervention, the identification of the web of determinants that strongly influences the outcome is important - including intrinsic and extrinsic risk factors.[24]



N F N Bittencourt et al. Br J Sports Med 2016;50:1309-1314 doi: 10.1136/bjsports-2015-095850

Figure 3. Complex model for sports injury, web of determinants for ACL injury in basketball athletes (A) and ballet dancers (B) (Bittencourt et al,[24] retrieved and reproduced with permission from Br J Sports Med, 23 January 2018). The group of variables (factors) at the bottom are the web of determinants. Determinants (factors) circled by darker lines have more interactions than variables circled by lighter lines and exert a greater influence on the outcome. Dotted lines represent a weak interaction and thick lines represents a strong interaction between the determinants.

One objective of a PHE may be to identify the intrinsic risk factors predisposing an athlete for injury to initiate early intervention on the intrinsic factors identified to mitigate injury risk (Wilson-Jungner criteria 2-4). A risk factor (intrinsic and extrinsic) can be modifiable or non-modifiable.[14, 38] Modifiable factors can be changed by injury prevention strategies such as muscle strengthening, stretching and/or balance exercises, and a screening test is typically designed to measure such modifiable risk factors. Non-modifiable risk factors relevant to sport include age, gender or previous injury history; these cannot be altered. Still, non-modifiable risk factors may have utility; they can identify subgroups that may be at increased risk for injury and warrant intervention. These should be kept in mind as they can be used to target intervention measures to the subgroup thought to be at increased risk for injury.[14, 171] In theory, identifying both modifiable and non-modifiable risk factors during a PHE can be used to develop risk profiles for specific injuries and thereby used to identify those athletes at greatest risk for injury. This may in turn guide injury prevention interventions targeting these modifiable risk factors (i.e. strength training programme targeting athletes with strength deficits).[38]

Injury prevention

For musculoskeletal screening to be effective, identified problems (risk factor or injuries) must be treatable.[23] There should be a treatment or prevention program that reduces the injury risk. This is the final step of the injury prevention research model (Figure 1, p10)[239] and can be illustrated by two football examples from almost 20 years ago.

Hamstring strengthening programs, based on the Nordic hamstring exercise (NHE), reduce the rate of acute hamstring injuries in football. [5, 200, 235] This simple partner exercise was developed on the assumption that hamstring injuries occurs as a result of inadequate eccentric muscle strength.

In 2001 Mjølsnes et al[176] developed an eccentric hamstring strength training programme based on the NHE. In a randomized trial study on well-trained Norwegian football players (about half of the players were elite football players), NHE training for 10 weeks was much more effective in developing maximal eccentric hamstring strength compared to a program based on traditional concentric hamstring curls.[176] Note that hamstring strain was not measured as an outcome. The following year, the same investigators implemented the NHE in the Norwegian premier league and the incidence of hamstring injuries was 57% lower in teams that used the NHE training programme compared with those teams that did not use the programme.[5]

In 2008, Petersen et al[200] completed a cluster-randomised intervention trial (RCT) of the NHE on 50 Danish male professional and amateur soccer teams (942 players) allocated to an intervention (eccentric group) or control group (usual training group); the incidence of acute hamstring injuries was 59% lower in the intervention group that completed the 10-week NHE programme. The number needed to treat (NNT) to obtain this benefit was 13.

Importantly, the intervention effected recurrent hamstring injuries was even more dramatically. The reinjury rate was 86% lower in the intervention group and, the number needed to treat (NNT) to prevent one recurrent injury, was a mere 3 players.[200] This powerful argument for the NHE was reinforced in a 2015 RCT of 40 Dutch male amateur clubs (292 players).[235]

The FIFA 11+ is another injury prevention programme that reduces the overall injury risk in both male and female football players.[213, 214, 217, 228] It was designed to address the most common football related injuries including hamstring injuries. The prevention programme includes specific strengthening, balancing and jumping/landing exercised aimed to improve strength, balance and jumping/landing ability to mitigate injury risk. The NHE is one of the strength exercises in this programme, and the programme is performed as part of a structured warm-up session.[228]

To successfully tailor and implement injury prevention programmes, it is of the utmost importance to identify modifiable risk factors. Injury prevention programmes have proven effect in reducing injury risk (addressing risk factors for injury). However, there is limited evidence as to whether these programmes are more beneficial in terms of cost-effectiveness (both economic cost and time) when applied to individual athletes identified at higher risk for injury as identified on a screening test, or universally applied (train all athletes).

Swart et al [222] evaluated the cost-effectiveness of training methods to improve neuromuscular control and screening strategies for preventing ACL injuries in young athletes. A decision-analysis model was created to evaluate the cost-effectiveness of these methods. Three strategies for a hypothetical cohort of young athletes (high school and college athletes) participating in organised team ball sport was analysed 1) no training or screening, 2) universal neuromuscular training, and 3) universal screening, with neuromuscular training for identified high-risk athletes only. They reported that the universal training strategy was the dominant strategy in preventing ACL injuries (ACL injury incidence from 3% per season to 1.1% per season) and lower cost compared with screening (from 3% to 1.8% reduction in ACL, $25 lower cost per player per season).[222] Noted that the usefulness of the vertical drop jump test as an injury prediction tool that was modelled as the screening test in this study, is debated.[13, 122, 127, 146]

Methodological approaches to identify and prevent risk factors for injuries

To identify risk factors for injury, prospective cohort studies need to be conducted to establish the strength of association between a candidate risk factor and subsequent injury. For example, numerous studies across different sports have examined the association between risk factors and injury, and identified a statistical significant association for one or more factors (e.g. the association between muscle strength and hamstring injury).[97, 233] However, the utility of a test as screening tool not only depends on the strength of its association with injury risk, but also on its ability to predict who is at risk of injury and who is not.[13] The cut-off value separating the athletes at high risk of injury from those who are not, needs to be defined (Figure 4). As with disease detection (i.e. the medical screening and public health screening), the injury prediction test needs to be translated into a dichotomous outcome (high/low risk). This is the first of the three research steps required in the development and validation of injury prevention screening programmes, as recently outlined by Bahr.[13] According to Bahr,[13] these two concepts are often, and erroneously, confused. Therefore, the aim of Papers II-IV was to investigate if and how a musculoskeletal PHE can be used to identify the athletes at risk.

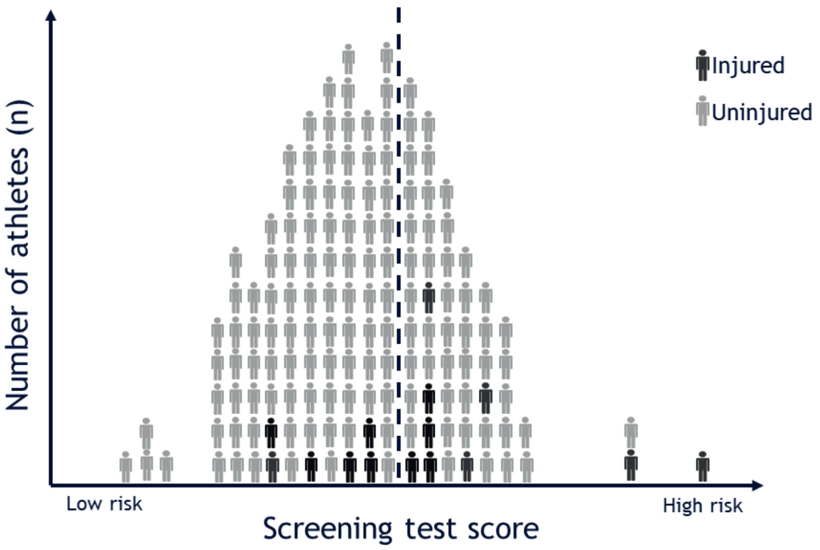


Figure 4. Step 1 in the development and validation of injury prevention screening programme; Prospective cohort study to identify risk factor(s) & define cut-off values(s) (adapted from Bahr, 2016,[13] and reproduced with permission from Br J Sports Med, 8 January 2018)

Step two of the research model proposed by Bahr,[13] is to validate the screening test and cut-off value in multiple cohorts. Step three is to examine the efficacy of an intervention programme based on the screening test;[13] high risk athletes are prescribed the intervention programme whereas the low risk athletes are not (i.e. a randomized controlled trial).

Screening test properties

For musculoskeletal screening to be effective in detecting risk factors or injury risk, it is essential that the screening tools or clinical tests are reliable, valid, responsive, and have acceptable measurement error.[62, 103, 122, 123, 254]

In general, validity of a measurement refers to whether a test measures what it is intended to measure.[226] There are different types of validity such as face, content, construct and criterion validity. The objective of a screening test is to be able to accurately predict outcome scores (i.e. identifying risk factors associated with injury in cohort studies). This is known as predictive validity, which is one type of criterion validity.[178, 226] A screening test's predictive validity is essential to be able to identify those who correctly are at risk of injury (sensitivity) and those who correctly are not at risk of injury (specificity).[13] Sensitivity, specificity, positive predictive value (how many with a positive test have the disease or are injured) and negative predictive value (how many with a negative test do not have the disease or are not injured) are the same test properties that are used for diagnostic testing in public health screening.[13]

Sensitivity and specificity are inversely related. This means that if a test is highly sensitive, the specificity will be low; more healthy individuals will be diagnosed with a disease.[4, 173, 196] When identifying a cut-off point, the aim is to maximise sensitivity and specificity so that we capture those having the disease while identifying those individuals who are healthy (do not have the disease). For example, in the case of ECG testing, the Seattle criteria has increased the specificity (reduced rate of false-positive ECG) while still capturing athletes with cardiac pathology (high sensitivity).

However, the question for a musculoskeletal screening test is where the cut-off value should be set. For a screening test to be relevant in injury prevention, it must capture the majority of athletes with increased injury risk (high sensitivity, few false negatives), so they do not miss the opportunity to prevent injury through targeted training programs.[13]

Another important pre-requisite for a screening test to have the ability to predict the athlete at-risk of a future injury, is the reproducibility or reliability of a test. For any clinical measure, the limit of validity is constrained by reliability.[120, 179] In other words, for a screening test to have the accuracy as an injury prediction test or as a clinical test in measuring treatment progress, it should be stable in stable subjects (reproducibility i.e. test-retest reliability). However, it should also be able to detect changes in unstable athletes (to detect clinically relevant changes over time), which is known as responsiveness.[17]

The reliability of a test includes precision of a score within the same athlete, between testers or between two test scores (or sessions) by the same athlete (reproducibility of a test over time).[120] The reproducibility or test-retest reliability is vital for the predictive validity of a screening test. Poor reproducibility indicates that the measurement includes a high degree of measurement error, meaning it would be difficult to differentiate the athletes with or without the variable of interest i.e. injury.[120]

A measurement error is typically considered as either systematic or random, and both errors are assessed in establishing the reproducibility of a screening test.[245] Systematic error is the chance that there is something inaccurate in the measurement system or testing procedure (instrumental, methodological or personal mistakes) causing consistently deviation in one direction from the true value, which is assessed by examining the difference in mean between two test scores.[245] Random error is error due to chance factors (luck, alertness, attractiveness of tester, and normal biological variability), and are traditionally expressed by the intraclass correlation coefficient (ICC).[245] While ICC measure the strength of the relationship between subjects in repeated measures on a dimensionless scale between 0 and 1 (1= perfect reliability and 0= no reliability), it does not provide the expected trial-to-trial noise in the data (the standard error of the measurement; SEM).[60, 245] An absolute measure of reliability, like the SEM, is therefore recommended to estimate the random error in assessing the reproducibility of a test. The advantage of the SEM is that it is expressed on the actual scale of measurement value.[60, 245] Hence, the larger the random error (or measurement error), the larger the change needed to know a difference in a test score is a true difference (or a real change in test score); known as the minimal detectable change (MDC) or smallest detectable difference (SDD).[17, 255] It is argued that an outcome measure loses meaning unless the MDC is known.[17, 123] Therefore, the appropriate MDC needs to be considered when determining the cut-off values of a test.

Injuries in male football

Playing football is associated with high injury risk. The injury incidence among male senior players ranges between 2.1 to 11.8 injuries per 1000 hours of training, and 14.5 to 28.2 per 1000 hours of match play.[6, 74, 78, 109] According to studies on players playing at the Champions League level in Europe, a professional football team (a squad of 25 players) can expect about 50 injuries causing time loss from play each season, equalling two injuries per player.[78] Similar, a player in QSL is expected to sustain at least one time-loss injury per season.[74] The majority of the injuries are acute, and injuries to the lower extremity are most common, representing up to 90% of all time-loss injuries in senior male players.[73, 74, 78, 131] The thigh, knee, ankle and hip/groin are the most common injury locations. A thigh muscle strain represents the single most common injury subtype (ranging between 12 to 34% of all injuries),[6, 74, 78, 131] and the rate of acute muscle strains and severe ligament injuries does not seem to decline. In an 11-year surveillance study on players at the Champions League level, Ekstrand et al[77] reported that the rate of muscle injuries and severe ligament injuries had not changed. Worryingly, the same group reported in a 13-year follow-up study on the same population that the rate of hamstring injuries (the single most common injury diagnosis in football) has increased by 4% annually.[79] Clearly, injuries are sufficiently common to warrant the screening effort in football (Wilson-Jungner criterion 1). Thus, knowing the risk factors for these most common injury types is important to be able to compose the most efficient screening tests (Wilson-Jungner criterion 2), in order to instigate targeted prevention program.[170]

Risk factors for lower extremity injury

A variety of intrinsic factors predispose football players to lower extremity injuries. These include previous history of injury, age, leg dominance, poor flexibility (muscle and joint ROM), and neuromuscular factors (decreased muscle strength and muscle strength imbalance).[7, 111, 208, 233, 247]

Previous history of injury

A history of previous injury is the most consistent risk factor for lower extremity injury in professional football.[6, 81, 83, 84, 110, 111, 242] In a two-year prospective study of elite Swedish male football players, Hägglund et al[110] reported that players with a previous hamstring injury, groin injury, and knee trauma were two to three times more likely to sustain an identical injury to the same leg in the following season. Similar findings have been reported in systematic reviews on risk factors for hamstring injury in professional football,[233] and groin injury in team-field sports,[208] as well as in prospective studies on risk factors for knee injuries[6, 242] and ankle injuries[6, 81] in professional football players. Risk associated with previous injury may not be limited to the identical injury. Hägglund et al[111] discovered that among Champions league players, previous injury to other muscle groups (adductor injuries, hamstring injuries, quadriceps injuries and calf injuries) increased the overall lower extremity injury rate.

There are at least two mechanisms that could explain this phenomenon and they are discussed in detail elsewhere.[111, 247] Inadequate rehabilitation (incomplete or aggressive rehabilitation, underestimation of an extensive injury etc) following the initial injury is one explanation. Second mechanism proposed is certain players are more prone to injuries from inherent physiological risk that makes the athlete at greater risk of both the initial and subsequent injuries.[111, 247]

Age

Are older players more susceptible to injury than younger players? The evidence is inconclusive. Arnason et al[6] reported that older players had a significantly higher risk of injuries compared to younger players in a prospective study of injury risk factors of elite Icelandic football players. The same study also reported similar findings in a sub-group analysis on hamstring injuries.[6] These conclusions are reinforced in recent systematic reviews on injury risk factors for hamstring injury in professional football,[233] groin injury in field-based sport[208] and for calf muscle injury in sport including football.[107]

On the other hand, older age was not associated with overall injury risk (i.e., various injuries in aggregate) in a prospective study of injury risk factors of elite Swedish football players.[110] In three separate prospective risk factor studies on groin injury,[83] knee injury[82] and ankle injury[81] in Norwegian sub-elite football players, age was not associated with those specific injuries. Hägglund et al[111] reported similar findings on hamstring injury, adductor muscle injury and quadriceps injury in a prospective study on lower extremity muscle injury in football players playing in the European Champions League. However, older players were reported to be two times more likely to sustain a calf muscle injury in the same study.[111]

The reason why older players may be at risk for an injury is unclear. One explanation might be that age-related changes such as increased body weight and a loss of flexibility increases the risk of injury.[111] Another reason may be that older players have a higher prevalence of history of previous injury. Most studies only include an injury sustained in the previous 12 months prior to baseline tests/analysis. It is not known how adaptations after an injury may influence the athletes susceptible to injury.[24, 171] A final possible explanation for the inconsistency in this risk factor could be explained by different study cohorts (highest professional level versus semi-professional or elite level) and different analysis method (continuous versus categorical (1 SD above or below mean variables).

Leg dominance

Existing dogma suggests that the dominant leg is more prone to injury than the non-dominant leg because of a greater volume of shooting and passing/crossing with the dominant leg.[111, 183] Also, there is speculation that leg dominance in football players may cause asymmetry between the strength of the dominant and non-dominant leg.[111, 183] However, the evidence is inconclusive.

Adductor muscle injuries were more common in the kicking leg (defined as the dominant leg) in two prospective studies on groin injuries in professional football players in Qatar[210] and in Europe (UEFA).[111] Also, quadriceps muscle injuries were more common in the kicking leg among UEFA players.[111] In contrast, there was no effect of limb dominance on thigh muscle injuries (hamstring and quadriceps injuries) in a prospective study of 146 male Belgian professional football players.[252] Illustrating the lack of consistency of this risk factor, a prospective study of Czech Republic male football players showed no side-to-side difference for ankle injuries or non-contact knee injury, but contact knee injuries were significantly more common in the dominant leg.[40]

The inconsistency in the results could possibly be explained by different injury mechanisms. Proposed mechanisms for a hamstring injury is a rapid acceleration or deceleration during sprinting or a quick change of direction during sprinting or jumping, when resisting knee extension or at foot strike.[14, 233] It is possible these different mechanisms may predispose the dominant or non-dominant leg for injury differently. Another explanation for the inconsistency can also be how leg dominance is defined or lack precise definitions. Some studies in football define the dominant leg as the kicking leg,[111, 210] while in other studies it is not clearly defined (i.e. if dominant leg is the kicking leg or stance leg).[40, 183]

Flexibility

Loss of flexibility (muscle tightness or joint ROM) may also represent as a risk factor for lower extremity injuries. Loss of ROM or muscle flexibility may lead to injury, particularly a muscle injury, due to synergistic and opposing muscle length or ROM causing strain on muscles (i.e. adductor muscle) leading to injury.[208] Decreased hip abduction and total hip ROM (external and internal rotation) are reported to increase the risk of sustaining a groin injury (particularly adductor injury) in a recent systematic review on groin injuries in field-based sports,[208] whereas another recent systematic review on groin injuries in all sports did not report an association between hip ROM and increased risk of a groin injury.[247] Restriction of ankle dorsiflexion is believed to increase the risk of a lateral ankle sprain and knee injury such as patellofemoral knee pain. Gribble et al[108] reported that US high school and national collegiate football players who sustained a lateral ankle sprain displayed poorer dorsiflexion as measured pre-season on the Star Excursion Balance test (SEBT) anterior reaching direction (displayed poor score on test). However, Engebretsen et al[81] found no association between ankle ROM and an ankle injury in a prospective study on Norwegian elite football players when measured with a traditional goniometer. Differences in conclusions regarding flexibility may be explained by the different measuring methods.

Similarly, inconsistent results are reported for muscle flexibility, particularly for hamstring injury. Three prospective studies on elite football players in Iceland[6], Norway[84] and English premier league players[124] reported no association between lower hamstring flexibility and hamstring injury risk, whereas a prospective study on a group of Belgian male professional football players reported that the injured group had significant lower hamstring flexibility prior to their injury compared to the uninjured group.[252] Comparable findings were reported in two prospective studies on lower extremity muscle strain risk of elite players; players sustaining a quadriceps and hamstring muscle injury displayed lower pre-season ROM in these muscle groups.[33, 95] Again, differences in conclusions regarding flexibility may be explained by the different measuring methods; passive knee extension versus supine straight leg raise.

Neuromuscular factors

One of the most frequently proposed risk factor for a lower extremity injury is muscle strength and/or muscle imbalance.[54, 55, 80, 95, 174, 208] Adequate muscle strength and anaerobic power of the neuromuscular system are important factors for sprinting, jumping, dueling and kicking performance in football, as well as for many other sports.[247, 256] Reduced muscle strength may result in reduced muscle capacity, imbalance between the synergistic functions of agonist and antagonist muscle groups (for example the balance between the hamstring and quadriceps muscle), and thereby increasing the risk of injury.[44, 256] Lower extremity muscle strength has been reported as a risk factor for injury in football in several prospective studies.[54, 56, 83, 95, 190] Two systematic reviews have synthesised the findings of the studies on hamstring injury.[97, 233] The reviews described conflicting results for muscle strength (absolute and relative to quadriceps strength), with a negative finding in elite football,[233] but an association between muscle strength and hamstring injury risk in all sports.[97] However, two systematic reviews on groin injury in field-based sport[208] and sports in general[247] concluded that low adduction strength (both absolute and relative to abduction strength) was a significant risk factor for groin injury.

Neuromuscular control and balance are factors believed to be associated with injury, particularly for ankle sprains. However, Fousekis et al[96] found no relationship between ankle neuromuscular proprioception and ankle sprain in Greek elite football players. Comparable findings were reported by Engebretsen et al[81] in a prospective study on ankle injury among Norwegian elite football players. There was no association when tested on a single leg balance test.[81]

In summary, the evidence for intrinsic risk factors is inconsistent, except for previous injury history, and there is still much debate on the significance of the various risk factors in conferring future injury risk.[59] One important limitation is that the predictive value of the screening tests is scarcely studied or unknown.[154] Consequently, our aims for Papers II and III were to investigate the predictive value of the musculoskeletal screening battery in this project, in addition to exploring the association between the risk factor and lower extremity injury.

Injury risk screening in football

Most top-level football clubs worldwide complete an annual comprehensive pre-competition musculoskeletal screening, including various tests, to identify risk factors for the most common injuries in football such as thigh and groin injuries.[106, 166] In a recent survey, McCall et al[166] investigated the perceptions and practices of 44 premier league football teams from around the world regarding risk factors, risk testing and prevention strategies for non-contact injuries. The top five perceived risk factors for lower extremity reported by the club medical teams were previous injury, fatigue, muscle imbalances, fitness and movement efficiency. The five most utilized screening tests to detect injury risk in professional football were (in ranked order); 1) functional movement screen (FMS) test, 2) questionnaires, 3) isokinetic muscle testing (or muscle strength tests), 4) physical tests and 5) flexibility tests.[166] Therefore, in Papers II-IV we wanted to explore the utility of the two most common screening tests, functional movement tests and muscle strength tests, as injury prediction screening tools in professional football.

Muscle strength testing

The use of isokinetic testing to establish whether the strength of the quadriceps and hamstring muscles could be identified as a risk factor for lower extremity injury has received much attention in the literature, in particular for hamstring strain injury and knee ligament injury (ACL). The results are inconsistent, with some studies on team and non-team sports reporting an association between isokinetic quadriceps and hamstring muscle strength and lower extremity injury risk,[54, 97, 184, 190] whereas other prospective studies do not support such a relationship.[80, 94]

Hip strength is also suggested to contribute a significant role in the causation of lower extremity injury. Low adductor strength increases the risk of lower extremity injury, particularly a groin injury, in field-based sports.[208, 247] Lower hip abduction strength is also suggested to be associated with increased risk of ACL injury and patellofemoral pain.[91, 135] Hip abductor muscle weakness is believed to increase ACL load by increasing medial knee motion and abduction moments through greater hip adduction and hip internal rotation.[140, 145, 187, 218]

A higher agonist/antagonist muscle ratio is suggested as a protective factor for lower extremity injury.[48, 231] Studies examining risk factors for muscle strain injury in a variety of team and individual sports have reported an association between low concentric hamstring-to-quadriceps (H:Q) ratio and adductor-to-abductor (ADD:ABD) ratio and risk of hamstring strain injury and groin injury, respectively;[54, 208, 231, 247] however, the evidence is conflicting for the H:Q ratio.[55, 97, 165]

Although several studies have investigated the strength of association between muscle strength and lower extremity injury risk, few studies have investigated the predictive ability of such tests. In a prospective study, Croisier et al[54] tested the muscle strength H:Q ratio in 462 male professional football players. They reported a four times increased risk of sustaining a hamstring muscle injury in players having pre-season strength imbalances (RR 4.66) compared with players displaying no imbalance.[54] Correction of a mixed H:Q (low-speed eccentric hamstring strength: high-speed concentric quadriceps strength) under 0.89 decreased the occurrence of hamstring injury. The authors concluded that isokinetic testing pre-season is useful in detecting those players at risk of injury.[54] It should be noted that the cut-off points were arbitrary. In contrast, Zvijac et al[258] conducted a sensitivity and specificity analysis to determine the peak H:Q value to predict hamstring injury in a prospective study of 172 injured professional National Football League (NFL) players. They found that a cut-off point of H:Q 0.66 provided the best fit for sensitivity and specificity. However, the corresponding sensitivity and specificity was only 51% and 54%, respectively, indicating that the predictive ability was no better than chance. They concluded that isokinetic strength data were not useful for predicting risk of hamstring injury.[258]

Despite the widespread use of muscle strength testing within professional football clubs, there are few prospective studies investigating the relationship between muscle strength and lower injury risk in professional football. And no studies have investigated the effect of a PHE muscle strength battery consisting of both isokinetic quadriceps and hamstring strength and hip strength on injury risk in professional male football players (Paper II).

Functional movement tests

Functional movement tests have become popular screening tools in many sports, including professional football,[121, 166] as they purport to be able to identify players at risk of injury.[29, 168] Given an injury is unlikely to result from a single risk factor,[170] these tests assess the athletes on fundamental movement patterns that simultaneously measure range of motion, stability, balance and strength. The aim is to identify limitation in these movements, which is believed to improve the sensitivity and specificity in identifying athletes at risk of injury.[47, 175] Cook et al[46] argued that muscle flexibility and strength imbalances might not be identified during the traditional assessment methods in musculoskeletal component of PHE. However, it is suggested that these risk factors could be identified by functional movement tests.[47] If athletes who display 'poor' movement pattern have a greater risk of injury than those who display 'good' movement patterns, then these test may be an important component of injury prevention strategies.[168] It is also argued that decreased movement quality resulting from decreased range of motion and reduced neuromuscular control increases the risk of an overuse injury.[143, 150]

The FMS and the 9+ test are two functional movement tests aimed at identifying limitations in fundamental movement patterns predisposing athletes to injury, of which the FMS is the test in most widespread clinical use and which has attracted considerable research attention since the start of this project in 2013 (Table 1). The FMS consists of 7 movement tests and three clearing tests, assessed by visual observation using standardised scoring criteria. Each movement test is scored on a 4-point scale (0-3) with a maximum composite score of 21 points. The reliability of the FMS seems established with three recent systematic review reporting acceptable intra-rater and inter-reater reliability for the composite score and also the individual tests.[29, 57, 179]

The popularity of the FMS as an injury prediction tool originates from a study of Kiesel et al[136] in 2007. In a prospective cohort of 46 US National football league (NFL) players tested in the pre-season, 13 sustained a severe injury (> 3 weeks absence from training and match play). They identified a cut-off point of ≤14 to predict injury with a specificity of 91% and a sensitivity of 54%, and an odds ratio of 11.67. This means that, if an athlete scores at or below 14, the athlete was at 11-fold increased risk of injury compared to those with a score above 14. They further reported that having a positive FMS test score (≤14) increased the probability of suffering a serious injury from 15% to 51%, concluding that players with a low FMS score were at significantly higher risk.[136]

Since the study of Kiesel et al,[136] many studies have attempted to verify the findings of Kiesel (step 2 in Bahr's[13] validation of a screening test) across a variety of sports and occupational settings, with an increasing number of studies the past two years. We identified 26 prospective studies (19 of these from the past two years) from a search strategy including an automatic search (since the start of this project in February 2013 to 27 January 2018) on Google Scholar for any studies on functional movement tests or functional movement screen test, a systematic search on PubMed (search syntax: "Functional movement screen" AND (injur* OR injury prediction OR injury risk OR injury prevention screening), final search 27 January 2018), and hand search of studies included in the three systematic reviews that has been published on the emerging literature of the FMS since 2015 (Table 1). The results are conflicting with seven[105, 136-138, 151, 186, 223] out of the 26 studies supporting the results of Kiesel et al,[136] whereas the remaining 18 studies do not support the injury predictive ability of the FMS. Two out of three systematic reviews that have synthesized the emerging literature on the FMS drew similar conclusions; the FMS does not allow clinicians to predict injuries.[66, 180]

The first review by Dorrell et al[66] in 2015 included seven prospective cohort studies, while Bonazza et al[29] in 2016 included nine prospective studies in their review. The most recent review of Moran et al[180] is the largest review to date with 24 prospective studies included. Although these systematic reviews have synthesized some of the same studies (n=9)[37, 41, 67, 105, 136-138, 186, 244], the conclusions of Bonazza et al[29] differs from those of Dorrel et al[66] and Moran et al.[180] Bonazza et al[29] supports the injury predictive value cut-off ≤14/21 of the FMS whereas, the other two systematic reviews do not support the use of FMS as an injury prediction tool. Specifically, Dorrel et al[66] reported that a cut-off of ≤14/21 only provided a sensitivity of 24.7% and a specificity of 85.7%, with an area under the curve (AUC) indicating that the overall diagnostic accuracy of the FMS is only slightly better than chance (AUC 0.58). Noted that Bonazza et al[29] did not assess the individual studies for risk of bias and instead pooled all studies regardless of quality in their review.

Out of the 26 prospective studies listed in Table 1, only six studies have investigated the injury prediction validity of the FMS among football players,[117, 185, 207, 209, 216, 257] and they all report no association between FMS composite score and injury risk. Newton et al[185] determined their own respective cut-off score in a population of premier academy youth players. They identified the same cut-off point as Kiesel et al,[136] but found the discriminative ability (AUC) of the FMS was no better than chance.[185] However, none of these studies included professional senior football players nor were they adequately powered to detect anything but strong to moderate associations (>200 injury cases are required to detect small associations). Also, only one study by Hammes et al[117] used a multivariate statistical approach to account for potential confounding factors. They are also the only study that has accounted for exposure in their analysis.[117]

To fill the gap for tests challenging dynamic trunk flexors, rotation of the spine and more demanding test for knee control, Frohm *et al*[100] developed the 9+ test in 2012. In addition to six tests from the FMS, they added one functional movement test from the United States Tennis Association high-performance profile (one-legged squat),[1] two tests for dynamic trunk flexors and rotation of the spine, and two tests challenging knee control (knee abduction) and strength (deep one-legged squat and drop jump test) to comprise a battery of 11 movement tests with a maximum total score of 33.[100] The test is scored on a 4-point scale as the FMS. However, the scoring criteria for the six tests from the FMS were modified. It was expected that the addition of these five tests may strengthen the battery as an injury prediction tool for different injury types, as well across a variety of sports. Also, it was believed the modified scoring criteria from the FMS may increase the sensitivity of the test to differentiate good movement pattern from poor movement pattern.[93] Therefore, we chose to examine this test battery in our project. Frohm *et al*[100] reported good inter-rater (ICC 0.81) and intra-rater reliability (ICC 0.75) of the 9+ total score in an initial study of 26 Swedish elite football players. Noted that in this study only nine out of elven test were investigated (not included were deep one-legged squat and drop jump test). However, its validity as an injury prediction tool and its cut-off point maximising sensitivity and specificity has not been examined. No prospective studies on the 9+ were identified in literature search on google scholar and PubMed using the search terms: (9+ screening battery or "nine test screening battery") AND (injur* OR injury prediction OR injury risk OR injury prevention screening) (updated search conducted 27 January 2018). The aim of Paper III was to determine these properties.

Table 1. Prospective studies on the injury predictive validity of the FMS (n=26)

Author, year	Study population	N	Age (SD)	Injury definition, type	FUP period	FMS cut-point	# Injuries	Association between scores and injury (95% CI)	Sensitivity/ Specificity	AUC	LR+
American football											
Kiesel et al, 2007[136]	Prof., males	46	NR	TL (≤3 weeks)	4.5 months	≤14	13	OR=11.67 (2.47-54.52)	Sn=0.54 Sp=0.91	NR	5.92
Kiesel et al, 2014[137]	Prof., males	238	NR	TL, 'any'	1 pre-season	≤14	60	RR=1.87 (1.20-2.96)	Sn=0.26 Sp=0.87	NR	NR
Wiese et al, 2014[249]	NCAA Div. I athletes, males	144	18.9 (1.3)	MA, TL (≥1 day), overuse and non-contact	1 season	≤ 17	93	OR=1.425 (0.6-3.2)	NR	NR	1.154
Football (soccer)											
Rusling et al, 2015[207]	Prof. academy, males	135	13.6 (3.3)	'Any', all non-contact	1 season	≤14	54	OR=1.125 (0.47-3.43)	NA	NA	NA
Zalai et al, 2015[257]	Elite male	20	23 (3.0)	?	6 months	NR	16	NSD	NA	NA	NA
Hammes et al, 2016[117]	Veteran males	238	44 (7)	TL, all & non-contact	9 months	NA	All=67 NC=47	All: HR=0.93 (0.85-1.01) NC: HR=0.92 (0.83-1.02)	NR	All=0.56 NC=0.55	NR
Schroeder et al, 2016[209]	Amateur, males	96	23.7 (3.5)	TL (≥3 days), LE non-contact	10 weeks	NA	8	P= 0.373	NA	NA	NA
Smith et al, 2016[216]	Semi-prof., males	89	23.2 (4.4)	TL, all non-contact	1 season	≤14	66	OR=0.63 (0.19-2.07)	Sn= 13% Sp= 82%	NR	NR
Newton et al, 2017[185]	Premier youth academy, males	84	13 (1.3)	TL, non-contact (all, overuse and SI)	1 season	≤15 (all, severe) ≤14 (overuse)	All=38 Overuse=24 SI=11	All: OR =1.16 (0.92-1.47) Ovr: OR= 1.26 (0.97-1.64) SI: OR=1.06 (0.76-1.48)	NR	All=0.59 Ovr=0.63 SI=0.52	All=0.66 Ovr=0.71 SI=1.28
Other team sports											
Dossa et al, 2014[67]	Jr. ice hockey players, males	20	16-20	TL (≥1 game), 'any'	1 season	≤14	17	NSA	Sn=0.5 Sp=0.7	NR	1.67
Azzam et al, 2015[11]	Basketball (NBA), males	34	NR	TL ≥1 week, overuse and trauma	4 seasons	≤14	17	P=0.16	NA	NA	NA

Martin et al, 2016[162]	Jr. cricket pace bowlers, males	27	16.8 (1.7)	MA, TL, 'any'	1 season	≤14	10	OR=2.18 (0.24-6.67)	Sn=0.2 Sp=0.65	NR	NR
Tee et al, 2016[223]	Prof. rugby union, males	62 (90 FMS)	NR	TL ≥28 days, 'any'	6 months over 2 seasons	≤13/14	26	OR=5.2 (2.0-14.0)	Sn=0.62 Sp=0.77	0.73	NR
Bond et al, 2017[30]	Collegiate basketball, males and females	119 (63M, 56F)	M: 21 (1.4) F:20.2 (1.4)	TL ≥0 days, all MSK and non-MSK injuries	1 season	≤14	56	OR=1.0 (0.36-2.80)	Sn=14.2% Sp=85.7%	0.46	NR
Duke et al, 2017[71]	Rugby union, males	68	22 (3)	TL, 'any'	4 months (1/2 season)	≤14	48	OR=10.42 (1.28 - 84.75)	Sn=0.36 Sp=0.90	NR	3.58
Multiple sports											
Chorba et al, 2010[41]	Collegiate (sc, bb and vb)	38	19.2 (1.2)	MA, ?	1 season	≤14	18	p=0.0496 (fisher extract), OR=3.85 (0.98-15.13),	Sn=0.58 Sp=0.74	NR	2.2
Letafatkar et al, 2014[151]	Students, females and males (sc, hb and bb)	100 (50M, 50F)	18-25	TL ≥1 exposure, any LE injury	1 season	≤17	35	OR=4.70	Sn=0.645 Sp=0.780	NR	2.46
Garrison et al, 2015[105]	Collegiate, males and females (sw/dv, rb and sc)	160	17-22	MA, any	1 season	≤14	52	OR=5.61 (2.73 – 11.51)	Sn=67% Sp=73%	NR	2.51
Warren et al, 2015[244]	College, males and females (bb, cc, afb, gf, taf, tn, vb, sc and sw/dv)	167 (89M, 78F)	18-24	MA, acute non-contact and overuse	1 season	≤14	74	OR= 1.01 (0.53 – 1.91)	Sn= 0.54 Sp= 0.46	0.48	NR
Mokha et al, 2016[177]	NCAA Div II (rw, vb and sc), males and females	84 (20M, 64F)	M: 20.4 (1.3) F: 19.1 (1.2)	MA and TL, any	1 academy year	≤14	38	RR=0.68 (0.39 – 1.19)	Sn=26.3% Sp=58.7%	NR	NR
Dorrel et al,	NCAA Div II	257	18-24	TL; MI, OI and	1 season	≤15	MI 117	MI: OR=1.51	MI: Sn=62%	0.54	1.21

2017[65]	(afb, vb, bab, sb, bb, tn, taf, sc)	176M, 81F)		SI			OI 124 SI 20	(0.92 – 2.48) OI: OR=1.51 (0.92 – 2.48) SI: OR=1.50 (0.58 – 3.9)	Sp=49% OI: Sn=61% Sp=49% SI: Sn=65% Sp=49%	0.56 0.53	1.21 NR
Individual sport											
Hotta et al, 2015[128]	College runners	84	20.0 (1.1)	TL ≥4 weeks, any but excl trauma injuries	6 months	≤14	15	OR = 3.0* (0.8 – 11.6)	Sn=0.73 Sp=0.46	0.65	NR
Military											
O'Connor et al, 2011[186]	US Marine Corp. officer candidates	874; LC 427, SC 447	LC: 23 (2.6) SC: 21.7 (2.6)	MA, overuse and trauma	38 days; 68 days	≤14	LC: 151 SC: 120	LC: RR=1.65 (1.05 – 2.59) SC: RR= 1.91 (1.21 – 3.01)	Sn=0.45 Sp= 0.71	NR	NR
Knapik et al, 2015[138]	US coast guard cadets, females and males	1045; 770M, 275F	M: 18.1 (0.7), F: 17.9 (0.7)	MA, any	8 weeks	≤11 M ≤14 F	M: 146 F: 79	M: RR=1.64 (1.17 – 2.32) F: RR=1.93 (1.27 – 2.95)	M: Sn=22% Sp=87% F: Sn=60% Sp=61%	M: 0.53 F: 0.59	NR
Kodesh et al, 2015[139]	Soldiers, females	158	19 (mdn)	MA and TL≥2 days, any	3 months	≤12	97	OR=0.98 (0.87 -1.1)	Sn= 24% Sp= 83%	0.51	NR
						≤14			Sn= 42% Sp=63%		
Bushman et al, 2016[35]	Light infantry brigade (US Army), males	2476	18-57	MA, any, overuse and trauma	6 moths	≤14	Any: 920 Overuse: 698 Trauma: 388	A-RR=2.00** (1.42-2.81) O-RR=1.84 (1.63-2-09) T-RR=1.26 (1.03-1.54)	Any: Sn=33% Sp=82% Overuse: Sn=37% Sp=81% Trauma: Sn=28% Sp=77%	Any: 60% Overuse: 61% Trauma: 54%	A-PPV 52% O-PPV 43% T-PPV 19%

*From multivariate analysis adjusting for age, height, weight, running experience, weekly training sessions, weekly mileage, performance and injury history.
**From multivariate analysis adjusting for age, body mass index, smoking status, muscular and cardiorespiratory endurance (maximum push-ups in 2 min. and a 2-mile run for time).
FUP, follow-up period; AUC, area under the curve; LR+, positive likelihood ratio; PPV, positive predictive value; TL, time-loss; MA, medical attention; ?, injury definition unclear in the paper; OR, odds ratio; RR, risk ratio, NSD/NSA, no significant difference/ no significant association reported but no p-value provided; NA, not assessed; NR, not reported; Sn, sensitivity; Sp, specificity; Mdn, median; LE, lower extremity; MSK, musculoskeletal; MI, musculoskeletal injury; OI, overall injury; SI, severe injury; M, males; F, females; Prof., professional; Jr., junior; NBA, National Basketball Association; NCAA, National Collegiate Athletic Association; afb, American football; bb, basketball; bab, baseball; cc, cross-country; gf, golf; hb, handball; rb, rugby; rw, rowing; sc, soccer; sb, softball; sw/dv, swimming/diving; taf, track and field; tn, tennis; tn, tennis; vb, volleyball.

Reproducibility of the screening tests

The large variability of the screening tests in detecting injury risk might be explained by the lack of reproducibility of the tests, best expressed by the measurement error and the MDC.

Muscle strength tests

There are several reports on the test-retest reliability of standardised isokinetic testing, claiming high reproducibility if calibration, gravity correction and patient positioning are adequate and standardized, with ICC for quadriceps and hamstring strength ranging between 0.83-0.98.[167, 192, 201] Similarly high ICC values are reported for standardised hip strength testing for groin-related injuries in football with ICC ranging between 0.92-0.94 for bilateral adductor strength (squeeze test at 45° knee flexion)[61, 157] and hip eccentric abduction (ICC 0.86) and adduction strength (ICC 0.91) as tested with a handheld dynamometer and in sidelying.[227] However, the measurement error (SEM) has been reported between low to moderate 4.8 to 10.8% for isokinetic strength measures[192, 201] with a minimum improvement in the strength score (MDC) of about 21% for quadriceps muscle strength and 24% for hamstring strength.[192] Similar good measurement errors are reported for the squeeze test at 45° knee flexion (SEM, 1.6% to 7.3%), hip eccentric abduction (SEM, 5.1%) and adduction strength test (SEM, 6.3%),[61, 153, 157] with a MDC of 4.4% to 13.2%.[61, 153] These values should be considered when setting the cut-off values for predicting the athlete at risk.

For instance, Otten et al[192] reported on the reliability of isokinetic testing where subjects were tested on four occasions with a minimum of 48 h of rest between each testing session. A MDC of 20.6% for quadriceps peak torque and 24% for hamstring peak torque were reported.[192] Given the recommended cut-off of the mixed H:Q ratio of 0.89 for safe participation in professional football in the study of Crosier et al[54] described above (p 23), Otten et al[192] argued that these data suggests an error margin would be in the order of 0.01. The authors further argued that the MDC in their study indicates that this level of precision would be extravagant.[192]

Reproducibility of the functional movement tests

The reproducibility of the FMS and 9+ test has also been examined. A good to high correlation (ICC 0.60-0.92) scores have been reported in several studies investigating the intra-rater and test-retest reliability of the FMS in physically active populations and college athletes when retested after 2-7 days.[189, 212, 215, 224] Similar good intra-rater correlation (ICC 0.75) was reported by Frohm et al[100] on the 9+ total score among eight trained observes when 18 male elite football players were re-tested after 7 days. They reported no systematic change between the two test occasions, indicating that the player and tester performance was stable across test sessions.[100] Frohm et al did not report the measurement error and MDC for the 9+ total score. However they did report the measurement error of the eight physiotherapists, which ranged between 2.0-4.6.[100] There are only two studies on the FMS that has reported the SEM and MDC of the FMS. Onate et al[189] reported an SEM of 0.51 when 19 volunteer civilians were re-tested after one week. Tehyen et al[224] reported a measurement error within one point (SEM 0.98) and that a minimum improvement between two and three points on the 21-point FMS composite score was required to prove a real change over time. These scores may explain the inconsistent result of the FMS cut-off score of ≤14. It may be argued that a more conservative cut-off score of 16 to 17 (based on the MDC) would be more appropriate to increase the sensitivity of the FMS; however, the specificity would then suffer. If the 9+ test or FMS or any screening tests is to successfully identify the at-risk athlete from the athlete not at risk, it is paramount the test is stable (i.e low variability) over time. In paper IV, we wanted to assess whether the 9+ test as a potential injury prediction test is stable over time (over a season).

Aims of the thesis

The overall aim of this PhD project was to assess the benefits of PHE in professional male football players. I focused whether the musculoskeletal component of screening detected current health problems and predicted the athlete at risk of future injury.

The specific aims of the separate papers were:

1. To assess the prevalence of health conditions detected by a comprehensive PHE in professional male football players and to evaluate their consequences for participation clearance (Paper I).
2. To examine the association between hip and thigh muscle strength and the risk of lower extremity injuries in professional male football players (Paper II).
3. To examine the association of the functional movement test 9+ total score with lower extremity injuries in professional male football players, and to identify the optimal cut-off point to predict lower extremity injury risk (Paper III).
4. To examine the season-to-season variability of the 9+ test in a group of professional male football players (Paper IV).

Methods

The four papers included in this thesis are based on data collected from a pre-season PHE of professional male football players during two consecutive football seasons, 2013/14 and 2014/15, at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar, as well as a prospective injury registration during these two seasons. In paper I, we used a cross-sectional study design to evaluate the prevalence of musculoskeletal and medical conditions detected on a PHE during the 2013/14 or 2014/15 seasons. Paper II and III describes the value of muscle strength testing and the 9+ test in predicting lower extremity injury, using the test from the musculoskeletal component of the PHE and the subsequent prospective injury registration for the two football seasons included. In paper IV, we assessed the season-to-season variability of the 9+ by including all players with a 9+ test results for both PHE seasons (2013/14 and 2014/15).

Participants

All participants included were professional male football players eligible to play in the QSL during one or both of the 2013/14 and 2014/15 football seasons. The QSL includes 14 teams and the players are heterogenous in ethnic origin with the majority of players coming from the Middle East, Central and West Africa.

The players were invited to participate as they presented for their annual pre-season PHE at Aspetar Hospital. The PHE is part of the qualification procedure for all players eligible to play in the QSL and was performed mainly during the pre-season period (66.6%) (July through September). For logistic reasons, a small group completed the tests during the early/mid competition phase (23.8%) (October through December) each year and a minor group post-season (9.7%) (end of April through June) in 2014. The latter test results were used as pre-season data for the 2014/15 season.

A total of 575 professional male football players, representing 858 player-seasons, completed the PHE during the 2013/14 and/or 2014/15 seasons, and 565 players (838 players-seasons) were enrolled in the cohort. There were 273 players who repeated the PHE in the 2014/15 seasons, 84 players who were screened only in the 2013/14 season, whereas 208 were screened only in the 2014/15 seasons (new players in the QSL). For Papers II-IV, we excluded players who reported a current injury or physical complaint limiting training and match play at the time of the PHE in the analysis.

Periodic health evaluation process (data collection)

The PHE process was divided into two stages performed on the same day. Each team (20-30 players) was allocated 3 days for their PHE, booked at each team's convenience. Stage One consisted of a comprehensive history and general medical, cardiovascular and musculoskeletal examination (Figure 5). At Stage Two, all test results collected during Stage One were reviewed by a sport physician and medical clearance was determined. All players had to complete both stages to be eligible to play in the QSL the following season. Paper I included all data from Stage One and Two of the PHE. As the focus of the current thesis was on the benefit of musculoskeletal PHE, data from musculoskeletal examination performed at Stage One of the PHE was included for Paper II-IV (Figure 5). After the baseline musculoskeletal screening tests, all injuries occurring during football training and match play throughout the 2013/14 and 2014/15 pre-seasons and seasons were recorded prospectively through the Aspetar Injury and Illness Surveillance Program (AIISP). During the two study seasons, a total of 1017 injuries (898 to the lower extremity and 119 to the upper extremity, trunk, head/neck) in 380 players were recorded. These data were used to investigate the value of muscle strength testing (Paper II) and 9+ test (Paper III) in predicting lower extremity injuries, and to investigate the season-to-season variability of the 9+ test in Paper IV.

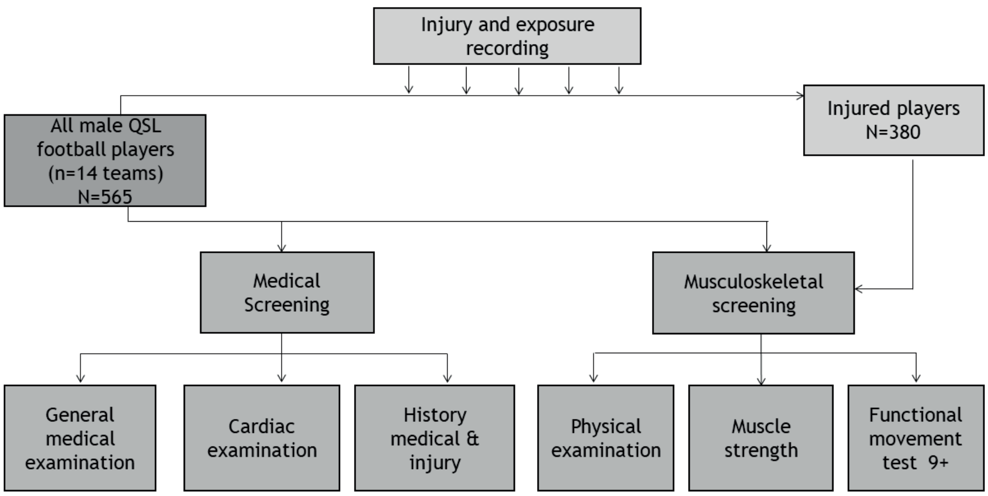


Figure 5. Flow chart of the data collection process during the study years, 2013-2015

The periodic health evaluation

Patient history

History regarding previous injury, general medical complaints, cardiovascular family history and (personal) symptoms was completed using the FIFA Pre-Competition Medical Assessment (PCMA) form,[72] and was undertaken by a sports medicine nurse. The general medical history included questions regarding respiratory, gastrointestinal, rheumatological symptoms, infections and concussion history. In addition, the players were asked about alcohol consumption and smoking, and eye sight (i.e. if wearing glasses or contact lenses). Cardiovascular history included questions regarding family history of SCD and coronary heart disease, as well as personal cardiovascular symptoms (e.g. syncope, palpitations/arrhythmias, dizziness). History of previous injuries included questions regarding previous groin strains, quadriceps femoris muscle strains, hamstring strains, knee and ankle ligament injuries. In addition, questions regarding any surgery and current complaints or pain in the lower extremity were also recorded. The standardised PCMA form only requires previous severe injury leading to more than four weeks of limited participation or absence of training or match play to be recorded. However, as a standard among our sport physicians, they also recorded injuries leading to less than four weeks of absence. For the purposes of Papers II and III, all previous injuries to the lower extremity sustained within the previous year (or 12 months before the PHE) were included for the analysis. Personal data such as age, date of birth and player position were also recorded on the PCMA form.

General medical screening

The general medical examination was undertaken by a sport medicine nurse and included a visual acuity assessment, measurements of height (m) and body mass (kg), respiratory function testing (spirometry (FEV, FEV_1, PEF, FEV_1/FVC)), chest x-ray if clinically indicated and laboratory blood tests. Fasting blood and urine were sampled by a qualified phlebotomist, and underwent immediate analysis (Table 2).

Table 2. Laboratory blood analyses performed in PHE

			Selected reference range*†
Haematology	Complete blood count (CBC)		
	Ferritin		26-388 ug/L
	C-reactive protein (CRP)		<9.1 mg/L
	Erythrocyte sedimentation rate (ESR)		
Serology	Hepatitis B		Reactive or non-reactive
	Hepatitis C		Non-reactive
	Human Immunodeficiency virus (HIV)		Negative
Renal function	Urine analysis dipstix (protein, blood, glucose)		Negative
	Creatinine		71-115 umol/L
Cardiovascular	Fasting lipids	Total cholesterol	<5.2 mmol/L
		Triglycerides	<1.7 mmol/L
		HDL	1.04-1.55 mmol/L
		LDL	<2.60 mmol/L
	Fasting glucose		4.1-5.9 mmol/L
Bone/muscle	Vitamin D, 25(OH)[3]	Severe deficiency	<10 ng/mL
		Deficiency	10-20 ng/mL
		Insufficiency	20-30 ng/mL
		Sufficiency	>30 ng/mL
	Calcium		2.12-2.52 mmol/L
	Corrected calcium		
	Alkaline phosphatase		50-136 U/L

*Reference ranges were those of the Laboratory Department of Aspetar Orthopaedic and Sports Medicine Hospital. These ranges were derived from several hundred athletes tested over an extended period of time and verified for use with this patient population.
†All reference ranges are available in supplementary table S1 (Paper I in the Appendix)

Cardiovascular screening

The cardiovascular examination was based on the European Society of Cardiology (ESC) Sport's Cardiology Section Consensus statement, and included a physical examination, ECG and echocardiography.[199] Bilateral brachial artery blood pressure, heart rate and precordial auscultation in supine and standing positions were examined by an experienced sports medicine physician.[199] A standard 12-lead ECG (GE MAC 5500,New York, USA) was obtained by a cardiac physiologist after a period of 5 min rest in the supine position. All ECGs were interpreted by an experienced sports cardiologist using the 2012 Seattle ECG criteria.[69] Echocardiography was performed by an experienced sports cardiologist and according to protocols previously published for high-level athletes.[193] All players completed both an ECG examination and an echocardiography as standard.

Players with symptoms, a family history of heart disease and/or SCD, or echocardiographic and/or ECG abnormalities indicating possible cardiac pathology were investigated further as indicated (24 h ECG, maximal exercise testing and/or cardiac MRI).

Musculoskeletal screening

Players were assessed on a comprehensive musculoskeletal test battery aimed at the identification of potential biomechanical and anatomical risk factors for lower extremity injuries, particularly hamstring and groin injuries.[78] The examination included hip and thigh muscle strength, flexibility, hip/groin pain provocation tests and the 9+ test (Table 3).[100, 136, 181, 230] In random order, players completed all tests at the Rehabilitation department at Aspetar Hospital performed by experienced sports physiotherapists. In addition to the musculoskeletal examination, all players underwent a general musculoskeletal examination by a sports physician using the FIFA PCMA clinical examination form[72] at Stage Two. Paper I included both the musculoskeletal test battery and the FIFA PCMA musculoskeletal examination, whereas Papers II-IV included only data from the hip and thigh muscle strength tests and the 9+ test. The reason for including only the hip and thigh muscle strength tests and 9+ was that these tests are the two most commonly utilized screening tests in professional football.[166] For Paper I the evaluation criteria as in Table 3 made the basis for the sport physicians evaluation at Stage Two. In Papers II-IV, we used the actual strength values (peak force) and 9+ total score for analysis.

Table 3. The comprehensive musculoskeletal examination and evaluation criteria for each test.

	Type of testing	Tests	Evaluation criteria*
Hamstring and Quadriceps muscle	Isokinetic muscle strength	Concentric knee flexion and extension at 60^0/s and 300^0/s	Normal Minor abnormal: ±1SD Major abnormal: ±2SD
		Eccentric knee extension 60^0/s	Normal Minor abnormal: ±1SD Major abnormal: ±2SD
	Flexibility	Hamstring AROM and PROM	Normal Abnormal: ±1SD
Hip and groin examination	Pain provocation tests	Hip adduction squeeze test in 0^0 and 45^0	Normal Abnormal: pain
		Impingement test	Normal Abnormal: Pain
		FABER test	Normal Abnormal: Pain
	Joint ROM and flexibility	Hip internal rotation in 90^0	Normal Abnormal: ±1SD
		Hip external rotation in 90^0	Normal Abnormal: ±1SD
		Hip internal rotation in prone	Normal Abnormal: ±1SD
		Bent knee fall out	Normal Abnormal: ±1SD
		ROM hip abduction side lying	Normal Abnormal: ±1SD
	Muscle strength	Eccentric hip adduction	Normal Abnormal: ±1SD
		Eccentric hip abduction	Normal Abnormal: ±1SD
Lower leg and ankle	ROM and flexibility	Ankle dorsiflexion lunge	Normal/abnormal
Functional movement test		9+ screening battery‡	Normal: ≥22 of 33 Abnormal: ≤21 of 33

*Evaluation criteria, based on normative data on QSL players from previous years, tests were considered abnormal if more than one standard deviation (SD) from the mean.
‡The 9+ test was considered abnormal if the total score was below 67% of the maximum score.[100, 136]
AROM, active range of motion; PROM, passive range of motion; FABER, flexion, abduction, external rotation; ROM, range of motion

The musculoskeletal test team

To complete all musculoskeletal tests for each player within one day of testing, we required a total of 7 sports physiotherapists designated to the test stations each day during the screening period each season. All testers worked at Aspetar Hospital or in the National Sports Medicine Programme (NSMP), a division of Aspetar Hospital. All teams participating in the QSL are provided with medical services by the NSMP. All testers received a minimum of 5 h of training in the hip and thigh test methods. For the 9+ test, all testers underwent a two-day course of the 9+

prior to testing. In addition, all the physiotherapists had to be performing the 9+ regularly in their clinical practice.

Throughout the two years of screening (2013/14 and 2014/15), a total of 20 sport physiotherapists were involved in performing the musculoskeletal screening tests, of which 14 performed the 9+ test. We aimed for consistency and most of the testers participated each season. Given the use of multiple testers and to ensure reliable results from the test battery, we measured the inter-tester reliability of our testers for the 9+ test (Paper IV). The inter-tester reliability for the hip/groin assessments was measured by Mosler et al[181] on the same cohort as the present thesis, demonstrating moderate to good inter-tester reliability (ICC 0.66-0.84) for the hip strength measurements included in Paper II.

Muscle strength tests (Paper II)

For Paper II we included the three hip and thigh strength tests from the musculoskeletal examination, isokinetic quadriceps and hamstring muscle test, hip eccentric abduction and adduction and bilateral adductor test (squeeze test at 45^0 knee flexion), to investigate their ability to predict lower extremity injury. Before the strength tests, the players performed a self-selected 5-10 min warm up routine, consisting of either light running or cycling on a stationary exercise bike (Bike Forma, Technogym®, Cesena, Italy), most players preferring cycling. We randomized the test order for each strength test and leg (left, right). We obtained information on leg dominance prior to testing and defined the dominant leg as the limb preferred for a penalty kick.

Quadriceps and hamstrings strength

Maximal isokinetic knee flexion and extension were tested using an isokinetic dynamometer (Biodex Multi-joint System 3; Biodex Medical Systems Inc. NY, USA). We used a standardised protocol comprised of three different modes and speeds, as previously described.[230, 237] The axis of rotation of the dynamometer was individually aligned with the knee joint, and the hip angle at 90°. We used straps around the thigh, waist and trunk to minimize secondary joint movement. After an explanation of the testing methodology, players were first tested over five repetitions of concentric knee flexion and extension at 60 °/s. This was followed by 10 repetitions of concentric knee flexion and extension at 300 °/s. Finally, players performed five repetitions of eccentric knee extension at 60 °/s. Accordingly, we calculated hamstring-to-quadriceps ratios (H:Q-ratio) for the same mode and speed of the concentric contraction, and a mixed ratio from hamstring eccentric at 60 °/s to quadriceps at 300 °/s. The highest peak torque (Nm) observed from all repetitions performed for each of the three different tests was recorded. Between each mode of testing a minimum of 60 s of rest was provided. The isokinetic muscle strength testing has been established as a reliable tool for assessing muscle force with ICC of 0.83-0.96.[192, 201]

Hip strength

Hip eccentric adduction and abduction test. We measured maximal eccentric hip adduction and abduction strength with a break test, using a handheld dynamometer (PowerTrack ll Commander, JTECH Medical, Midvale, Utah, USA) and with the player in a side-lying position as previously described.[181, 227] The leg being tested was placed in a straight position, in line with the body, and the contralateral leg in 90° hip and knee flexion. Players held their hands on the side of the examination table to stabilize themselves during the testing. We applied resistance in a fixed position 8 cm proximal to the most prominent point of the lateral malleolus, and the player exerted a 3 s maximum isometric contraction against the dynamometer, followed by a 2 s break performed by the examiner. The player was given one practice trial followed by three tests, with a minimum of 30 s rest between each test. We recorded the maximum score (N), and also calculated an adduction-to-abduction (ADD:ABD) ratio for analysis.[181]

Adductor squeeze test (bilateral adductor test). Maximal isometric adductor squeeze strength was measured using the handheld dynamometer and the player in a supine position. We placed the dynamometer between the player's knees with the hip flexed at 45° and feet flat on the table, and players pressed knees together against the handheld dynamometer with maximal force without lifting the legs or pelvis. The player was allowed one test trial followed by one maximum trial, which was recorded for analysis (N). A detailed description of the test is given by Mosler et al.[181]

Functional Movement test 9+ (Papers III and IV)

9+ procedure

The 9+ test comprises 11 functional movement exercises to assess stability, mobility, and neuromuscular control in the kinetic chain, and was performed as described by Frohm *et al.*[99, 100] The exercise items are the deep squat, in-line lunge, active hip flexion, trunk stability push-up, diagonal lift and shoulder mobility (all from the FMS with modified criteria) and one-legged squat, deep one-legged squat, straight leg raise, seated rotation and drop jump test. Seven of the 11 tests are assessed bilaterally (one-legged squat, deep one-legged squat, in-line lunge, active hip flexion, diagonal lift, seated rotation, shoulder mobility), looking for asymmetries between left and right. For these tests, the left extremity was tested first and the lower of the two scores for the left and right side was used for data analysis. Each movement test was scored on a four-point ordinal scale (3-0), with 3 representing correct completion of the task with no compensatory movements, 2 correct but with presence of compensatory movement, 1 not correct despite compensatory movements, and 0 if pain was present. Thus, each player could reach a maximum score of 33 points.

All players performed the tests barefoot, with shorts and a t-shirt, except for the drop jump test. As described by Frohm *et al*,[99] the players wore their own training shoes for this test. Due to equipment availability, the participants performed the drop-jump test from a 30 cm box, not a 40 cm box height as described by Frohm *et al*.[99] The physiotherapists gave a standardised verbal instruction, and showed the player a photo of the starting and finishing position of an optimally performed exercise. Each player performed each test 3 times, and the maximum score achieved was recorded and used for evaluation of test performance. Verbal corrections were given during the three trials to achieve the most optimal performance. The complete assessment took 20-30 min to complete. All testers and players were blinded to the player's score from test occasion 1 (season 1[2013/14]) and test occasion 2 (season 2[2014/15]), and no specific intervention was advised based on 9+ score from test 1 (Paper IV).

Inter-tester reliability of the 9+ (Paper IV)

We measured the inter-tester reliability for the 14 physiotherapists performing the 9+ in a sub-group of 63 randomly chosen players during the screening setting in the 2014/15 season. The inter-tester reliability for the total score and each test was examined with two testers from a randomly selected pool of 8 of the 14 physiotherapists (4 of these were involved in testing both seasons, 4 in the 2014 tests only). The testers were blinded for each other's 9+ score.

Evaluation and clearance status (stage two)

At stage two of the PHE, a sport physician evaluated all results from the medical, cardiovascular and musculoskeletal examination. The clinical findings detected were documented on a report form, and the physician noted if there were any abnormalities. A diagnostic code (the Sport Medicine Diagnostic Coding System[172]) was assigned (if possible) to each finding and recommended management recorded as free text. Based on the interpretation of the results, the sport physician determined whether to give the player medical clearance or to withhold it. Clearance was given if clinical findings were considered to have no, minimal, or mild risk for the player's future health. Clearance was temporarily withheld when clinical findings were considered as a moderate risk to the player's health (usually requiring further investigation or treatment). Permanently not cleared was reserved for a player diagnosed with a health condition considered unsafe for participation in competitive football. At the end of stage two, the test results were discussed with the player and club doctor and the report form was given to the club medical staff. Data from the Stage two of the PHE made the basis for the analyses in Paper I.

Injury and exposure registration (Papers II-IV)

We obtained injury and exposure data from the AIISP, which includes prospective injury and exposure recording from all 14 QSL teams. As all club medical doctors and physiotherapists are part of the centrally regulated NSMP, it allowed for standardisation of injury and exposure recording. The team physician for each team recorded all injuries and individual training and match exposure daily throughout the 2013/14 and 2014/15 pre-season and season (July-May; 44 weeks). Injury and exposure data were passed on to the study group each month and the accuracy was checked regularly and clarified with the team doctor as needed.

The consensus statement on injury registration in football served as the basis for injury recording, and a time-loss injury definition was used.[101] An injury was recorded if the player was unable to fully participate in football training or match play at least one day beyond the day of injury.[101] The player was considered injured until declared fit for full participation in training and available for match selection by medical staff. For each injury recorded, the team physician completed a standardised injury card containing information on the body part injured, injury type and injury aetiology (acute or overuse). Acute and overuse injuries were defined according to the consensus statement on injury definitions and data collection procedures in studies of football injuries.[101] An acute injury was defined as an injury resulting from a specific, identifiable event, and an overuse injury as an injury caused by repeated micro trauma without a single, identifiable event.[101] In addition, the injury card included questions related to re-injury, injury mechanism (contact or collision), as well as information on whether the injury occurred during training or a match. Injury severity was determined by the number of days of absence from matches or training sessions due to injury and was classified as mild (1-3 days), minor (4-7 days), moderate (8-28 days) or severe (>28 days).[74] We included all injuries (upper and lower extremity injuries) occurring during the intervening season (2013/14) between the two 9+ test in paper IV, whereas only lower extremity injuries were included in Paper II and III. Exposure data were not included in Paper IV, as the purpose of this paper were to assess the variability in the 9+ test between two consecutive seasons.

Statistical analysis

Data were analysed using SPSS version 21 (Papers III and IV) or 24 (Paper II) (IBM Corp., Armonk, NY, USA), Stata Statistical Software (STATA version 11.0, StataCorp, College Station (Texas), USA) (Papers II and III) and Excel (Microsoft Excel 2010 for Windows, Microsoft Office Professional Plus, v14.0.7147.5001, California, USA) (Paper I). In all papers, descriptive data were presented either as means ± standard deviations (SD) or frequency and percentage.

Paper I

Data management

The clinical findings documented on the report form from Stage two of the PHE made the basis for the analyses. Therefore, data were included only for those players who completed both Stage One and Two of the PHE. We defined a health condition as any condition sufficient to require either treatment, further investigation, or recommendation to follow-up.

To analyse the data, we created a database in Excel where we entered all data collected from the PHE, injury and medical history, clinical examination data, and data from the report form. In the case of abnormal cardiovascular findings, detailed information on ECG, echocardiography, clinical examination and results of follow-up tests were also entered.

Based on the physician's diagnosis and/or clinical findings on the report form, the general medical and musculoskeletal findings were classified post-hoc by the principal investigator of this study and the head physician at the Aspetar Screening Department, into groups based on the IOC consensus statement on PHE of elite athletes and IOC injury and illness surveillance protocol for analysis.[85, 132, 154] Haematology data was classified by the authors into two categories: iron deficiency (serum ferritin < 30) with or without anaemia (haemoglobin lower than laboratory normal range) and other CBC alterations. We also grouped infection/immunology into hepatitis B and other infective immunology. Health conditions not fitting the categories were classified as 'other'. The musculoskeletal findings were classified according to body part and type of condition, grouped as current problem (injury or current physical complaint), abnormal finding on examination or positive history (previous injury or physical complaint reported on history taking).

Analyses

Descriptive statistics presented as mean values with standard deviations or frequencies reported as absolute numbers with percentages were used to evaluate the prevalence of musculoskeletal injuries and medical conditions detected on a PHE.

Paper II and III

The same statistical method was used for papers II and III, which were based on all players completing the muscle strength tests (Paper II) and 9+ test (Paper III) for one or both of the 2013/14 and 2014/15 football seasons, and who had injury and exposure recording for the subsequent seasons. We calculated the individual exposure data as the sum of the total number of hours of training and match play from the date of screening until the end of each season or until the date of the first injury. Univariate and multivariate Cox regression analyses were used to examine the relationship between any lower extremity injury (yes/no) with muscle strength (Paper II) and 9+ total score (Paper III) and other potential risk factors (anthropometric data, player position, previous injury, season, dominant leg [Paper II only]), with each leg (Paper II) or player (Paper III) as the unit of analysis. We only included the player's first lower extremity injury, and a bilateral injury was included in the analyses as an injury sustained to both legs (Paper II). In paper II, strength measures were presented as absolute (peak torque for the quadriceps and hamstring strength tests and peak force for the hip strength tests) and body mass normalised values. The eccentric hip abduction and adduction strength measures were normalised to body mass and lever arm (Nm/kg).[181, 227] Legs with missing data for all three strength tests were excluded from the final analyses (Paper II).

The muscle strength test (Paper II) and 9+ test score (Paper III) for each season was used as a predictor for injury (yes/no) for that respective season. To account for the repeated measures performed over the two seasons, as well as the fact that not every participant had the same number of measurements (i.e. some participants would have test results for both seasons, some for only one season), we used player identity to cluster the related observations when estimating the Cox model. Similar and separate analyses were performed for assessing the relationship between muscle strength scores and acute lower extremity, overuse lower extremity and knee injury (including knee ligament, meniscus or cartilage injuries) (Paper II), and 9+ total score and injuries to the hip/groin, thigh, knee, lower leg and ankle. We excluded injuries to the foot/toe from these analyses because of the low number of such injuries (n=19) (Paper III). The hazard ratios (HRs) presented with 95% CIs were per 1-unit of change in the independent continuous risk factor (muscle strength, 9+ test, anthropometric data). For categorical variables (season, position, previous injury history and dominant leg), the HR represented the change in risk when compared to the reference category. After the univariate analyses, all factors with a *P* value of <.20 were investigated further in a backward stepwise multivariate model to evaluate potential predictor variables. The significance level was set at *P* <.05.

We calculated ROC curves to describe the sensitivity and specificity of the 9+ test for each dependent variable (Paper III) or the identified significant association between a strength variable and outcome measure (Paper II). The area under the curve (AUC) indicates how well the muscle strength variable or 9+ total score would discriminate between injured and uninjured players and was interpreted as excellent (1.00-0.90), good (0.90-0.80), fair (0.80-0.70), poor (0.70-0.60), or fail (<0.60).[4, 173] In paper III, the ROC curve was also used to determine an optimal cut-off point for identifying high- and low-risk players for lower extremity injuries. Identified cut-offs with maximum sensitivity and specificity were further used as a factor in the Cox regression analysis as described above to evaluate differences in injury risk. We also calculated the positive likelihood ratio (LR+) (Paper III only). LR is a combination of sensitivity and specificity values reported as a ratio used to determine whether a test result usefully changes the probability that a condition exists.[169]

Paper IV

To measure the season-to-season variability of the 9+ test, the analyses were based on players presenting with a 9+ test result for both football seasons (2013/13 and 2014/15) and injury registration for the intervening football season. A paired t-test were used to test for systematic differences in the 9+ total score between test occasions. Significance level was set at p <0.05. The variability (random error) of the 9+ total score between tests was assessed using the intraclass correlation coefficient ($ICC_{1.1}$) with 95% CI, and SEM.[26, 245] The SEM was calculated from the square root of the mean square of the residual (MSr) term derived from the analysis of variance (ANOVA). The MDC with 95% certainty was calculated as SEM x 1.96 x $\sqrt{2}$.[141, 245]

Systematic differences and the variability of each movement tests between test occasions were also examined. As each movement test is measured on an ordinal scale, a non-parametric test (Wilcoxon signed rank test) and weighted kappa ($\varkappa_w$) were used.

The inter-tester reliability for the total score was analysed using $ICC_{1.1}$ with scores between 0.75 and 1.00 interpreted as good, 0.50 to 0.74 as moderate, and those below 0.50 as poor.[202] The $\varkappa_w$ was used to analyse the inter-tester reliability for each movement test with scores interpreted as follows: <0.20 as poor, 0.21-0.40 as fair, 0.41-0.60 as moderate, 0.61-0.80 as substantial and 0.81-1.00 as excellent.[148]

Ethics

The study was approved by the Institutional Review Board, Anti-Doping Lab Qatar (IRB project no E2013000003 and F2013000003). These approvals cover all the four included studies. All players signed a written informed consent form at inclusion for each season, permitting their data to be utilised for research. All data collected was treated confidentially.

Results and discussion

The PHE and detecting current health problems (Paper I)

The results are based on 558 players (age: 25.5 ± 4.8 years; height: 177 ± 7 cm; body mass: 72.3 ± 9.2 kg; BMI: 23.0 ± 2.0 kg/m^2) who completed both stages of the PHE at the beginning of 2013/14 or 2014/15 football seasons. Of these, 95.5% (n=533) were detected with at least one current health condition requiring further assessment, treatment or recommendation to follow up (Figure 6). General medical conditions (n=522, 93.5%) and musculoskeletal conditions (n=180, 32.3%) were the most prevalent health conditions detected, whereas 8.6% (n=48) were identified with a cardiovascular condition.

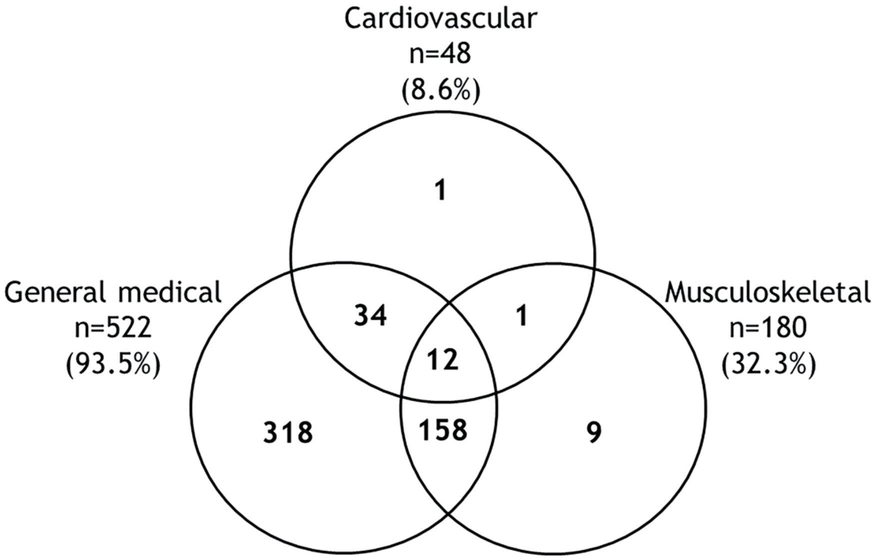


Figure 6. Venn diagram of players detected with one or more health conditions on the periodic health evaluation (PHE) (n=558).

General medical examination

Table 4 display the prevalence of all general medical conditions detected, and type of follow-up required.

Table 4. General medical condition detected and type of follow up required (n=558)

	Total conditions n	Total players %	Further investigations n	Treatment n	Prevention recommendation n	Repeat examination n
Vitamin D	499	89.4	-	496	3	0
Hepatitis B	164	29.4	4*	160	0	0
Lipids	59	10.6	-	-	47	12
Iron deficiency/anaemia	56	10.0	9	38	7	2
CBC alterations (other)	42	7.5	24	-	1	17
Vision	38	6.8	29	-	9	0
Urological	36	6.5	2	-	3	31
Endocrine/ metabolic	12	2.2	-	1	1	10
Pulmonary	12	2.2	8	2	1	1
Ear, nose, throat (ENT)	3	0.5	3	-	-	-
Infective/ immunology (other)	2	0.4	1	-	-	1
Dermatological	2	0.4	1	-	1	-
Neurological	2	0.4	1	1	-	-
Other	6	1.0	1	-	4	1
Total	933	167.3	83	698	77	75

* Hepatitis B, 4 of the players were seropositive. Three of the 4 were chronic carriers under long term follow up (one was lost to follow up) with normal or near normal liver function tests, whereas 1 was core antibody positive following previous infection.

Although a thorough discussion of each finding is beyond the scope of this thesis, most of the results confirmed expectations, based on clinical experience and previous epidemiological studies on Qatari athletes as well as epidemiological studies across different sport and ethnicities.

As shown in Table 4, Vitamin D deficiency or insufficiency (≤30 ng/mL) requiring treatment, mainly vitamin D supplementation, was the main reason for the high prevalence of health conditions detected in this study (89.4%). This prevalence of Vitamin D deficiency or insufficiency is consistent with previous findings on Qatari athletes,[113] but much higher than reported for athletes in western countries.[90] Cultural clothing and training outside of sun hours in Qatar are believed to be the main cause of Vitamin D deficiency or insufficiency in this population.

Whether to supplement athletes is a topic of debate.[43, 115] The role of vitamin D on performance, musculoskeletal health (injury risk, stress fractures), and it's role in immune function, inflammatory response and chronic and autoimmune disorders (i.e. hypertension, osteoarthritis, certain type of cancer) has increased clinicians' index of suspicion to detect deficiencies or insufficiencies upon which treatment can be initiated.[149, 203] Supplementing athletes with vitamin D levels below 25 ng/mL may improve performance and reduce injury risk;[43, 221] however, a 2013 systematic review on athletes across sports suggests there is limited evidence for an association between low vitamin D levels and injury risk or performance.[203] Also, there is currently no consensus on the 25 (OH) D cut-off values that define an optimum (in terms of optimum health) vitamin D status, neither for general health, for sport-specific benefits, nor for ethnicity.[161] Although it remains unknown at what level supplementation is beneficial for musculoskeletal health as well as non-skeletal health,[10] current consensus opinion recommends vitamin D levels in athletes to be above 30 ng/mL.[90, 149]

Hepatitis B non-immunity or infection, the second most frequent medical condition detected, was observed in almost one third of the players (Table 4). Our findings extend a previous study from our group showing that the prevalence of hepatitis B among sportsmen in Qatar is markedly higher than observed in Australian Rules footballers or sumo wrestlers.[116] Our study population includes many participants from countries where vaccination is not routine;[49, 116] regular screening for hepatic infection/ immunity is therefore beneficial in our athlete population.

One result that contrasted with prior research was the surprisingly low prevalence of respiratory and gastrointestinal (GI) symptoms (Table 4). Respiratory symptoms and GI problems are generally the most common complaint in elite athletes. [32, 73, 85, 191] The lack of cold air, minimal pollens in Qatar and the use of only general spirometry tests may explain the low prevalence of abnormal respiratory findings. On the other hand, Doha has high levels of air pollution.[248] The fact that PHE is only a snapshot in time and the limited in-depth questions on respiratory and GI symptoms in the standard PCMA may partly explain the low prevalence of GI and respiratory problems.

Although we detected a high prevalence of players with general medical conditions believed to be relevant for health and performance (n=522), only 12 (2.3%) of the players were temporarily restricted (not cleared) from competitive sport. All twelve players were given clearance after appropriate investigation.

Cardiovascular examination

Cardiovascular screening required 8.6% of the players to perform further investigations, mostly because of suspect anomalies on ECG (mainly T-wave inversion) and echocardiography (Table 5).

Table 5. Cardiovascular conditions detected and type of follow up required (n=558)

	Total conditions n	Total players %	Further investigations n	Repeat examination n
ECG	19	3.4	19	-
Echocardiography	14	2.5	14	-
History*	11	2.0	11	-
Blood Pressure**	8	1.4	7	1
Heart Rate	1	0.2	-	1
Total	53	9.5	51	2

*History, symptoms suggestive of cardiac disease (including dizziness and/or chest pain during exercise and/or syncope) and/or a family history of SCD in a first relative.
**Resting blood pressure ≥140/90 mm Hg

The discussion regarding routine inclusion of an ECG and echocardiography in the PHE of athletes is ongoing[114, 156, 195] because ECG is not a perfect instrument to differentiate physiological adaptation owing to sustained and intensive exercise from inherited or congenital cardiac pathology.[8, 69] Interpreting ECG results according to the 2012 Seattle criteria as opposed to the 2010 ESC recommendations has reduced the proportion of abnormal ECG markedly (17 to 4% and 29 to 11%).[21, 22, 205] Our data extend these findings in the setting of a football competition in the Gulf Region. The prevalence of 3.4% of players in our study having an ECG abnormality is lower than that reported by previous studies on footballers and athletes across sports.[28, 198] ECG revealed probable long QT syndrome in one player, who was advised against competitive football pending further investigation.

Echocardiography has been suggested as a supplementary investigation to improve the accuracy of cardiac screening and is mandatory for some FIFA and UEFA competition.[156] However, experts from Norway and Qatar contend its value is limited.[21, 204] We found that of the 2.5% (n=13) of players with an abnormal echocardiography one case of abnormal coronary artery origin was detected after follow up investigation. The player was advised not to play football as that is a life-threatening condition. This player had a normal ECG.

Although few players were identified with a cardiovascular condition requiring further evaluation, it was the main reason for temporary restriction from participation in football in Paper I. More than half (n=30, 62.5%) of the players identified with a cardiovascular condition were not given immediate clearance whilst further investigation was undertaken. After follow-up investigations, only one player (abnormal coronary artery identified on echocardiography as mentioned above) was permanently disqualified for competitive football; whereas one other player (possible long QT syndrome) was advised against competitive football.[70, 130]

Musculoskeletal examination

Our targeted comprehensive musculoskeletal examination focusing on the lower extremities identified at least one musculoskeletal condition necessitating follow-up, treatment or further investigation in more than 1 in 3 players. Injuries or substantial strength or flexibility deficits to the hip/groin and thigh accounted for the largest proportion (Table 6). This supports previous epidemiological studies which have documented that these are the most common injury locations among elite football players.[74, 78, 131] Interestingly, we found that the hip/groin was the region most frequently affected (n=62, 11.1%). This may be a reflection of the screening battery chosen, which did include a series of tests targeting the groin.

Table 6. Musculoskeletal conditions detected related to body part and type of condition (n=558)

Body part	Total conditions	Total players	Current problem	Abnormal finding	Injury history
	n	%	n	n	n
Neck/cervical spine	2	0.4	2	-	-
Sternum/upper back	1	0.2	-	1	-
Low back/pelvis	8	1.4	7	1	-
Shoulder/clavicle	5	0.9	4	-	1
Forearm	1	0.2	1	-	-
Wrist	4	0.7	4	-	-
Hip/groin	62	11.1	21	38	3
Thigh	56	10.0	13	42	1
Knee	32	5.7	20	5	7
Lower leg/Achilles tendon	9	1.6	4	5	-
Ankle	33	5.9	19	11	3
Foot/toe	2	0.2	2	-	-
Other	10	2.0	-	10	-
Total	225	40.3	97	113	15

Of the 225 conditions identified, 43.1% (n=97) represented a current problem (injury or physical complaint), mostly leading to further investigations (n=50, 22.2%) or treatment (n=31, 13.8%) (Table 6), whereas more than half of the musculoskeletal conditions (50.2%) represented an abnormal test result from the musculoskeletal assessment suggestive of a player being at risk of future injury, but not limiting play or training. These findings led to recommendations for prevention programs (strength training, stretching). Whether these abnormal test result confer future injury risk for the individual player is debatable; the predictive value of the tests used in this thesis has been questioned.[165, 182] Lower adductor strength is identified as a risk factor for groin injuries, whereas there are low levels of evidence for the predictive value of isokinetic muscle strength testing, flexibility, ROM and functional movement tests on lower extremity injury risk.[165, 208, 233] This was substantiated by the majority of the findings not restricting the player from participation in football (81.6% of 180 players). For the 17.8% (n=32 of 180 players) not given immediate clearance, the delay was caused by the need for treatment or further investigations for a current problem (injury or physical complaint).

Given our results, using a targeted physical examination based on careful history is beneficial in detecting current injury and musculoskeletal problems. However, prospective studies are necessary to assess whether identifying risk factors and acting on them reduces future injury risk. To assess whether a musculoskeletal examination can identify the player at risk, we further investigated the predictive value of muscle strength testing and the 9+ on lower extremity injury risk (Papers II-IV).

PHE musculoskeletal examination and predicting injury (Papers II – IV)

The results for Papers II-IV are based on 554 football players who completed the comprehensive musculoskeletal screening component of the PHE at the beginning of the 2013/14 and/or 2014/15 QSL seasons (n=808 player-seasons), and the subsequent injury registration for both seasons. Players were excluded from analysis if they did not consent for their data being utilised for research, provided no or incomplete data from either the musculoskeletal screening tests or the prospective injury registration, or reported a current time-loss injury at the time of testing. Players were also excluded if they did not compete for the QSL clubs during the 2013/14 and/or 2014/15 seasons (Papers II and III).

Muscle strength tests (Paper II)

A total of 369 players were included in Paper II, participating in 514 player-seasons. Of these, 206 (55.8%) sustained at least one lower extremity injury during the two football seasons and a total of 538 lower extremity injuries were reported in 294 legs. An acute muscle injury was the most frequent injury type. Univariate analysis of the strength variables identified greater concentric quadriceps peak torque at 300 °/s (HR: 1.005, 95% CI: 1.00 to 1.01; P=0.044) and eccentric hamstring peak torque at 60 °/s (HR: 1.003, 95% CI: 1.00 to 1.01; P= 0.031) as potential risk factors for lower extremity injury, whereas players with a greater ADD:ABD ratio (HR 0.63, CI: 0.41 to 0.98; P=0.039) were at lower risk of lower extremity injury. In the multivariate analyses, greater concentric quadriceps peak torque at 300 °/s was the only factor retained as associated with increased lower extremity injury risk (HR 1.005, 95% CI: 1.00 to 1.01; P=0.037) (Table 4, Paper II).

We also analysed the association with lower extremity acute and overuse injuries, and any knee and acute knee ligament, meniscus or cartilage injuries separately. Of the 20 strength variables examined, we identified greater quadriceps concentric peak torque at 60^0/s (HR 1.004, 95% CI: 1.00 to 1.01; P=0.026) as significantly associated with the risk of overuse injury in the multivariate analyses, whereas none of the strength variables investigated influenced the risk of acute lower extremity injuries (Table 4 and 5, Paper II). For knee injuries, only greater bilateral adductor strength adjusted for bodyweight was associated with lower risk of any knee injury, decreasing injury risk by 23% (CI 0.57 to 0.98) per 1 N/Kg increase in strength (Table 4, Paper II).

Muscle strength test and lower extremity injury risk

The main finding of paper II was that out of the 20 strength variables examined, only two strength variables were statistically associated with an increased risk of lower extremity injury. Greater quadriceps concentric peak torque strength at high (300^0/s) speed increased the risk of any lower extremity by 0.5% per 1-unit increase in quadriceps concentric torque strength (mean difference of 3.4 Nm, 136.6 vs 133.2 Nm), whereas greater quadriceps concentric peak torque strength at low (60^0/s) speed increased the risk for overuse lower extremity injury by 0.4% per 1-unit increase quandricpes concentric torque strength (mean difference 8.0 Nm, 240.6 vs 232.6 Nm). Our results extend previous reports[97, 236] that suggest greater quadriceps strength increases risk for lower extremity injury, particularly for a thigh muscle injury.[97, 236]

However, for a screening test to predict sports injury, in addition to demonstrating an association with injury, it also needs to identify who becomes injured and who does not.[13] Although we found a statistically significant association, the association was weak and the absolute group difference in strength between the injured and uninjured players was small (2.5 % for any lower extremity injury and 3.4% for overuse injury). Thus, it would be impossible to distinguish between the injured and uninjured groups clinically. Noted that the smallest detectable difference (SDD) for concentric quadriceps peak torque is reported to be 20%,[192] hence the difference in strength between groups is likely less than the measurement error, which is 4.8 to 10.8% for isokinetic strength measures.[192, 201] Our findings suggest that the isokinetic quadriceps strength test is not sensitive or specific enough to establish a cut-off separating players at low injury risk from those at high injury risk. The area under the ROC curve was less than 0.5 (0.46 for quadriceps concentric strength at 300°/s and 0.45 for quadriceps concentric at 60°/s) for the strength variables identified as potential risk factors, confirming that these strength variables are no better than chance in predicting the player who will go on to suffer a lower extremity injury.[173]

Interestingly, we identified greater bilateral adductor strength, adjusted for bodyweight, as a protective factor for any knee injury. This has previously not been described as an independent risk factor for knee injury, and contradicts previous reports on the association between low hip abductor strength and increased risk of ACL injury and patellofemoral pain.[91, 135] However, as for the isokinetic quadriceps strength, the group difference in bilateral adductor strength between injured and uninjured players was small (3.14 vs 3.34 N/Kg, respectively, corresponding to a mean difference of -0.2 N/Kg). Also, the SDD for the adductor squeeze test from 11% to 13%,[153] suggesting that these findings are most likely of limited clinical value. The area under the

ROC curve was only 0.56, confirming that the adductor squeeze test cannot be used as a screening test to predict which player is at risk of knee injury.

Muscle imbalance is not related to lower extremity injury

Muscle imbalance is frequently considered as a major factor in injury causation.[165] Out of the four ratios examined in Paper II (three for thigh strength and one for hip strength), only lower ADD:ABD ratio was associated with an increased risk of any lower extremity injury. However, these findings were not confirmed in the multivariate model. Our findings that there was no association between any of the ratios examined and the risk of lower extremity injury, regardless of injury type, suggest that muscle imbalance as expressed in a H:Q-ratio or ADD:ABD ratio are not effective in identifying players at risk of a lower extremity injury. Similar findings have been reported for the H:Q-ratio in a meta-analysis on risk factors for hamstring injuries.[97] Contrary to our result, ADD:ABD ratio was reported as a significant risk factor in two systematic reviews relating to groin injury.[208, 247] A possible explanation for the apparent discrepancy may be that while ADD:ABD ratio may be related to risk of groin injury specifically, this effect is diluted when looking at lower extremity injuries in general.

Functional movement test 9+ (Papers III and IV)

The 9+ test and predicting lower extremity injury (Paper III)

For paper III, we included 362 players, representing 508 player-seasons, who provided complete data sets for both the 9+ test and the prospective injury and exposure registration for one or both football seasons (2013/14 and/or 2014/15). Of these, 203 (56.1%) players sustained at least one lower extremity injury during the two football seasons, and a total of 526 lower extremity injuries were reported in 283 player-seasons. A muscle strain to the thigh was the most frequent injury type. We found no association between 9+ total score and the risk of lower extremity injuries (HR, 1.02, 95% CI: 0.99 to 1.05; P=0.13), even after adjusting for other risk factors in a multivariate analysis (Table 4, Paper III).

Also, the outcome was the same when hip/groin, thigh, knee, lower leg and ankle injuries, as well as acute and overuse lower extremity injuries were used as the dependent variable in separate univariate and multivariate analyses (Table 3 and 4, Paper III).

9+ test and lower extremity injury risk

Our finding of no association between 9+ total score and risk of lower extremity injury regardless of injury definition used, does not support the continued use of the 9+ test to predict injury.[13] This conclusion complements the findings of recent original data studies among football players[117, 185, 207, 209, 257] and meta-analysis[66, 180] of the FMS screening tool.

The predictive ability of the 9+ test

As for paper II, the intention of Paper III was not only to demonstrate if there were an association with injury, but also to identify the optimal cut-off point to separate the players with high risk from the those who are not.[13] Similar to the findings in paper II, there was complete overlap of and similar distributions in the 9+ total score for the injured and uninjured groups. As shown in Figure 2 in Paper III, there was no cut-off point on the horizontal (9+ score) axis that would allow us to separate injured and uninjured groups. The ROC curve analysis revealed an AUC of only 0.48, indicating that the 9+ test is no better than a coin toss in predicting lower extremity injuries. Comparably low AUC have also been reported in other studies on the FMS.[36, 66, 117, 185] Although our ROC curve analysis could not identify a clinically useful cut-off point, we tested a cut-off of ≤23 points (≤69.7% of the possible maximum of 33 points) which provided the best fit for sensitivity and specificity as a predictor for lower extremity injury. Interestingly, this cut-off point is comparable to the recently debated cut-off point of 67% (≤14 points of possible 21) of the FMS.[29, 66, 168, 254] Nevertheless, this cut-off provided a sensitivity and specificity of only 0.54 and 0.44, respectively, and a LR+ of 0.96 meaning the post-test probability of an injury is altered to an insignificant degree, if at all, by the 9+ test.

As for lower extremity injuries in general, we also observed a similarly low AUC for hip/groin, thigh, knee, lower leg, and ankle injuries, as well as acute and overuse lower extremity ranging between 0.53 to 0.45. Therefore, the 9+ test has poor accuracy as an injury prediction tool for any of these most common injury types in football.[9]

The variability of the 9+ test over time (Paper IV)

A total of 220 players completed the 9+ at the beginning of both football seasons (mean time between tests 359.7±65.4 days). There was a small but statistically significant increase in mean total score of the 9+ test (mean difference 1.6 point, 95% CI: 1.0 to 2.2, P<0.001) from season 1 (22.2±4.1) to season 2 (23.8±3.3). However, the variability was substantial (ICC: 0.24, 95% CI 0.11 to 0.36, Figure 7).

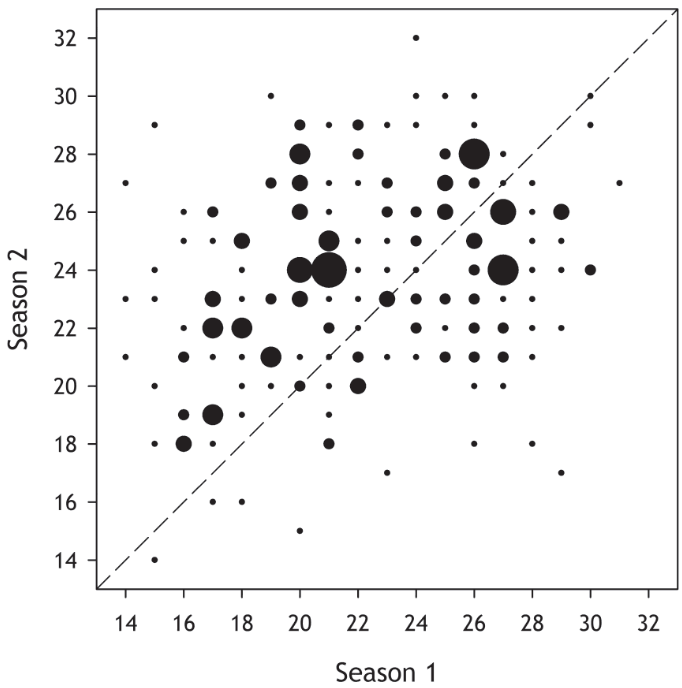


Figure 7. Bubble plot presenting the total score for all players (n=220) on season 1 (test 1) and season 2 (test 2). The bubble size depicts the number of players with identical total score; the smallest points represent one player, the largest seven players. The hatched line represents the identity line.

We further examined the variability of the 9+ of the players who sustained at least one time-loss injury between the two tests (n=136, 61.8%) and those who did not. Injury to the lower extremity was most frequent (n=124, 91.2% of all injured players). We observed a similar consistent improvement in the 9+ total score across all subgroups, which tended to be greater for the injured than the uninjured groups. However, the variability between season 1 and 2 was large, irrespectively of injury type or severity (Table 7).

Table 7. Inter-season characteristics of the 9+ total score for all players and for injured versus uninjured groups.†

	n	Mean ±SD Test 1	Mean difference test 2 to test 1 (95% CI)	ICC (95% CI)	SEM‡	MDC‡
All	220	22.2±4.1	1.6 (1.0 to 2.2)*	.24 (.11 to .36)	3.1	8.7
Any injury						
Yes	136	22.1±4.0	2.0 (1.3 to 2.7)*	.25 (.09 to .40)	3.0	8.3
No	84	22.4±4.3	0.9 (-.1 to 1.9)	.24 (.02 to .43)	3.3	9.1
Lower extremity injury						
Yes	124	22.1±4.1	2.0 (1.2 to 2.7)*	.25 (.08 to .41)	3.1	8.5
No	96	22.3±4.2	1.1 (.1 to 2.0)*	.23 (.03 to .41)	3.2	8.8
Any severe injury						
Yes	40	21.5±4.1	2.9 (1.4 to 4.4)*	.16 (-.15 to .45)	3.3	9.1
No	180	22.3±4.1	1.3 (.6 to 1.9)*	.27 (.13 to .40)	3.1	8.5
Severe lower extremity injury						
Yes	36	21.6±4.2	3.0 (1.3 to 4.6)*	.13 (-.20 to .44)	3.4	9.5
No	184	22.3±4.1	1.3 (.7 to 1.9)*	.27 (.14 to .40)	3.0	8.4

†Mean ± SD for test 1 (season 1), mean inter-season difference and intraclass correlation coefficient (ICC) with 95% CI, and measurement error (SEM and MDC) from test 1 (season 1) to test 2 (season 2) are reported. 9+ total score (0-33).
‡ Expressed in same unit as the measurement (9+ points)
* Significant at $P< 0.05$ (paired t-test)
SEM, standard error of measurement, MDC, minimal detectable change
Severe injury: > 28 days absence

Limited clinical applicability to detect change over time

This study was initiated assuming that, in the absence of any intervention or injury, the 9+ total score would be stable (i.e. low variability) between seasons. The intra-rater reliability of the 9+ test is good (ICC 0.75) with no systematic change when players are re-tested after 7 days; player and tester performance is stable across test sessions.[100] The FMS has similarly good ICC scores across different recreational and college athletes when re-tested after 2 to 7 days.[212, 215, 224]

Our finding of a remarkably low season-to-season ICC across all groups, irrespective of injury, suggests that the 9+ test is very limited in detecting changes in functional movement patterns – the measurement error is too large. These results support the findings from Paper III, that the intraindividual variability in the 9+ total score is too large for the 9+ test to detect change attributed to injury or clinical interventions.[141, 243] This is substantiated by the observed large measurement error (SEM, 3.0 to 3.4 points, Table 7) and MDC (8.3 to 9.5, Table 7) irrespective of injury and severity. Given that a minimum improvement of at least 8 points is required to represent a real change in the 9+ test, it would be very difficult (or impossible) to determine a cut-off point to separate those who may benefit from corrective exercise prescription to help mitigate injury risk from the rest. These findings reinforce the results in Paper III; the 9+ test has very limited value (if any at all) in predicting injury. The 9+ test cannot be recommended as an injury prediction tool in this population.

Is the 9+ measurement error related to rater variation?

The inter-tester reliability of our testers for the total score was moderate (ICC=0.68), while the inter-tester reliability for each test ranged from fair to excellent (κ_w=0.31 to 0.81). Our inter-tester reliability is lower than that reported by Frohm et al,[100] except for seated rotation and shoulder mobility. Frohm et al[100] examined the inter-tester reliability in a small group of male football players using eight physiotherapists and the present study included a larger number of testers (n=14). Our setting provides better generalizability but it likely decreased the inter-tester reliability score. This indicates that the same player was not necessarily scored the same way by our testers, a factor which may have influenced the results in Paper III and IV. However, given the difference in ICC values, which for the total score was 0.68 for between testers but only 0.24 between seasons, the large variability observed in the 9+ test resulted mainly from variability in player performance and chance rather than variability between testers.[141, 245]

9+ scoring system

Another possible explanation for the poor predicitve ability and variability of the 9+ test may be the ambiguity of the scoring system. In a injury prediction study on FMS in veteran athletes, Hammes et al,[117] argued that the scoring system may not be discriminative enough because a score of 3 is only given when the tests are performed with perfect quality. A score of 1 is only given when unable to perform the test, and every other option is subsumed under 2, hence representing a wider range.[117] A score of 2 on all eleven individual tests will equal a total score of 22. This may explain the similar mean total score for all injured and non-injured subgroups in this study (22 points) as well as the small group difference between the injured and uninjured group in Paper III (22.9±3.8 points versus 22.7±4.1, mean difference of only 0.2 points). Also, the difficulty in assessing and performing the more complex tests involving multiple joints and complex physical qualities such as balance, coordination and core stability make scoring and performance uncertain, and subsequently will cause variability in both athlete performance and in scoring (tester variability).[100, 175]

Functional movement test – is it worth the effort?

Functional movement tests such as the 9+ test and the FMS are a simple and low-cost tests, easy to implement in clinical settings and believed to be reliable, at least as a 'snapshot' at one point in time. Therefore, boosted by promising early evidence suggesting they may predict injury, the test has gained popularity as a screening test and also as a clinical tool to evaluate progress of treatment. Recently, the FMS has been scrutinised and new data do not support its use as an injury prediction tool.[29, 66, 180] Our results serve to emphasize that the 9+ test should not be used as an injury prediction tool. The addition of exercises and the modified criteria to improve the inter- and intra-tester reliability and sensitivity and specificity of the tests included in the 9+ test do not appear to improve the predictive validity of the 9+ test. One major concern is the high variability of the 9+ test (Paper IV).

The low internal consistency of functional movement tests is another concern. Frohm et al[100] and, most recently, Flödstrom et al[93] reported a Chronbach's alpha of 0.43 and 0.41, respectively; factor analysis suggested that the individual exercies do not load around one single factor. Similar results were reported for the FMS.[134, 152] The sum score derived from multiple tests (total score of the 9+ and composite score of the FMS) is believed to be a test of the same latent variable or measure a unitary construct (i.e. movement dysfunction). Latent variables are not directly observable and they are directly apparent in each item score on the FMS or 9+ test. Measurement of a latent variable (total score of the FMS or 9+ test) is assumed to have the same properties as measurement of the observable variables (each item score).[134] The observed low internal consistency of the 9+ test and FMS suggests that these tests are not valid as a unitary construct, and the use of a total score to predict injury is ambiguous. For example, two athletes displaying the same total score on the 9+ test or the FMS may not have the same type of injury risk; one individual may be at higher risk of lower extremity injury because of movement deficits on the deep squat. Another player may be at higher risk of low back injury because of movement deficits in the trunk stability push up or straight leg raise (9+ test).[100, 152] Future studies, which use the score of each individual exercise to predict injuries are warranted. However, Bushman et al[36] provided no evidence supporting the injury prediction validity of individual tests on the FMS on a large sample (n=2476) of military personel. The sensitivity (ranging between tests from 3-22%) and the diagnostic accuracy (AUC, 52-57%) for each individual test of the FMS was low.[36]

We acknowledge that we included only one functional movement test. There is a variety of other functional movement screens such as the Vertical Drop jump (included in the 9+), Star Excursion Balance Test (SEBT), Landing Error Scoring System (LESS), single-leg squat screens, truck jump assessment and Netball movement screening tool. McCunn et al,[168] assessed the reliability and predicitve validity of these tests in a critical review. Similar to the FMS and 9+ test, none of these movement screens have enough evidence in the literature to justify the tag of injury prediction tool.[168] McCunn et al[168] also raised the concern that there is no consensus on what defines movement quality or dysfunctional movement. We believe there is enough evidence now to discontinue the use of functional movement test *total score* as an injury prediction tool. However, movement screens may be useful for the practioniers to enhance their holistic knowledge of an athlete. Based on the measurement error identified in Paper IV, we suggest that clinicians exercise caution and consider the large variability of the 9+ total score when using the 9+ test or similar functional movement screen as a clinical tool in monitoring treatment progress.

Methodological considerations

Health condition criteria (Paper I)

One of the main limitations of a PHE is that there is limited evidence to help clearly define what constitutes a significant health condition, particularly for musculoskeletal and general medical conditions. In our study (Paper I), abnormal test results were interpreted according to reference ranges based on current research evidence and normative data on our population. A test result outside of these values was considered abnormal. For example, the isokinetic muscle strength tests were interpreted according to a traffic light system based on normative data on the QSL players from previous years. Players were considered at minor risk (yellow light) if the test was one SD from the mean and high risk (red light) if more than two SD from the mean. Whether these were considered significant to require further clinical consideration (further investigation, treatment or recommendations for follow-up), was a decision based on the interpretation of the physician, most likely representing a source of inconsistency in our study. However, we suggest this is reflective of the "real clinical practice world". There were several sports medicine physicians who performed the Stage Two assessment; this adds uncertainty to the reliability of the evaluation of findings and conditions identified. However, this also strengthens the external validity of the results. Note that we evaluated each PHE as a separate encounter even if the player had performed PHE during preceding seasons. We do not know how data from previous years may have influenced the physician's interpretation of the results.

Another important limitation of Paper I, is the cross-sectional design, which does not allow us to assess the predictive value of the conditions detected on future health risk. Whether many of the conditions (such as vitamin D levels below 30 ng/mL) confer future health risk is not known. Prospective studies are needed to address this question.

The PHE program (Paper I-IV)

As there is limited evidence that clearly defines a significant health condition, there is no universal PHE that should be applied to all athletes across different sports. For a PHE to be effective, it is recommended that the characteristics of the population and sport in question should be taken into consideration.[89] We used the standardised FIFA PCMA, which represents the standard PHE for elite football players. However, we tailored the medical part of the PCMA to specific characteristic of our populations. For example, Vitamin D deficiency or insufficiency and hepatitis B are prevalent in the Qatari football player population.[113, 116] For the musculoskeletal screening, we included parameters important in the musculoskeletal assessment to assess limitations in strength, flexibility or muscle imbalances that could hinder performance or possible risk of injury in elite football players. For the medical examination of the PHE, which the test is appropriate to identify a specific condition is clearly defined (i.e. screening for Vitamin D requires a blood test to be taken). Within musculoskeletal examination this is less clear (which test is best to identify hamstring strain risk). We chose a comprehensive battery of tests based on previous investigations and tests most commonly used in professional football. However, we recognise that the relative prevalence described in Paper I is in part an artefact of the screening battery chosen. Positive findings can only be found in tests that are conducted. We suggest that this reflects clinical practice.

We also acknowledge that we have only investigated the predictive validity of two test batteries (Paper II-IV). Although these are the two most commonly used screening tests in professional football, there may be other tests that may have better predictive ability. However, Krosshaug et al[146] reported poor discriminative ability of the vertical drop jump test in identifying female handball and football players at risk for a future ACL injury in a cohort of >700 players (n=42 ACL injuries). While they reported no association between knee abduction moment and ACL injury risk, ACL injured players displayed greater total medial knee placement.[146] As with our results, there was substantial overlap between the groups and it would not be possible to select a cut-off value.

Timing

The optimal timing of the PHE, post-season or pre-season is discussed.[45, 154] The incidence of injuries in elite football is reported to differ from pre-season to in-season. Injury data from the UEFA report a higher incidence of overuse injuries in the pre-season, whereas there are peaks of acute injuries in the in-season.[78] The majority of the players in this thesis were screened in the pre-season period (July through September) each season; however, a small group was screened outside of the pre-defined pre-season period. This may have affected the prevalence of musculoskeletal problems detected in Paper I. We performed analyses on those screened outside the pre-season period and found no difference in the type of musculoskeletal or medical conditions detected nor in their prevalence. For papers II and III, we chose Cox regression analysis to account for the different follow-up time.

The musculoskeletal predictive assessment (Paper II-IV)

Testers

The musculoskeletal screening tests in Papers II-IV utilised the same isokinetic testing system and standardized instructions for the hip tests and 9+ test performed in a professional multi-national and multi-language athlete setting, using multiple testers. Although every effort was made to ensure players understood the test procedure and instructions, it is possible that some players did not fully comprehend the instructions. This reflects clinical practice, increasing the external validity of this thesis, but also might have adversely influenced the inter-tester reliability in Paper III. In Paper IV, we found only moderate reliability between our testers on the 9+ test.

The team medical staff responsible for the injury and exposure reporting in Papers II-IV, were not blinded to the musculoskeletal screening results (muscle strength and 9+ test). Also, we did not control for any interventions that may have been implemented based on the player´s test score during the study period. Given the high number of injuries recorded in Papers II-IV for the two seasons, we believe these factors represent a low risk of bias.

Outcomes

In paper II, we chose to perform sub-analyses for acute and overuse lower extremity injury, and knee injury, and not for each body part as in Paper III. We acknowledge that the strength tests examined in Paper II are commonly used to identify risk of muscle injury to the thigh, particularly hamstring strain and groin injuries,[19, 55, 91] and not for identifying the risk of lower extremity injury in general. Muscle strength is widely considered an important factor in the injury causation,[55, 171] and we believe examining the injury prediction value of these tests for any injury type is valuable. Given the high number of knee, thigh and hip/groin injuries in our cohort (more than 50% of the injuries were located to these regions), we believe that our results would not differed substantially regardless of injury definition used. The association might have been stronger. However, the accuracy in identifying the individual player at risk, would still be low. This is supported by van Dyk et al[236, 238] who investigated the association between isokinetic strength test and hamstring strain injury on the same cohort as the present studies. In two separate cohort studies, they found a significant association between isokinetic concentric quadriceps and eccentric hamstring muscle strength at 60°/s adjusted for body weight (OR 1.41 and 1.37, respectively)[238] and at 300°/s adjusted for body weight when considered categorically (>1 SD above the mean) and accounting for exposure (HR 2.06).[236] However, the small effect size and absolute difference between the injured and uninjured group indicates it would not be possible to discriminate between the injured and uninjured groups based on the strength deficits identified.[236, 238]

In Paper III, we included all injuries regardless of injury mechanism (contact or non-contact). Contact injuries may represent a more heterogenous group in terms of their mechanisms and possibly also their risk factors. It may be argued that intrinsic risk factors (screening tests) such as muscle strength are more relevant for non-contact than for contact injuries. However, the counter-argument is that the stronger a player is, the better he will be able to tolerate tackling duels, collisions and falls without injury. Also, from a screening perspective, the most important question for the players (or team) is whether he is at risk of an injury or not, irrespective of injury mechanism. The aim of this thesis was to examine the utility of pre-season strength testing to inform injury likelihood. Interestingly, in the sub-analysis in Paper II where we excluded contact injuries, the outcome remained the same. Comparable findings are reported from several studies on the FMS that have assessed the predictive ability of the FMS including both any injury and non-contact injuries, reporting poor predictive validity of the FMS regardless of injury definition used.[180, 185]

In the second screening season (2014/15), the two teams who were relegated from the 2013/14 QSL season completed the 2014/15 pre-season musculoskeletal screening battery (PHE). The musculoskeletal screening data from these teams were excluded from the analyses in Papers II and III to ensure the study population was as homogeneous as possible with respect to exposure and injury rate.

Another limitation of Papers II and III is the low number of injuries for some of the subgroup analyses. This applies to the result of knee injuries in Papers II and III and lower leg injuries in Paper III. This reduced the statistical power for such subgroup analyses, and we interpret 'no association' with caution. That does not influence any of our major conclusions.

Covariates

In Papers II and III, previous injury history was one of the potential candidate risk factors adjusted for in the Cox proportional hazard ratio model to obtain an estimate of association between the musculoskeletal screening tests and lower extremity injury. Previous injury represents the most consistent risk factor injury in the literature.[6, 111, 119] Interestingly, previous history of injury was not consistently associated with an increased risk of injury in Paper II and III. This is in contrast to most cited studies in professional football.[6, 110, 111] The PCMA form only asks for previous injury leading to more than 4 weeks absence from football. Although we made the a priori decision to define a previous injury as any injury occurring 12 months before the PHE as recorded on the PHE form, there may have been inconsistency in the data recording. However, players with a previous knee injury had a 2-fold increased risk for a knee injuries of those without previous knee injuries and this matches previous findings among male football players documenting an increased risk for new knee injuries after an ACL rupture.[242] Noted that the FIFA PCMA does not ask specifically for ACL injuries, only knee ligament injury in general.

Conclusions

1. A PHE is beneficial in detecting current health conditions for which treatment, investigation, or prevention management may be instigated. We have demonstrated that a targeted PHE on professional football players in Qatar identified at least one current health condition in the majority of players, and one in three players with a musculoskeletal condition required some form of follow up.
2. Muscle strength is a poor screening test for predicting lower extremity injuries in professional football players. We found only a weak association with the risk of lower extremity injury for two muscle strength variables, quadriceps concentric strength at (i) high and (ii) low speed. However, these associations were too small to differentiate between high-and low-risk players.
3. We found no association between 9+ total score and the risk of lower extremity injury, and the test was no better than chance in distinguishing between injured and uninjured players. The 9+ test does not predict injury and should not be used as an injury prediction tool in professional football players.
4. We found substantial intra-individual variability in the 9+ test between two consecutive seasons, irrespective of injury between the tests occasions. A change above 8 points is necessary to represent a real change in the 9+ test between seasons, indicating that the variation in test results was too large for the 9+ to detect change attributed to injury or clinical interventions.

Future perspectives

In this thesis, we have provided new knowledge on the PHE, particularly for the musculoskeletal PHE, but predicting future injury is not one of them. A PHE program targeted to the sport in question can detect current health problem for which treatment, investigation or prevention can be initiated. As shown in Paper I, in a football squad of 30 players, we would have identified at least 10 players with a musculoskeletal condition requiring some form of follow-up. Follow-up might include treating a player for an ongoing injury or physical symptoms or introducing a prevention programme. For example, it is possible to intervene with prevention programs such as the Nordic hamstring exercise to reduce lower extremity injuries in football.[16, 228] However, based on our results, in healthy players such prevention programs should be implemented at the group level (i.e team) rather than on the individual level based on screening tests.

None of the screening tests investigated in this thesis proved sufficiently accurate to identify the individual at risk of a future lower extremity injury. As pointed out in the recent review on why predicting injury will never work by Bahr,[13] identifying a significant association between one or more factors and injury risk does not allow for simple direct translation to injury prediction. Future prospective risk factors studies investigating potential factors for an injury across various sports, should acknowledge this difference. Identifying a risk factor is valuable in growing our understanding of the etiology but does not equal predicting individual injury risk. It should be recognised that the findings of this thesis are on a group of male professional football players – the need for validation of a musculoskeletal PHE in other athlete population, female athletes and other age groups should be emphasized.

Another reason to conduct PHE and to why the musculoskeletal screening test included in the current thesis might still be valuable in a PHE, is to establish a performance baseline for the athlete in a healthy state. Injuries generally result from a complex interaction of multifactorial factors;[170] a player's injury risk is probably dynamic and subject to frequent changes in external factors (heavy training load, congested playing schedule or psychological factors).[170, 171] Multiple assessments (or monitoring) of the player throughout the sport season may represent a more suitable strategy to prevent injury.[98] Wollin et al[253] recently reported clinically meaningful isometric adductor strength reduction during periods of match congestion in elite youth soccer players compared to baseline, when players were monitored daily for adductor strength. In this way, the clinician can monitor and manage the musculoskeletal health of the athlete. However, the ability of a functional movement tests to serve as a performance baseline test is debated.[29, 168] This thesis reinforces this conclusion.

Although a targeted PHE of professional football players in Qatar identified at least one health condition in most players, the clinical relevance and benefits on future health of many of the medical conditions detected in this thesis are still unclear. Prospective studies are needed to determine the benefits of screening (and subsequent targeted interventions) for these health conditions.

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Papers I-IV

Paper I

Health conditions detected in a comprehensive periodic health evaluation of 558 professional football players

British Journal of Sports Medicine

Health conditions detected in a comprehensive periodic health evaluation of 558 professional football players

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ABSTRACT

Background Despite the widespread use of periodic health evaluation (PHE) to detect and prevent injury and illness in athletes, its effectiveness in detecting health conditions and relevant risk factors is still debated.

Aim To assess health conditions detected by a comprehensive PHE in professional male football players and evaluate their consequences for participation clearance.

Methods A total of 558 professional football players in Qatar completed a PHE prior to the 2013 or 2014 seasons: history, general medical (including blood test), cardiovascular (12-lead ECG and echocardiography) and a musculoskeletal examination, including a specific test battery targeting lower extremity strength and flexibility. On the basis of the PHE, players were either cleared or not cleared for participation.

Results In 533 players (95.5%), at least one health condition was detected requiring treatment or follow-up. Vitamin D deficiency or insufficiency (≤30 ng/mL) was the most common medical condition (n=499, 89.4%), followed by hepatitis B non-immunity or infection (n=164, 29.4%). Cardiac screening identified 48 players (8.6%) with one or more abnormal findings (ECG (n=19, 3.4%) and echocardiography (n=14, 2.5%)). Musculoskeletal conditions were observed in 180 players (32.3%); injuries to or strength deficits of the hip/groin and thigh accounted for the largest proportion. Medical clearance was temporarily not given in 69 players (12.4%), while further examinations were being conducted. One player was disqualified from competitive football.

Conclusions PHE revealed a high prevalence of health conditions requiring treatment or follow-up in professional footballers; however, only 12.4% of conditions impacted on final clearance for participation.

INTRODUCTION

A periodic health evaluation (PHE) or health screening is widely used to identify potential risk factors for diseases or disorders early with the view of implementing targeted prevention measures to reduce future morbidity and mortality.[1] Cancer screening (eg, breast and prostate) and PHE in work settings (eg, for hypertension, musculoskeletal disorders) represent integral elements of public health practice; however, evidence for their effect on total or cause-specific mortality is limited.[2 3]

Professional sport, including football, is well known for its high physical demands with high risk of injury, illness and also potentially negative long-term health consequences.[4–6] Protection of the health of the athlete is therefore of utmost importance for sports authorities.[7 8] In the sport setting, the PHE also serves the purpose of detecting and managing current health problems which may influence the ability to train and compete, as well as to determine whether an athlete is medically suitable to participate in competitive sport. Although the International Olympic Committee (IOC) released a consensus statement on the PHE of elite athletes in 2009, the extent and elements of the PHE vary widely between sport federations. It may vary from a short general health examination to a day-long comprehensive assessment that may include ECG and echocardiography, as well as an extensive general medical and musculoskeletal assessment.[7 9–11]

FIFA encourages all players to complete the FIFA Pre-Competition Medical Assessment (PCMA), which includes a comprehensive cardiovascular, general medical (including blood tests) and musculoskeletal assessment.[7] Despite the debatable validity of ECG and echocardiography in detecting serious anomalies,[12 13] cardiovascular screening with a 12-lead ECG and echocardiography is mandated for some FIFA and UEFA competitions.[14 15] Most top-level football clubs worldwide complete a comprehensive precompetition musculoskeletal screening, including questionnaires, functional testing and isokinetic strength testing of the lower extremity.[9 16] While a PHE is recommended by sports authorities such as FIFA and IOC,[7 8] there is little scientific evidence of its effectiveness.[17 18] Considerations such as cost (time and financial), possibilities of significant findings, and the impact of these are frequently discussed.[8 19–21]

The purpose of this study was therefore: (1) to assess the health conditions detected on a PHE in professional male football players and (2) to evaluate their consequences for participation clearance.

METHODS

Participants and PHE procedure

All male football players eligible to compete in the Qatar Stars League (QSL) were asked to participate in this cross-sectional study. The players were recruited as they presented for their annual PHE at

Aspetar Orthopaedic and Sports Medicine Hospital in Doha (Qatar), in the two preseason periods from July through September in 2013 and 2014. The QSL is the highest professional football league in Qatar (including 14 teams), with the majority of players coming from the Middle East and Central Africa. The PHE is part of the qualification procedure for all players expected to play in the QSL, and was divided into two stages performed on the same day.

Stage 1 consisted of a comprehensive history and clinical examination (general medical, cardiovascular and musculoskeletal examination). At stage 2, all test results collected during stage 1 were reviewed by a sport physician and medical clearance was determined. At inclusion, players provided written consent for their data being utilised for research. Refusal to consent or failure to complete key components (stage 2) of the PHE process resulted in exclusion from the study. Ethical approval was obtained from the Institutional Review Board, Anti-Doping Lab Qatar.

History and clinical examination

History and general medical examination was undertaken by a sports medicine nurse. History regarding injury and general medical, cardiovascular family history and personal symptoms was completed using the FIFA PCMA form.[7] The general medical examination included a visual acuity assessment, measurements of height (m) and body mass (kg), and respiratory function testing (spirometry (forced expiratory volume, FEV_1, peak expiratory flow, FEV_1/forced vital capacity)). Physical examination of bilateral brachial artery blood pressure, heart rate and precordial auscultation in supine and standing positions was performed by an experienced sports medicine physician.[22]

Since the majority of football injuries are to the lower extremity, particularly hamstring and groin injuries,[6] the identification of potential risk factors for these injuries was the primary focus of the comprehensive musculoskeletal test battery. The examination, performed by an experienced sports physiotherapist, included isokinetic muscle strength tests of knee flexors and extensors using an isokinetic dynamometer (Biodex Multi-joint System 3; Biodex Medical Systems Inc, New York, USA), strength, flexibility and pain provocation tests at the hip, groin and ankle, and a functional movement test (Nine-test screening battery; table 1).[23–26 26a] In addition to the musculoskeletal examination, all players underwent a general musculoskeletal examination by a sports physician using the FIFA PCMA clinical examination form[7] at stage 2.

Additional examinations

Additional examinations included laboratory blood tests, X-ray, ECG and echocardiography. Fasting blood samples and urine were sampled by a qualified phlebotomist and underwent immediate analysis (table 2). A chest X-ray was performed if clinically indicated.

Table 1 The comprehensive musculoskeletal examination and evaluation criteria for each test

	Type of testing	Tests	Evaluation criteria*
Hamstring and quadriceps muscle	Isokinetic muscle strength†	Concentric knee flexion and extension at 60°/s and 300°/s	Normal Minor abnormal: ±1SD Major abnormal: ±2SD
		Eccentric knee extension 60°/s	Normal Minor abnormal: ±1SD Major abnormal: ±2SD
	Flexibility	Hamstring AROM and PROM	Normal Abnormal: ±1SD
Hip and groin examination	Pain provocation tests	Hip adduction squeeze test at 0° and 45°	Normal Abnormal: pain
		Impingement test	Normal Abnormal: Pain
		FABER test	Normal Abnormal: Pain
	Joint ROM and flexibility	Hip internal rotation at 90°	Normal Abnormal: ±1SD
		Hip external rotation at 90°	Normal Abnormal: ±1SD
		Hip internal rotation in prone position	Normal Abnormal: ±1SD
		Bent knee fall out	Normal Abnormal: ±1SD
		ROM hip abduction side lying	Normal Abnormal: ±1SD
	Muscle strength	Eccentric hip adduction	Normal Abnormal: ±1SD
		Eccentric hip abduction	Normal Abnormal: ±1SD
Lower leg and ankle	ROM and flexibility	Ankle dorsiflexion, lunge forward to a wall	Normal/abnormal
Functional movement test		Nine-test screening battery‡	Normal: ≤22 of 33 Abnormal: ≥21 of 33

Evaluation criteria were based on normative data on Qatar Stars League (QSL) players from previous years. Tests were considered abnormal if more than one SD from the mean.
†The data from the isokinetic muscle strength tests were normalised to body weight.
‡ The Nine-test screening battery was considered abnormal if the total score was below 67% of the maximum score.[24 26]
AROM, active range of motion; FABER, flexion, abduction, external rotation; PROM, passive range of motion; ROM, range of motion.

Table 2 Laboratory blood analyses performed in a PHE

			Selected reference range*†
Haematology	Complete blood count (CBC)		
	Ferritin		26–388 μg/L
	C reactive protein (CRP)		<9.1 mg/L
	Erythrocyte sedimentation rate (ESR)		
Serology	Hepatitis B		Reactive or non-reactive
	Hepatitis C		Non-reactive
	HIV		Negative
Renal function	Urine analysis dipstix (protein, blood, glucose)		Negative
	Creatinine		71–115 μmol/L
Cardiovascular	Fasting lipids	Total cholesterol	<5.2 mmol/L
		Triglycerides	<1.7 mmol/L
		HDL	1.04–1.55 mmol/L
		LDL	<2.60 mmol/L
	Fasting glucose		4.1–5.9 mmol/L
Bone/muscle	Vitamin D, 25 (OH)[29]	Severe deficiency	<10 ng/mL
		Deficiency	10–20 ng/mL
		Insufficiency	20–30 ng/mL
		Sufficiency	>30 ng/mL
	Calcium		2.12–2.52 mmol/L
	Corrected calcium		
	Alkaline phosphatase		50–136 U/L

*Reference ranges were those of the Laboratory Department of Aspetar Orthopaedic and Sports Medicine Hospital. These ranges were derived from several hundred athletes tested over an extended period of time and verified for use with this patient population.
†All reference ranges are available in online supplementary table S1.
HDL, high-density lipoprotein; LDL, low-density lipoprotein; PHE, periodic health evaluation.

A standard 12-lead ECG was obtained by a cardiac physiologist using a GE MAC 5500 (New York, USA) after a period of 5 min rest in the supine position. All ECGs were interpreted by an experienced sports cardiologist using the Seattle ECG criteria.[27] Echocardiography was performed by an experienced sports cardiologist and according to protocols previously published for high-level athletes.[28] All athletes completed both an ECG examination and an echocardiography as standard.

Athletes with symptoms, a family history of heart disease and/or sudden cardiac death (SCD), or echocardiographic and/or ECG abnormalities indicating possible cardiac pathology were investigated further as indicated (24 h ECG, maximal exercise testing and/or cardiac MRI).

Evaluation and clearance status

At the end of the PHE (stage 2), a sport physician evaluated all results and documented the clinical findings detected on a report form. The physician noted if there were any abnormalities. A diagnostic code (the Sport Medicine Diagnostic Coding System[30]) was assigned (if possible) to each player and recommended management recorded as free text. On the basis of the interpretation of the results, the sports physician determined whether to give the player medical clearance or to withhold it. Clearance was given if clinical findings were considered to have: no, mild or minimal risk for the player's future health. Clearance was temporarily withheld when clinical findings were considered as a moderate risk to the player's health (usually requiring further investigation or treatment). Permanently not cleared was reserved for a player diagnosed with a health condition considered unsafe for participation in competitive football. At the end of stage 2, the test results were discussed with the player and club doctor and the report form was given to the club medical staff.

Data management and analyses

The clinical findings documented on the report form formed the basis for the current analyses. A health condition was defined as any condition sufficient to require treatment, further investigation or recommendation to follow-up. Only health conditions requiring a follow-up as per the above definition were included for analysis.

History, clinical and report form data from the PHE were entered into a database in Excel (Microsoft Excel 2010 for Windows, Microsoft Office Professional Plus, V.14.0.7147.5001, California, USA) for analysis. In the case of abnormal cardiovascular findings, detailed information on ECG, echocardiography, clinical examination and results of follow-up tests were also entered.

On the basis of the physician's diagnosis and/or clinical findings on the report form, the general medical and musculoskeletal findings were classified post hoc by the researcher (AB) and head physician (ST) at Aspetar Screening Department into groups based on the IOC consensus statement on PHE of elite athletes and IOC injury and illness surveillance protocol for analysis.[8 31 32] Haematology data were classified by the authors into two categories: iron deficiency (serum ferritin <30) with or without anaemia (haemoglobin lower than laboratory normal range) and other complete blood count alterations. We also grouped infection/immunology into hepatitis B and other infective immunology. Health conditions not fitting the categories were classified as 'other'. The musculoskeletal findings were classified according to body part and type of condition, grouped as a current problem (injury or current physical symptom), abnormal finding on examination or positive history (previous injury or physical symptom reported on history taking).

Descriptive statistics are presented as mean values with SDs, unless otherwise noted. Frequencies are reported as absolute numbers with percentages.

RESULTS

Participants

During the 2-year study period, 858 male professional elite football players attended the annual PHE (figure 1). In total, 22 players (2.6%) did not consent and were excluded. Five players (0.6%) were excluded for not completing stage 2. Of the 490 players screened in 2014, 273 had already been screened in 2013, and their repeat PHE was removed from the analysis. Thus, the final sample included 558 unique players (age 25.5±4.8 years; height: 177±7 cm; body mass: 72.3±9.2 kg; body mass index 23.0±2.0 kg/m^2). The players were mainly of Arab (n=316, 56.6%), Black (n=155, 27.8%), Caucasian (n=33, 5.9%) and Persian (n=33, 5.9%) ethnic origins.

Distribution of health conditions detected on PHE

In 533 players (95.5%), at least one health condition was detected that required further assessment, treatment or recommendation to follow-up. Of all players (n=558), 522 (93.5%) were identified with a general medical condition, 180 (32.3%) with a musculoskeletal condition and 48 (8.6%) with a cardiovascular condition. More than one-third of the players (n=205, 36.7%) were identified with two conditions from the three main domains, while 12 (2.1%) were identified with a condition in all three domains (figure 2).

Of all players identified with a health condition (n=533), a total of 1211 health conditions were reported. The total number of conditions for the three main screening components and the type of follow-up required are presented in table 3.

General medical findings

Vitamin D deficiency or insufficiency (≤30 ng/mL) was identified in 89.4% (n=499) of players and accounted for the majority of the medical conditions detected (figure 3). Hepatitis B non-immunity or infection was the second most frequent medical condition (29.4%, n=164), followed by dyslipidaemia (10.6%, n=59), iron deficiency/anaemia (10%, n=56), reduced visual acuity (6.5%, n=38) and abnormal urinalysis test results (blood, glucose or protein) (6.8% n=36).

In 74.8% of the medical conditions detected, treatment was required and initiated (tables 3 and 4). Further investigation was required in 8.9% of cases, and 8.2% required prevention recommendations (primarily dietary advice), while 8.0% of the conditions required repeat examinations.

Cardiovascular findings

Among the 48 (8.6%) players presenting with one or more cardiovascular findings (table 3), 19 had ECG features associated with cardiac pathology, 14 had abnormal echocardiographic findings, 11 reported symptoms suggestive of cardiac disease (including dizziness and/or chest pain during exercise and/or syncope) and/or a family history of SCD in a first relative, while eight players presented with a resting blood pressure ≥140/90 mm Hg (figure 4).

The most common ECG anomalies were T-wave inversion (n=14), profound first-degree atrioventricular block (>300 ms) (n=2), prolonged QT interval (>490 m) (n=1), and profound sinus bradycardia (<30 bpm) (n=1), with information missing in one case. Echocardiographic abnormalities included reduced right ventricular free wall contractility (n=3), increased right ventricular dimensions above upper physiological limits (n=3), mitral valve prolapse (n=1), abnormal coronary artery origin (n=1), abnormal diastolic function (n=1), profound hypertrabeculation (n=1) and poor subcostal echo windows (n=4).

Almost all (n=51, 96.2%) cardiovascular anomalies required further investigation (table 3). Consequently, a total of 74 additional cardiovascular investigations were ordered. These included 28×exercise stress tests, 16×24 h Holter ECGs, 22×cardiac MRI with late gadolinium enhancement, 6×24 h Holter BP, 1×tilt test and 1×cardiac CT scan.

Musculoskeletal findings

Among the 180 players presenting with musculoskeletal conditions, 225 conditions were detected. Musculoskeletal conditions

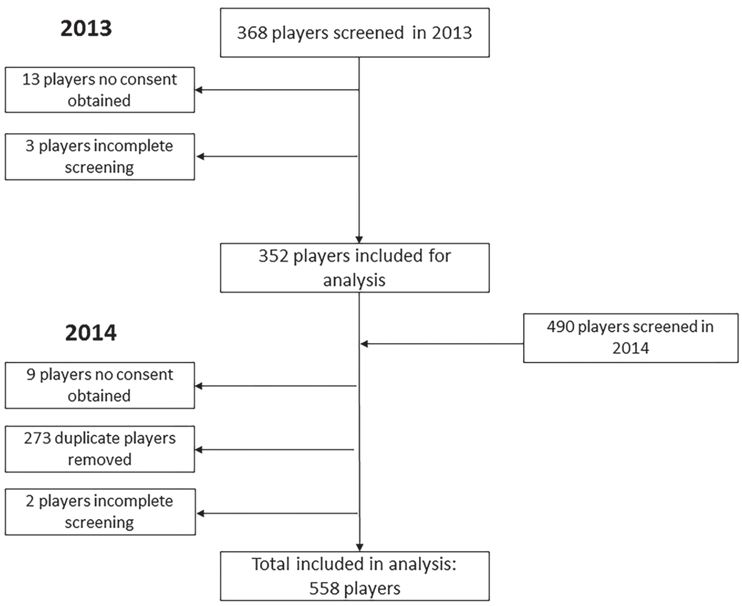

Figure 1 Flow chart showing the inclusion of participants during the 2-year study period.

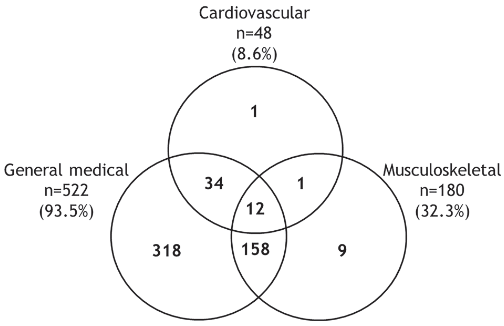

Figure 2 Venn diagram of players detected with one or more health conditions in the periodic health evaluation (PHE) (n=558).

in the lower extremity accounted for 86.2% (table 5). Of the 225 conditions, 97 represented a current problem (injury or physical complaint), 113 an abnormal finding on musculoskeletal assessment (strength deficits, flexibility or decreased range of motion, (ROM)) but not limiting play or training, while 15 resulted from a self-reported injury history. The majority of the musculoskeletal conditions identified led to prevention recommendations (n=142, 63.1%); 68.3% of these were based on abnormal findings from the musculoskeletal assessment. Prevention recommendations consisted primarily of referral to the club physiotherapist for general prevention programmes (strength training, stretching). Conditions leading to further investigations (n=50, 22.2%) and treatment (n=31, 13.8%) were mostly due to current musculoskeletal problems (injury or ongoing physical symptom).

Medical clearance status

Immediate medical clearance was given in 481 (86.2%) players (table 6). In 8 cases (1.4%), clearance was temporary, waiting for test results (general medical, n=2; cardiovascular, n=1), pending completion of the specific musculoskeletal assessment (n=1) or pending ongoing rehabilitation for current injury (n=3), and due to cardiovascular findings suggestive but not diagnostic of apical hypertrophic cardiomyopathy, requiring a repeat examination after 6 months (n=1).

In 69 (12.4%) cases, medical clearance was temporarily not given while further investigations or treatment were being carried out. Following the further investigations, one player was disqualified from competitive football (abnormal coronary origin; table 6), whereas another player with a high suspicion of long QT syndrome was still not provided with medical clearance pending additional investigations. The player left the country before completing these. Thus, final clearance status could not be concluded. However, the player was advised against competitive football.

DISCUSSION

The key finding from this study was that a targeted and comprehensive PHE identified at least one health condition requiring further assessment, treatment or recommendation to follow-up in 95.5% of professional football players. General medical and musculoskeletal components had the highest prevalence with 93.5% and 32.3%, respectively. The cardiovascular examination with ECG and echocardiography identified a cardiovascular condition in 8.6% of players. However, the vast majority of cases were given immediate medical clearance for competitive football (12.4% were temporarily not cleared).

General medical examination

In this study, general medical conditions represented more than 9 in 10 of the health conditions requiring treatment, further investigation or recommendations to follow-up. This was predominantly because of a high prevalence of vitamin D deficiency or insufficiency and hepatitis B non-immunity. Almost 90% of players were vitamin D deficient or insufficient. This is consistent with previous findings on Qatari athletes, including footballers,[33] but much higher than those reported for athletes in western countries.[34] Cultural clothing and training outside of sun hours in Qatar are believed to be the main cause in this population.

The potential role of vitamin D on performance, musculoskeletal health (injury risk, stress fractures), immune function and inflammatory response has increased the awareness of detecting athletes with deficiency upon treatment can be initiated.[35 36] Oral supplementation was the most common treatment initiated. Supplementing athletes with vitamin D levels below 25 ng/mL may have improved athletic performance;[37] however, whether or not to supplement is a topic of debate.[38 39] A recent systematic review on athletes from different sport suggests that there is limited evidence for an association between low vitamin D levels and injury risk or performance.[36] Also, there is currently no consensus on the optimal level of vitamin D for general health, sport-specific benefits or ethnicity.[40] Thus, it is debatable at what level supplementation is beneficial.

Almost one-third of the players were treated (vaccination) for hepatitis B non-immunity. A previous study from our group has shown that the prevalence of hepatitis B among sportsmen in Qatar is markedly higher than that observed in Australian Rules footballers or sumo wrestlers.[41] Our study population includes large groups originating from countries known not to have routine vaccination schedules[41]; regular screening for hepatic infection/immunity is therefore beneficial in our athlete population.

Of interest was the relatively high prevalence of dyslipidaemia (10.6%). This is in contrast to the findings of Meyer and Meister,[42] who documented much lower rates among German professional football players. However, it supports the findings

Table 3 Health conditions detected and type of follow-up required for the 533 players detected with a health condition

	Total conditions N (%)	Further investigations	Treatment	Prevention recommendations	Repeat examinations
General medical	933 (77)	83	698	77	75
Cardiovascular	53 (4.4)	51	–	–	2
Musculoskeletal	225 (18.6)	50	31	142	2
Total n (%)	1211 (100)	184 (15.2)	729 (60.2)	219 (18.1)	79 (6.5)

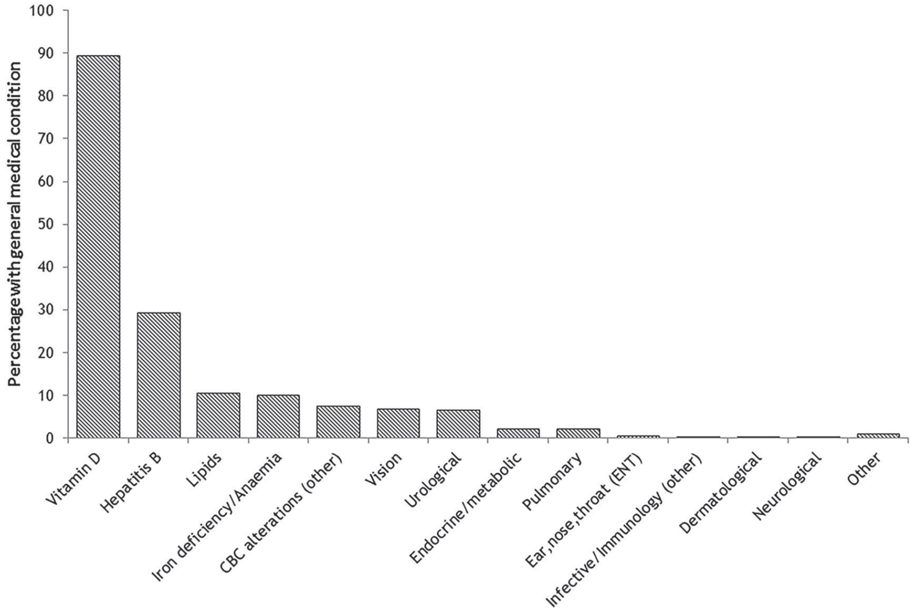

Figure 3 Proportion of players with general medical conditions detected on a periodic health evaluation (PHE) (n=558). CBC, complete blood count.

of Eliakim *et al*[43] and Fallon,[44] who found substantial levels of dyslipidaemia in a mixed-sport population. Similar to Eliakim *et al*,[43] several players in our study had a family history of dyslipidaemia. In almost all cases, players were referred to a dietician or given dietary advice.

Contrary to expectations, there was a surprisingly low prevalence of respiratory symptoms (n=12, 2.2%) and gastrointestinal (GI) symptoms (0%) that required further investigations, treatment or recommendation for follow-up in this study. Airway hyper-responsiveness/asthma, respiratory infections and GI problems are common among elite athletes and are the most frequently affected system reported from elite sports events including the FIFA World Cup.[32 45–47]

The lack of cold air and minimal pollens in Qatar is believed to be one cause for the low prevalence. Another explanation for the low number may be that the lung function test in this study was performed only with a general spirometry test at rest along with the self-reported history. Lung function testing with bronchodilator reversibility and bronchoprovocation tests is required to detect bronchial hyper-responsiveness associated

Table 4 Type of follow-up required for the general medical findings

	Total conditions n	Further investigations n	Treatment n	Prevention recommendation n	Repeat examination n
Vitamin D	499	–	496	3	0
Hepatitis B	164	4*	160	0	0
Lipids	59	–	–	47	12
Iron deficiency/anaemia	56	9	38	7	2
CBC alterations (other)	42	24	–	1	17
Vision	38	29	–	9	0
Urological	36	2	–	3	31
Endocrine/metabolic	12	–	1	1	10
Pulmonary	12	8	2	1	1
Ear, nose and throat (ENT)	3	3	–	–	–
Infective/immunology (other)	2	1	–	–	1
Dermatological	2	1	–	1	–
Neurological	2	1	1	–	–
Other	6	1	–	4	1
Total	933	83	698	77	75

*Hepatitis B, 4 of the players were seropositive. Three of the 4 were chronic carriers under long-term follow-up (one was lost to follow-up) with normal or near normal liver function tests, whereas 1 was core antibody positive following previous infection.

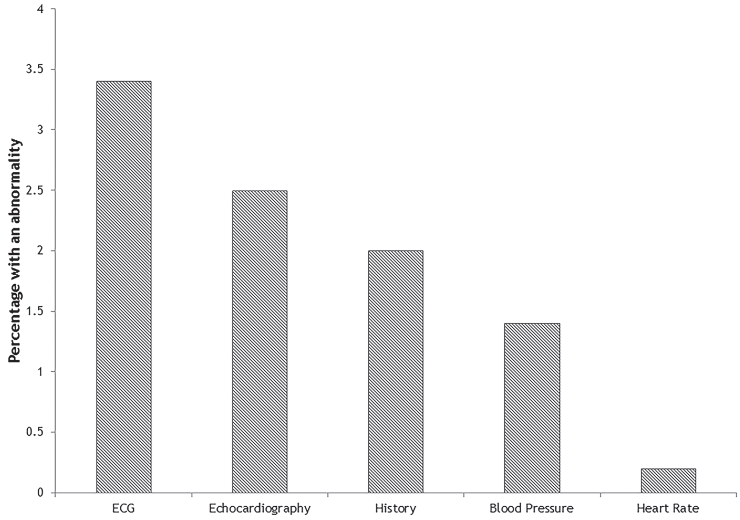

Figure 4 Proportion of players detected with an abnormality on cardiovascular screening (n=558).

with training.[46] These tests were not routinely performed in this study.

GI problems are more common in endurance athletes than in other athletes including football players.[48] Also, the fact that a PHE is only a snapshot of the time and the limited in-depth questions about GI symptoms in the standard PCMA questionnaire may explain the lack of GI symptoms in this study.

Cardiovascular examination

ECG abnormalities gave reason for further testing in 19 players (3.2%), mostly due to T-wave inversion, and were the main reason for the cardiovascular abnormalities detected. None of the players with T-wave inversions showed any sign of cardiac pathology after additional testing. However, ECG revealed probable long QT syndrome in one player, who was advised against competitive football pending further investigations.

The discussion regarding routine inclusion of an ECG in the PHE of athletes is ongoing, with opposing recommendations from the USA and Europe.[12 49] The concern is the ability of ECG to correctly differentiate physiological adaptation owing to sustained and intensive exercise from inherited or congenital cardiac pathology.[27] Our prevalence of 3.2% of players with an ECG abnormality is lower than that reported by previous studies of footballers or athletes from various sports.[50 51] In this study, the ECG results were interpreted according to the Seattle criteria, which have reduced the rate of abnormal ECG markedly.[52–54]

It is argued in the literature that the value of including echocardiography is limited.[52 55] We found that echocardiography gave reason for additional testing in 14 players (2.5%) and resulted in a diagnosis of abnormal coronary artery origin in one player who presented with a normal ECG. The player was disqualified for competitive football due to elevated risk of SCD.

Musculoskeletal examination

Our targeted and comprehensive musculoskeletal test battery focusing on the lower extremities identified at least one musculoskeletal condition necessitating further investigation, treatment or recommendation for follow-up in more than 1 in 3 players.

Interestingly, we found that the hip/groin was the region most frequently affected, with 11% of the players identified with a hip/

Table 5 Musculoskeletal conditions detected related to body part and type of condition (n=558)

Body part	Total conditions n	Total players Per cent	Current problem n	Abnormal finding n	Injury history n
Neck/cervical spine	2	0.4	2	–	–
Sternum/upper back	1	0.2	–	1	–
Low back/pelvis	8	1.4	7	1	–
Shoulder/clavicle	5	0.9	4	–	1
Forearm	1	0.2	1	–	–
Wrist	4	0.7	4	–	–
Hip/groin	62	11.1	21	38	3
Thigh	56	10.0	13	42	1
Knee	32	5.7	20	5	7
Lower leg/Achilles tendon	9	1.6	4	5	–
Ankle	33	5.9	19	11	3
Foot/toe	2	0.4	2	–	–
Other	10	1.8	–	10	–
Total	225	40.3	97	113	15

Table 6 Medical clearance status for all players who underwent a PHE (n=558)

	Total	Yes		No	
		Cleared n (%)	Temporarily cleared n (%)	Temporarily not cleared n (%)	Permanently not cleared n (%)
All players	558	481 (86.2)	8 (1.4)	68 (12.2)	1 (0.2)
General medical	522	508 (97.3)	2 (0.4)	12 (2.3)	0 (0)
Cardiovascular	48	16 (33.3)	2 (4.2)	29 (60.4)	1 (2.1)
Musculoskeletal	180	144 (79.4)	4 (2.2)	32 (17.8)	0 (0)

PHE, periodic health evaluation.

groin problem requiring follow-up. However, this may be a reflection of the screening programme, which included a series of tests targeting the groin (pain provocation tests and strength test).

More than one-third of the conditions were identified as a current injury or ongoing physical symptom, which led to further investigation or treatment and resulted in the athlete being temporarily not cleared to play. Given that previous injury and unresolved injuries represent the greatest risk factor for recurrent injury, it is important that these are identified.[56] However, self-reported history of previous injury resulted in follow-up in only 15 cases. Most likely, this represents gross under-reporting of past injuries, given that data from injury surveillance of QSL players have reported that a player can expect at least one injury per season.[5]

Ideally, the PHE should also be used to identify athletes at risk for future injury. In this study, half (50.2%) of the musculoskeletal findings represented an abnormal test result, leading to prevention recommendations. However, the predictive value of the tests used is debatable.[20 57] Lower adductor strength is identified as a risk factor for groin injuries, whereas there are low levels of evidence for the predictive value of testing isokinetic muscle strength, flexibility, ROM and functional movement tests.[20 58 59]

Considering these results, using a targeted physical examination based on careful history seems beneficial in detecting current injury and musculoskeletal problems. However, prospective studies are necessary to assess whether identifying such risk factors and acting on them reduces future injury risk.

To clear or not to clear?

In 86.2% of the players, the health conditions did not restrict the athlete from competitive sport, suggesting that most were interpreted as not being severe. However, they may be significant from the point of view of the athlete. By identifying these conditions, treatment and prevention strategies can be initiated to potentially prevent future health/injury risk.[8] The purpose of a PHE is to ensure safe participation for the player, but at the same time not to disqualify athletes unless there is an evidence-based medical reason.[60] For the 12.4% of players not given immediate clearance, the delay was caused by the need for further investigations, with suspected cardiovascular conditions as the main reason. However, after follow-up investigations, only one player (abnormal coronary artery) was permanently disqualified, whereas one player (possible long QT syndrome) was advised against competitive football.

Methodological considerations

The strength of the present study was that it was undertaken in one sports medicine hospital with a large group of male football players. This allowed for development of a PHE targeting history and examination characteristics thought to be relevant for the population and sport in question.[44]

A further strength of our study is that several sports medicine physicians performed the stage 2 assessment. This provides good generalisability, but also adds uncertainty to the reliability of the evaluation of findings and conditions identified. We only included health conditions requiring further investigation, treatment or recommendations for follow-up. This may have been subjective, depending on the physician's experience or field of expertise. Also, we evaluated each athlete's PHE as a separate encounter, even if the player had performed a PHE during the preceding seasons. We do not know how this may have influenced the physician's interpretation of the results.

It should be noted that, in contrast to cardiovascular conditions, there is limited evidence to help clearly define what constitutes a significant general and musculoskeletal finding. In our study, this was a decision based on the interpretation of the physician, most likely representing a source of inconsistency. We also acknowledge that as our study included a homogeneous group of male professional football players in a specific setting, this limits the generalisability of the findings to other sports, settings, age groups and women. Furthermore, the relatively small numbers of players in ethnic groups other than Arabic and black means that the results may not be relevant to other populations.

Positive findings can only be found in tests that are conducted. We recognise that the relative prevalence described here is in part an artefact of the screening battery chosen. We suggest that this is reflective of clinical practice; however, more work needs to be carried out to establish its veracity through prediction of injury and illness events. For PHE to be effective, however, the characteristics of the population and sport in question should be taken into consideration.[44] The PHE in this study used the standardised PCMA based on knowledge of our populations. For example, vitamin D deficiency and hepatitis B are known to be prevalent in our population from previous studies.[33 41] Although the health conditions detected in this study may not be prevalent in other sport settings/groups, we believe that the elements used in our PHE are beneficial to other sport settings in the frame that each sport setting knows the characteristics of their population.

Finally, a major limitation to this study is the cross-sectional design, which does not allow us to infer the predictive value of the conditions detected on future health risk. Prospective studies are warranted to address this question. Also, considering the high prevalence of conditions requiring follow-up, longitudinal follow-up studies are required to examine the usefulness of interventions.

CONCLUSION

This study demonstrated that a targeted PHE in professional Qatari football players is beneficial in detecting current health conditions for which treatment, investigation or prevention management can be instigated. However, the clinical relevance and benefits on future health are still unclear.

What are the findings

- A targeted periodic health evaluation (PHE) of professional football players revealed a high prevalence of current health conditions that required clinical consideration.
- Management of health conditions ranged from reassurance, treatment, further investigations or recommendations to follow-up.
- General medical and musculoskeletal conditions were the most prevalent.
- Delayed clearance was mainly due to abnormalities on the cardiovascular examination and current musculoskeletal injuries.
- Disqualification for competitive football was extremely rare in our group.

How might it impact on clinical practice in the future?

- The current study documents that a PHE targeted at the characteristics of the population and sport in question detects a number of conditions (musculoskeletal, cardiovascular and medical), which are believed to be relevant for health and performance.
- However, whether many of these conditions (such as vitamin D levels below 30 ng/mL) confer future health risk is not known. Prospective studies are needed to determine the benefits of screening (and subsequent targeted interventions) for each of the components of the PHE.

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Competing interests KMK is Editor in Chief of *BJSM* and was at arm's length (and blinded) from the review process in *BJSM*.

Ethics approval The study has been reviewed and approved by the Institutional Review Board, Anti-Doping Lab Qatar (ADLQ), Doha, Qatar.

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Supplementary, Table 1 Laboratory blood analyses performed in PHE

			Reference range*
Haematology	Complete blood count (CBC)	WBC	4.0-10.5 x10*9/L
		RBC	4.50-5.70 x10*12/L
		Hb	13.5-17.2 g/dL
		Hct	0.400-0.500 L/L
		MCV	80.0-95.0 fL
		MCH	27.0-33.0 pg
		MCHC	33.2-35.3 g/dL
		RDW	12.1-15.3 %
		Platelets	150-450 x10*9/L
		MPV	7.0-10.6 fL
		Neutrophils %	42.0-74.0 %
		Lymphocytes %	17.0-45.0 %
		Monocytes %	5.0-12.0 %
		Eosinophils %	1.0-7.0 %
		Basophils %	< 1.1 %
		Neutrophils Abs	1.4-6.6 x10*9/L
		Lymphocytes Abs	1.0-3.5 x10*9/L
		Monocytes Abs	0.3-0.8 x10*9/L
		Eosinophils Abs	< 0.41 x10*9/L
		Basophils Abs	< 0.11 x10*9/L
	Ferritin		26-388 ug/L
	C-reactive protein (CRP)		<9.1 mg/L
	Erythrocyte sedimentation rate (ESR)		
Serology	Hepatitis B	Hepatitis B core Antibody, IgM	Non-reactive<0.80
		Hepatitis B core Antibody, Total	Negative:1.001-3.000
		Hepatitis B Surface Antibody	Reactive ≥10 mIU/mL
		Hepatitis B surface Antigen	Non-reactive <1.00
	Hepatitis C	Hepatitis C antibody	Non-reactive <1.000
	Human Immunodeficiency virus (HIV)		Negative

Renal function	Urine analysis dipstix	Glucose	Negative
		Bilirubin	Negative
		Ketone	Negative
		Specific Gravity	1.001-1.030
		Blood	Negative
		pH	4.6-8.0
		Protein	Negative
		Urobilinogen	3.2-16
		Nitrite	Negative
		Leukocytes	Negative
	Creatinine		71-115 umol/L
Cardiovascular	Fasting lipids	Total cholesterol	<5.2 mmol/L
		Triglycerides	<1.7 mmol/L
		HDL	1.04-1.55 mmol/L
		LDL	<2.60 mmol/L
	Fasting glucose		4.1-5.9 mmol/L
Bone/muscle	Vitamin D, 25(OH)	Severe deficiency	<10 ng/mL
		Deficiency	10-20 ng/mL
		Insufficiency	20-30 ng/mL
		Sufficiency	>30 ng/mL
	Calcium		2.12-2.52 mmol/L
	Corrected calcium		
	Alkaline phosphatase		50-136 U/L

*Reference ranges were those of the Laboratory Department of Aspetar Orthopaedic and Sports Medicine Hospital. These ranges were derived from several hundred athletes tested over an extended period of time and verified for use with this patient population.

Paper II

Muscle strength is a poor screening test for predicting lower extremity injuries in professional male socccer: A 2-year prospective cohort study

American Journal of Sports Medicine

Muscle strength is a poor screening test for predicting lower extremity injuries in professional male soccer: A 2-year prospective cohort study

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ABSTRACT

Background: Lower extremity muscle strength tests are commonly used to screen for injury risk in professional soccer. However, there is limited evidence on the ability of such tests in predicting future injury.

Purpose: To examine the association between hip and thigh muscle strength and the risk of lower extremity injuries in professional male soccer players.

Study design: Cohort study

Methods: Professional male soccer players from 14 teams in Qatar underwent a comprehensive strength assessment at the beginning of the 2013/14 and 2014/15 seasons. Testing consisted of concentric and eccentric quadriceps and hamstring isokinetic peak torques, eccentric hip adduction and abduction force, and bilateral isometric adductor force (squeeze test at 45^0). Time-loss injuries and exposure in training and matches were registered prospectively by club medical staff throughout each season. Univariate and multivariate Cox regression analyses were used to calculate hazard ratios (HRs) with 95% confidence intervals (CIs).

Results: In total, 369 players completed all strength tests and had injury and exposure registration. Of these, 206 players (55.8%) suffered 538 lower extremity injuries during the 2 seasons; acute muscle injuries were the most frequent. Of the 20 strength measures examined, greater quadriceps concentric peak torque at 300 ^{0}/s (HR 1.005, 95% CI: 1.00 to 1.01; P=.037) was the only strength measure identified as significantly associated with a risk of lower extremity injury in multivariate analysis. A greater quadriceps concentric peak torque at 60 ^{0}/s (HR 1.004, 95% CI: 1.00 to 1.01; P=.026) was associated with the risk of overuse injury, and greater bilateral adductor strength adjusted for body mass (HR 0.75, 95% CI: 0.57 to 0.97; P=.032) was associated with a lower risk for any knee injury. A receiver operating characteristic curve analysis indicated poor predictive ability of the significant strength variables (area under curve; 0.45 to 0.56).

Conclusions: There was a weak association with the risk of lower extremity injury for two strength variables; greater quadriceps concentric muscle strength at (i) high and (ii) low speed. These associations were too small to identify an 'at-risk' player. Therefore, strength testing, as performed in the present study, cannot be recommended as a screening test to predict injury in professional male soccer.

What is known about the subject

Lower extremity injuries are frequent in senior male professional soccer, and players with muscle weakness are believed to be at increased risk of injury. Lower extremity muscle strength tests are one of the most utilized screening tests in professional soccer to detect injury risk. Despite their widespread clinical use, there is limited evidence of the utility of such tests to predict future injury.

What this study adds to existing knowledge

The small association between isokinetic quadriceps concentric peak torque at high and slow speed and risk of lower extremity injury, extends previous risk factors studies on acute muscle strain injury. Because the association was weak (although statistically significant) and the group difference in strength between the injured and uninjured players was small, these strength tests provide very little clinical value in identifying individual players at risk of injury. Therefore, muscle strength testing, as performed in the present study, cannot be recommended as a screening test to predict injury in professional male soccer players.

INTRODUCTION

Lower extremity injuries represent a disconcerting cause of time lost from male professional soccer,[10, 14, 24] decreased player performance,[11, 22] financial cost,[13] and possibly long-term player health.[9, 27] Screening to identify players at increased risk for injury with a view to prescribing individualized prevention measures is commonly seen as an integral component of a periodic health evaluation (PHE) of athletes.[1, 29] Muscle strength is considered an important factor predisposing a player to lower extremity injury,[6, 7, 15, 18, 42] and muscle strength testing is one of the most utilized screening tests in professional soccer to detect injury risk .[32]

The role of muscle strength as a risk factor for lower extremity injury has been widely discussed.[7, 19, 31, 42] Isokinetic quadriceps and hamstring muscle strength have been associated with risk of lower extremity injuries, in particular for acute muscle injury and knee ligament injury, in team and non-team sports in some studies,[6, 19, 37, 38] whereas other prospective studies do not support such a relationship. [15, 17] In field-based sports, low hip adduction strength increases the risk of lower extremity muscle injury.[42, 51] Moreover, low hip abduction strength was associated with an increased risk of lower extremity knee ligament injuries[25]; however the results are inconsistent.[7]

Muscle strength imbalances, typically expressed as a ratio between an agonist and antagonist muscle, have also been associated with an increased risk of lower extremity injury;[6, 42, 46, 51] however, the evidence is inconclusive.[7, 19, 31]

Despite the widespread use of muscle strength testing within professional soccer clubs,[32] there are few prospective studies investigating the association between muscle strength and injury risk in professional soccer and even fewer studies have investigated the predictive ability of such tests.[31] The utility of muscle strength testing as a screening tool not only depends on the strength of its association with injury risk, but also on its ability to predict who is at risk of injury and who is not.[1]

Therefore, the aim of this study was to assess whether hip and thigh muscle strength was associated with an increased risk for lower extremity injury in professional male soccer players. Secondly, we assessed whether muscle strength represented a risk factor for acute lower extremity injuries, overuse lower extremity injuries or knee injuries. We hypothesized that lower hip and thigh muscle strength would be associated with increased risk for lower extremity injury and that strength testing could be used to separate high-risk players from low-risk players.

METHODS

Study Design and Participants

In the present study, we prospectively collected data from a PHE of male professional soccer players in Qatar.[4] All players eligible to compete in the Qatar Stars League (QSL), the professional first division of soccer in Qatar, were invited to participate as they presented for their annual PHE at Aspetar Orthopaedic and Sports Medicine Hospital in Doha (Qatar) during the 2013/14 and 2014/15 seasons. The PHE were mainly performed during the pre-season period (66.6%) (July through September), with a small group completing the tests during the early/mid competition phase (23.8%) (October through December) each year and a minor group post-season (9.7%) (end of April through June) in 2014 (i.e. used as the baseline for the 2014/15 season).

As part of the musculoskeletal component of the PHE, all players underwent a comprehensive musculoskeletal test battery aimed at identifying potential biomechanical and anatomical risk factors for lower extremity injuries at the Rehabilitation department of Aspetar hospital.[4] Data from three strength tests were included in the current study. Players who competed for QSL clubs during the 2013/14 and 2014/15 seasons, did not report a current time-loss injury at the time of testing and reported injury and exposure surveillance data for the entire season were eligible for analysis. Ethics approval was obtained from the Institutional Review Board, Anti-Doping Lab Qatar (IRB F2013000003 and E2013000003). All players signed a written informed consent form at inclusion, permitting their data to be utilized for research.

Study Procedure

All test procedures were performed by sports physiotherapists who had received a minimum of 5 h of training in the methods. A total of six testers performed the strength tests during the study period. Before the strength tests, the players performed a self-selected 5-10 min warm up routine, consisting of either light running or cycling on a stationary exercise bike (Bike Forma, Technogym®, Cesena, Italy), most players preferring cycling. We randomized the test order for each strength test and leg (left, right). Data on player characteristics (i.e. age, date of birth, player position) and previous injury history (lower extremity injury, groin, hamstring, quadriceps femoris, knee and ankle injury) were collected from the FIFA Pre-competition medical assessment form, which was completed during the medical part of the PHE on the same day as the strength testing.[4] A previous injury refers to any time-loss injury occurring within 12 months before the PHE. We obtained information on height, body mass and leg dominance prior to testing and defined the dominant leg as the limb preferred for a penalty kick.

Quadriceps and hamstrings strength

Maximal isokinetic knee flexion and extension were tested using an isokinetic dynamometer (Biodex Multi-joint System 3; Biodex Medical Systems Inc. NY, USA). We used a standardized protocol comprised of three different modes and speeds, as previously described.[45, 50] The axis of rotation of the dynamometer was individually aligned with the knee joint, and the hip angle at 90°. We used straps around the thigh, waist and trunk to minimize secondary joint movement. After an explanation of the testing methodology, players were first tested over five repetitions of concentric knee flexion and extension at 60 °/s. This was followed by 10 repetitions of concentric knee flexion and extension at 300

°/s. Finally, players performed five repetitions of eccentric knee extension at 60 °/s. Accordingly, we calculated hamstring-to-quadriceps ratios (HQ-ratio) for the same mode and speed of the concentric contraction, and a mixed ratio from hamstring eccentric at 60 °/s to quadriceps at 300 °/s. The highest peak torque (Nm) observed from all repetitions performed for each of the three different tests was recorded. Between each mode of testing a minimum of 60 s of rest was provided. The isokinetic muscle strength testing protocol has been established as a highly reliable tool for assessing muscle force (ICC of 0.83-0.96).[39, 41]

Hip strength

Hip eccentric adduction and abduction test. We measured maximal eccentric hip adduction and abduction strength with a break test, using a handheld dynamometer (HHD) (PowerTrack ll Commander, JTECH Medical, Midvale, Utah, USA) and with the player in a side-lying position as previously described.[36, 43] The leg being tested was placed in a straight position, in line with the body, and the contralateral leg in 90° hip and knee flexion. The players held their hands on the side of the examination table to stabilize themselves during the testing. We applied resistance in a fixed position 8 cm proximal to the most prominent point of the lateral malleolus, and the player exerted a 3s maximum isometric contraction against the dynamometer, followed by a 2 second break performed by the examiner. The player was given one practice trial followed by three tests, with a minimum of 30 s rest between each test. We recorded the maximum score (N), and also calculated an adduction-to-abduction (ADD:ABD) ratio for analysis.[36]

Adductor squeeze test (bilateral adductor test). Maximal isometric adductor squeeze strength was measured using the HHD and the player in a supine position. We placed the dynamometer between the player's knees with the hip flexed at 45° and feet flat on the table, and players pressed knees together against the HHD with maximal force without lifting the legs or pelvis. The player was allowed one test trial followed by one maximum trial, which was recorded for analysis (N). A detailed description of the test is given by Mosler *et al*.[36] These strength procedures have been established as highly reliable for assessing hip strength (ICC, 0.83 to 0.94).[8, 30, 43] Also, Mosler et al[36] demonstrated moderate to good inter-rater reliability (ICC 0.66-0.84) of the hip strength measurement, when measured on the same cohort and testers as the present study.

Injury Registration

Injury and exposure data were obtained from the Aspetar Injury and Illness Surveillance Program (AIISP). The AIISP includes prospective injury and exposure (minutes of training and match play) recording from all 14 QSL teams.[10] An injury was recorded if the player was unable to fully participate in future soccer training or match play because of an injury to the lower extremity (time-loss injury).[10, 21] The player was considered injured until declared fit for full participation in training and available for match selection by medical staff.

The team physician for each team recorded all injuries and individual training and match exposure daily throughout the 2013/14 and 2014/15 soccer season (July-May; 44 weeks). For each injury recorded, the team physician completed a standardized injury card containing information on the body part injured, injury type and injury etiology (overuse or acute). Overuse and acute injuries were defined according to the consensus statement on injury definitions and data collections procedures in studies of soccer injuries.[21] In addition, the injury card included questions related to re-injury, injury mechanism (contact or collision), as well as information on whether the injury occurred during training or match. Injury severity was determined by the number of days absent from matches or training sessions due to injury and was classified as mild (1-3 days), minor (4-7 days), moderate (8-28 days) or severe (>28 days).[10] Injury and exposure data were passed on to the study group each month; data were checked, cleaned and any questions clarified with the team doctor as needed.

Statistical analysis

Data were analyzed with IBM SPSS statistics, version 24.0 (IBM Corp., Armonk, NY, USA). Descriptive data are presented as the mean ± standard deviation (SD) unless otherwise stated. Muscle strength measures are presented as absolute (peak torque for the quadriceps and hamstring strength tests and peak force for the hip strength tests) and body mass normalized values. The eccentric hip abduction and adduction strength measures were normalized to body mass and lever arm (Nm/kg).[36, 43] Legs with missing data for all three strength tests were excluded from the final analyses.

Individual exposure data were calculated as the sum of the total number of hours of training and match play from the date of screening until the end of each season or until the date of the first injury. Based on a previous epidemiological study[10] on the injury incidence of the QSL, we expected between 200-300 lower extremity injuries per season as well as about 250-300 soccer players to present for PHE at our study center each year. Therefore, a priori, we estimated the statistical power to be sufficient to detect small to moderate associations (n=200 injury cases), as outlined by Bahr and Holme.[2]

To examine the relationship between any lower extremity injury (yes/no) with muscle strength scores and other potential risk factors (anthropometric data, player position, previous injury, season, dominant leg) we used Cox regression analyses (STATA version 11.0, StataCorp, College Station (Texas), USA) with each leg as the unit of analysis. For players sustaining more than one injury following baseline testing, we only included their first lower extremity injury. In the case of a bilateral injury, these were included in the analyses as an injury sustained to both legs. To account for the repeated measures performed over the 2 seasons, as well as the fact that not every participant had the same number of measurements (i.e. some participants would have test results for both seasons, some for only one season), we used the player identity to cluster the related observations when estimating the Cox model. Similar and separate analyses were performed for assessing the relationship between muscle strength scores and acute lower extremity, overuse lower extremity and knee injury (including knee ligament, meniscus or cartilage injuries). The hazard ratios (HRs) presented with 95% CIs are per 1-unit of change in the independent continuous risk factor (muscle strength, anthropometric data). For categorical variables (season, position, previous injury history and dominant leg), the HR represents the change in risk when compared to the reference category. After the univariate analyses, all factors with a *P* value of <.20 were investigated further in a backward stepwise multivariate model to evaluate potential predictor variables. The significance level was set at *P* <.05. In case there were significant associations between a strength variable and outcome measure, we performed receiver operating characteristics (ROC) analyses to investigate the sensitivity and specificity characteristics of the particular variable. The area under the curve (AUC) indicates how well the strength variable discriminates between the injured and uninjured players and was interpreted as excellent (1.00-0.90), good (0.90-0.80), fair (0.80-0.70), poor (0.70-0.60), or fail (<0.60).[35]

RESULTS

Participants

A total of 369 players were included in the final analyses, participating in 514 player-seasons (1028 legs) and representing 42 nationalities, the majority from the Middle East (64.5%) (figure 1 and table 1). The mean player exposure was 213 ± 92 h per season, with 188 ± 87 h of training and 25 ± 17 h of match play.

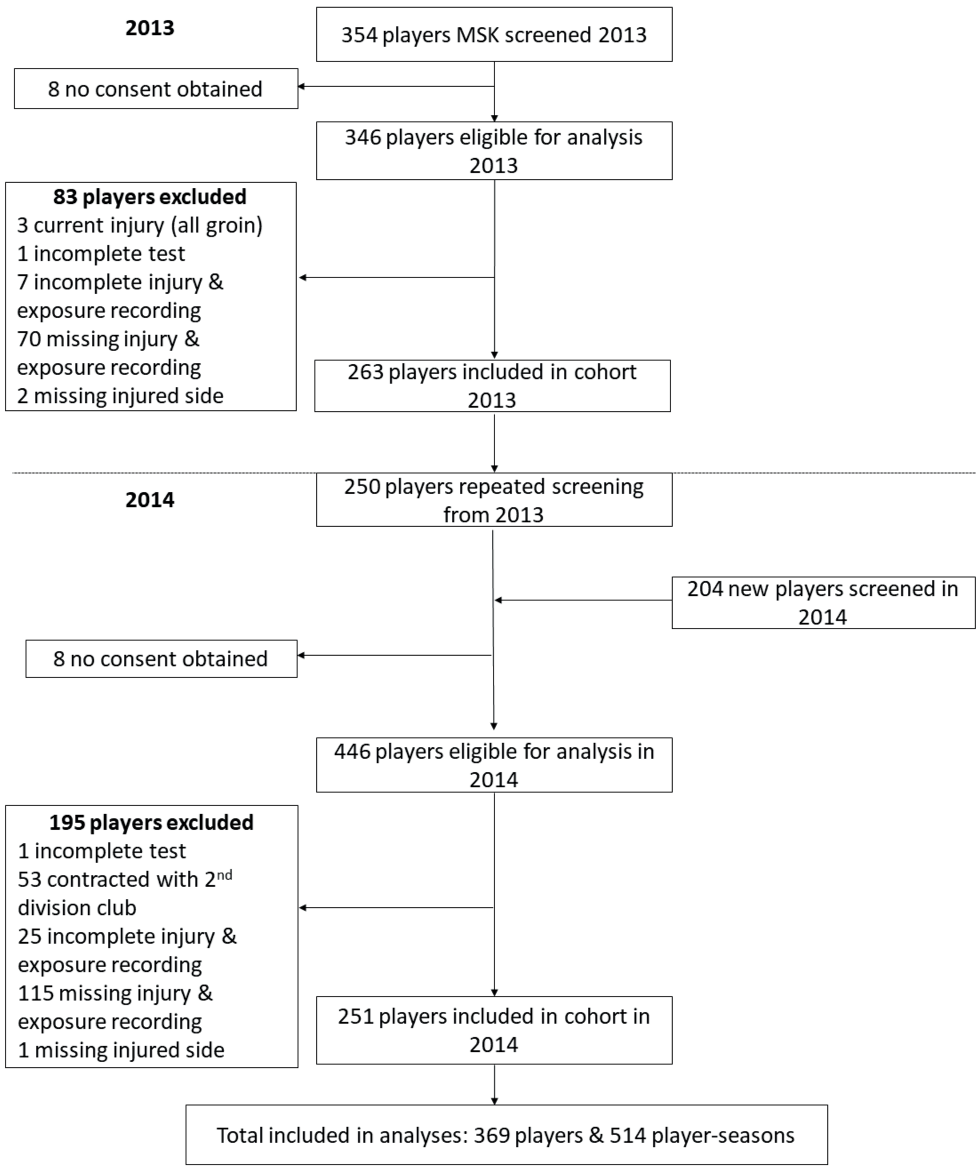

Figure 1 Flow chart demonstrating the movement of players and repeated strength tests between the two seasons. MSK, musculoskeletal

Table 1 Characteristics of all players (n=369).[a]

	Players
Age, y	26.0 ± 4.7
Height, cm	176.8 ± 6.9
Body mass, kg	72.2 ± 9.1
BMI, kg/m^2	23.0 ± 1.9
Ethnicity, n (%)	
- Arab	201 (54.5)
- Black	112 (30.4)
- Caucasian	20 (5.4)
- East Asian	7 (1.9)
- Persian	21 (5.7)
- Other	8 (2.2)
Player position, n (%)	
- Goalkeeper	39 (10.6)
- Defender	130 (35.2)
- Midfielder	133 (36.0)
- Forward	67 (18.2)
Previous lower extremity injury, n (%)	
- Yes	127 (34.4)
- No	233 (63.1)
- Missing	9 (2.4)
Player seasons, n (%)	
- Season 1 only	118 (32.0)
- Season 2 only	106 (28.7)
- Two seasons	145 (39.3)

[a] Data are presented as mean ± SD unless otherwise indicated.
BMI, body mass index

We recorded a total of 543 (n=13 bilateral) lower extremity injuries during the 2 seasons. For 3 of the players, data on the injured side was missing for their index injury and these injuries were excluded from the final analyses. Of the 369 players included, 206 (55.8%) sustained at least 1 lower extremity injury during the 2 seasons, and a total of 538 lower extremity injuries were reported in 294 legs, of which 12 (n=24, 4.5%) were bilateral (mainly groin injuries). An acute muscle injury was the most frequent injury type (Table 2). During the 2013/14 season, 145 of the 263 (55.1%) players (1 player with bilateral injuries) suffered at least one lower extremity injury, while during the 2014/15 season 139 of the 251 players (55.4%) (9 players with bilateral injuries) experienced at least one lower extremity injury. Slightly more than half of the injuries occurred during training (n=288, 53.5%), and more than one third of the injuries were moderate (n=210, 39 %), leading to an absence from soccer training and match play for 8-28 days. Most players were right leg dominant (80.5%, n=297 out of 369 players), and almost two thirds (61.2%, n=329 out of 538 injuries) of the injuries occurred on the player's dominant side.

Table 2 Injury characteristics (n=538)

Injury classification	Injuries, n (%)
Acute	302 (56)
Overuse	236 (44)
Any knee	85 (16)
Acute knee[a]	39 (7)
Injury type	
- Muscle strain	193 (36)
- Muscle cramps/spasm	69 (13)
- Sprain/ligament	89 (17)
- Contusion	71 (13)
- Meniscus/cartilage	15 (3)
- Tendon	56 (10)
- Fracture	10 (2)
- Other	35 (7)
Severity	
- Mild (1-3 days)	124 (23)
- Minor (4-7 days)	117 (22)
- Moderate (8-28 days)	210 (39)
- Severe (>28 days)	86 (16)
- Missing[b]	1 (0.2)
Injured side	
- Right	296 (55)
- Left	216 (40)
- Bilateral	12 (n=24, 5)
- Missing[b]	2 (0.4)

[a]Acute knee injury refers to acute ligament, meniscus or cartilage injuries.
[b]Non-index injury.

Association between muscle strength tests and lower extremity injuries

The results of the univariate analyses are shown in Table 3. Analysis of the strength variables identified greater concentric quadriceps peak torque at 300 °/s and hamstring eccentric peak torque at 60 °/s as potential risk factors for lower extremity injury, whereas players with a greater eccentric ADD:ABD ratio were at less risk of lower extremity injury. However, only greater concentric quadriceps peak torque at 300 °/s remained significant in the multivariate analysis (Table 4). Of the other candidate risk factors, age, player position, injury to the dominant leg and playing in season 2 were factors associated with an increased risk of lower extremity injury; these remained significant in the multivariate model (Table 4). We also performed similar and separate sub-analysis where we excluded contact injuries (n=67). Because there were many cases with missing information (n=105), only the category any non-contact lower extremity injury (n=122) was analyzed. In addition to the strength variables identified as significantly associated with risk of lower extremity injury in Table 3, greater hip eccentric abduction peak force (N) (HR 1.006, 95% CI 1.00 to 1.01, p=0.001) and body mass and lever arm adjusted (Nm/kg) (HR 1.49, 95% CI 1.01 to 2.19, p=0.044) were significantly associated with lower extremity injury risk. However, the outcome remained the same; greater concentric quadriceps peak torque at 300 °/s was the only factor significantly associated with increased risk of lower extremity injury when adjusted for other candidate risk factors in the multivariate model (HR 1.01, 95% CI 1.00 to 1.02, p=0.009).

Table 3 Univariate comparison from Cox regression analysis between legs with and without a lower extremity injury (n=1028 legs).[a]

Variables	n	Injured (n=294) Mean (SD)	Uninjured (n=734) Mean (SD)	HR (95% CI)	*P* value
Age, yrs	1028	26.9±4.7	26.2±4.7	1.04 (1.01 to 1.06)	**.006**
Height, cm	1028	176.9±6.9	176.6±6.6	1.01 (0.99 to 1.02)	.515
Body mass. kg	1028	72.7±9.0	72.0±9.0	1.01 (0.99 to 1.02)	.171
BMI, kg/m^2	1028	23.2±2.0	23.0±1.9	1.05 (0.99 to 1.11)	.131
Player position, n (%)	1028				
- Goalkeeper[b]		22 (7.5)	88 (12.0)	1.00	
- Defender		105 (35.7)	253 (34.5)	1.76 (1.15 to 2.69)	**.009**
- Midfielder		109 (37.1)	281 (38.3)	1.71 (1.13 to 2.59)	**.011**
- Forward		58 (19.7)	112 (15.3)	2.20 (1.40 to 3.46)	**.001**
Previous lower extremity injury (yes)[c], n (%)	996	99 (34.4)	249 (35.2)	1.05 (0.80 to 1.36)	.740
Dominant leg (yes), n (%)	1028	182 (61.9)	332 (45.2)	1.63 (1.29 to 2.06)	**<.001**
Season (season 2)[d], n (%)	1028	148 (50.3)	354 (48.2)	1.36 (1.07 to 1.72)	**.012**
Isokinetic quadriceps and hamstring strength					
- Quadriceps concentric at 60 ^{0}/s	864	237.8 ± 46.3	232.4 ± 46.4	1.002 (0.99 to 1.01)	.121
- BW adjusted (Nm/kg)	864	3.28 ± 0.55	3.25 ± 0.58	1.06 (0.85 to 1.32)	.623
- Quadriceps concentric at 300 ^{0}/s	862	136.6 ± 26.2	133.2 ± 25.3	1.005 (1.00 to 1.01)	**.044**
- BW adjusted (Nm/kg)	862	1.88 ± 0.30	1.86 ± 0.29	1.23 (0.80 to 1.89)	.347
- Hamstring concentric at 60 ^{0}/s	863	128.2 ± 26.6	125.3 ± 27.4	1.004 (0.99 to 1.01)	.113
- BW adjusted (Nm/kg)	863	1.77 ± 0.31	1.75 ± 0.34	1.11 (0.76 to 1.62)	.584
- Hamstring concentric at 300 ^{0}/s	862	97.4 ± 20.2	95.5 ± 19.3	1.005 (0.99 to 1.01)	.138
- BW adjusted (Nm/kg)	862	1.34 ± 0.25	1.33 ± 0.24	1.09 (0.65 to 1.82)	.740
- Hamstring eccentric at 60 ^{0}/s	857	206.5 ± 46.6	201.2 ± 40.9	1.003 (1.00 to 1.01)	**.031**
- BW adjusted (Nm/kg)	857	2.84 ± 0.54	2.81 ± 0.51	1.12 (0.88 to 1.43)	.367
- HQ concentric ratio at 60 ^{0}/s	863	0.54 ± 0.08	0.54 ± 0.10	0.92 (0.30 to 2.80)	.889
- HQ concentric ratio 300 ^{0}/s	862	0.72 ± 0.11	0.72 ± 0.12	0.67 (0.24 to 1.86)	.446
- HQ eccentric to concentric ratio at 60/300 ^{0}/s	855	1.53 ± 0.31	1.53 ± 0.29	1.02 (0.67 to 1.54)	.921
Hip strength					
- Adductor squeeze 45^0	1016	238.8 ± 63.6	238.1 ± 60.9	1.00 (0.99 to 1.00)	.567

- BW adjusted (N/kg)	1016	3.30 ± 0.83	3.33 ± 0.84	0.99 (0.85 to 1.14)	.860
- Hip eccentric adduction	1006	254.8 ± 56.5	256.3 ± 52.3	0.99 (0.99 to 1.00)	.561
- BW and lever arm adjusted (Nm/kg)	1004	3.03 ± 0.63	3.08 ± 0.61	0.84 (0.68 to 1.04)	.118
- Hip eccentric abduction	1019	209.7 ± 36.9	208.6 ± 40.7	1.00 (0.99 to 1.00)	.305
- BW and lever arm adjusted (Nm/kg)	1017	2.49 ± 0.40	2.50 ± 0.44	1.02 (0.78 to 1.33)	.882
- ADD:ABD ratio	1004	1.23 ± 0.27	1.25 ± 0.27	0.63 (0.41 to 0.98)	**.039**

[a] Data are presented as mean ± SD for injured versus uninjured limbs. Hazard ratio (HR), per 1 unit of change for continuous variables, and change in risk when compared to the reference category for categorical variables, are presented with 95% confidence intervals (CI) and p-values from Cox regression analyses accounting for clustering factors (player identity) and using leg as the unit of analysis. Bolded p values indicate statistical significance

[b]Reference group

[c]History of previous injury refers to any injury occurring within 12 months prior to testing.

[d]Reference group: Season 1 (2013/14)

BMI, body mass index. BW, body mass. HQ, hamstring-to-quadriceps ratio. ADD:ADB, adduction-to-abduction ratio

Table 4 Significant risk factors for lower extremity injury from multivariate Cox regression analysis[a]

	HR	95% CI	P value
Lower extremity injury			
Quadriceps concentric at 300 ^{0}/s (Nm)	1.005	1.00 to 1.01	.037
Age	1.04	1.01 to 1.07	.014
Player position[b]			
Defender	1.73	1.06 to 2.80	.027
Midfielder	1.66	1.02 to 2.70	.041
Forward	2.26	1.34 to 3.80	.002
Dominant leg (yes)	1.57	1.21 to 2.05	.001
Season (Season 2)	1.65	1.26 to 2.15	<.001
Acute injury			
Age	1.04	1.01 to 1.07	.018
Dominant leg (yes)	2.08	1.54 to 2.80	<.001
Season (Season 2)	1.66	1.25 to 2.21	<.001
Overuse injury			
Quadriceps concentric at 60 ^{0}/s (Nm)	1.004	1.00 to 1.01	.026
Player position[b]			
Defender	2.47	1.16 to 5.26	.020
Midfielder	2.18	1.02 to 4.67	.044
Forward	3.25	1.47 to 7.19	.004
Any knee injury			
Adductor squeeze 45^{0} (N/kg)	0.75	0.57 to 0.97	.032
Previous knee injury[c]	2.43	1.28 to 4.61	.007
Acute knee injury[d]			
BMI	1.19	1.02 to 1.39	.032

[a]Hazard ratio (HR) per 1-unit of change for continuous variables and change in risk when compared to the reference category for categorical variables, are presented with 95% confidence intervals (CI) and p-values from Cox regression analysis accounting for clustering factors (player identity) and using leg as the unit of analysis.
[b]Reference group: goalkeeper
[c]History of previous injury refers to any injury occurring within 12 months prior to testing.
[d]Acute knee injury refers to acute ligament, meniscus or cartilage injuries.
BMI, body mass index.

Risk factors for acute injuries

A total of 203 legs were affected by acute injuries during the two seasons, and 302 injuries were recorded. In the univariate analysis, players with a greater eccentric hip ADD:ABD ratio were less likely to sustain an acute injury (Table 5). None of the other strength variables were significantly associated with an acute injury. Age, injury to the dominant leg and playing in season two were other factors associated with acute injuries. In the multivariate model, these factors remained significant. Neither

ADD:ABD ratio nor any of the other strength variables were significantly associated with acute injury in the multivariate model (Table 4).

Risk factors for overuse injuries

Of the 236 overuse injuries recorded in 169 legs, greater concentric quadriceps peak torque at 60 °/s and greater concentric hamstring peak torque at 60 °/s were associated with an increased risk of overuse injury. Being a defender or forward was also associated with an increased risk of overuse injury (Table 5). Quadriceps concentric peak torque at 60 °/s and player position (compared with goalkeeper) remained a significant predictor of injury in the multivariate analyses (Table 4).

Risk factors for knee injuries

Seventy knees were affected by a knee injury and 85 injuries were recorded, of which 39 injuries represented an acute knee ligament, meniscus or cartilage injury. According to the univariate analysis (Table 5), greater bilateral isometric adductor strength adjusted for body mass was associated with a lower risk for any knee injury. None of the other strength variables were associated with an increased risk of knee injury, whereas players with a previous knee injury were more prone to knee injury. Bilateral adductor strength adjusted for body mass and previous knee injury remained significant in the multivariate model (Table 4).

We performed a sub-analysis on the 39 acute knee ligament, meniscus or cartilage injuries, of which the majority were collateral ligament injuries (48.7%; n=19) and 9 (23 %) were ACL injuries. Of the strength variables, only greater bilateral isometric adductor strength adjusted for body mass was associated with an acute knee ligament, meniscus or cartilage injury (Table 5). Of the other candidate factors, only greater BMI was associated with an increased risk of injury. Only BMI remained significant in the multivariate model (Table 4).

Table 5 Univariate hazard ratios for the relationship between all strength variables and other candidate risk factors and the binary outcome dependent injury variable (n=1028 legs).[a]

Variable	Acute (n=203) HR (95% CI)	Overuse (n=169) HR (95% CI)	Any knee (n=70) HR (95% CI)	Acute knee (n=39)* HR (95% CI)
Age, yrs	**1.04 (1.01 to 1.07)**	1.02 (0.99 to 1.05)	1.01 (0.97 to 1.06)	1.02 (0.96 to 1.08)
Height, cm	1.01 (0.99 to 1.03)	1.001 (0.98 to 1.03)	1.001 (0.97 to 1.04)	0.98 (0.94 to 1.03)
Body mass, kg	1.01 (0.99 to 1.02)	1.005 (0.99 to 1.02)	1.02 (0.99 to 1.05)	1.02 (0.99 to 1.06)
BMI, kg/m^2	1.03 (0.96 to 1.10)	1.03 (0.96 to 1.11)	1.13 (0.99 to 1.29)	**1.23 (1.06 to 1.42)**
Player position				
- Goalkeeper[b]	1.00	1.00	1.00	1.00
- Defender	1.29 (0.82 to 2.06)	**2.59 (1.29 to 5.20)**	0.81 (0.37 to 1.78)	1.07 (0.30 to 3.82)
- Midfielder	1.50 (0.94 to 2.39)	1.93 (0.97 to 3.83)	0.89 (0.40 to 1.96)	1.74 (0.51 to 5.91)
- Forward	1.42 (0.85 to 2.37)	**3.26 (1.58 to 6.72)**	1.49 (0.65 to 3.42)	2.10 (0.58 to 7.57)
History of previous injury[c]				
- Lower extremity injury (yes)	1.10 (0.82 to 1.47)	1.06 (0.76 to 1.48)	1.01 (0.60 to 1.69)	0.89 (0.45 to 1.77)
- Knee injury (yes)	1.49 (0.95 to 2.34)	1.09 (0.65 to 1.85)	**2.18 (1.15 to 4.12)**	2.04 (0.85 to 4.86)
Dominant leg (yes)	**2.08 (1.54 to 2.80)**	1.14 (0.85 to 1.53)	1.33 (0.84 to 2.11)	1.79 (0.94 to 3.38)
Season (season 2)[d]	**1.67 (1.26 to 2.22)**	1.05 (0.77 to 1.44)	1.49 (0.92 to 2.39)	1.03 (0.54 to 1.94)
Quadriceps and hamstring strength				
- Quadriceps concentric at 60^0/s	0.99 (0.99 to 1.00)	**1.004 (1.00 to 1.01)**	0.99 (0.99 to 1.01)	1.004 (0.99 to 1.01)
- BW adjusted (Nm/kg)	0.88 (0.68 to 1.15)	1.30 (0.97 to 1.74)	0.75 (0.49 to 1.15)	0.94 (0.56 to 1.58)
- Quadriceps concentric at 300^0/s	1.002 (0.99 to 1.01)	1.01 (0.99 to 1.01)	1.004 (0.99 to 1.01)	1.01 (0.99 to 1.02)
- BW adjusted (Nm/kg)	1.01 (0.60 to 1.70)	1.49 (0.86 to 2.58)	0.86 (0.34 to 2.15)	1.08 (0.32 to 3.61)
- Hamstring concentric at 60^0/s	1.003 (0.99 to 1.01)	**1.01 (1.00 to 1.01)**	0.99 (0.99 to 1.01)	1.001 (0.99 to 1.01)
- BW adjusted (Nm/kg)	1.07 (0.65 to 1.74)	1.57 (0.99 to 2.46)	0.61 (0.30 to 1.23)	0.62 (0.27 to 1.45)
- Hamstring concentric at 300^0/s	1.004 (0.99 to 1.01)	1.01 (0.99 to 1.01)	1.00 (0.99 to 1.01)	1.01 (0.99 to 1.02)
- BW adjusted (Nm/kg)	1.03 (0.54 to 1.94)	1.33 (0.68 to 2.57)	0.53 (0.16 to 1.74)	0.68 (0.14 to 3.29)
- Hamstring eccentric at 60^0 /s	1.004 (0.99 to 1.01)	1.003 (0.99 to 1.01)	1.002 (0.99 to 1.01)	1.003 (0.99 to 1.01)
- BW adjusted (Nm/kg)	1.16 (0.86 to 1.58)	1.12 (0.83 to 1.51)	0.85 (0.51 to 1.42)	0.82 (0.39 to 1.69)
- HQ concentric ratio at 60^0/s	2.33 (0.65 to 8.39)	0.99 (0.24 to 4.13)	1.25 (0.09 to 16.48)	0.25 (0.004 to 13.58)
- HQ concentric ratio at 300^0/s	0.85 (0.28 to 2.64)	0.75 (0.19 to 3.03)	0.24 (0.03 to 1.81)	0.20 (0.01 to 3.25)

- HQ eccentric to concentric ratio at 60/300 ^{0}/s	1.23 (0.78 to 1.93)	0.88 (0.51 to 1.54)	0.86 (0.34 to 2.19)	0.67 (0.14 to 3.13)
Hip strength				
- Adductor squeeze 45^{0}	1.001 (0.99 to 1.00)	1.00 (0.99 to 1.00)	0.99 (0.99 to 1.00)	0.99 (0.99 to 1.00)
- BW adjusted (N/kg)	1.02 (0.87 to 1.20)	1.04 (0.86 to 1.26)	**0.77 (0.60 to 0.99)**	**0.66 (0.46 to 0.97)**
- Hip eccentric adduction	0.99 (0.99 to 1.00)	0.99 (0.99 to 1.00)	1.002 (0.99 to 1.01)	1.003 (0.99 to 1.01)
- BW and lever arm adjusted (Nm/kg)	0.86 (0.68 to 1.10)	0.94 (0.72 to 1.24)	0.95 (0.67 to 1.35)	0.95 (0.60 to 1.51)
- Hip eccentric abduction	1.003 (0.99 to 1.01)	0.99 (0.99 to 1.00)	1.003 (0.99 to 1.01)	1.004 (0.99 to 1.01)
- BW and lever arm adjusted (Nm/kg)	1.24 (0.92 to 1.66)	0.90 (0.62 to 1.30)	1.03 (0.62 to 1.71)	0.89 (0.42 to 1.92)
ADD:ABD ratio	**0.53 (0.31 to 0.91)**	0.99 (0.54 to 1.82)	0.85 (0.37 to 1.95)	1.15 (0.35 to 3.79)

[a]Hazard ratio (HR) per 1 unit of change for continuous variables and change in risk when compared to the reference category for categorical variables, are presented with 95% confidence intervals (CI) and p-values from Cox regression analysis accounting for clustering factors (player identity) and using leg as the unit of analysis. Bolded p values indicate statistical significance

[b]Reference group

[c]History of previous injury refers to any injury occurring within 12 months prior to testing.

[d]Reference group: Season 1 (2013/14)

BMI, body mass index. BW, body mass. HQ, hamstring-to-quadriceps ratio. ADD:ABD, adduction-to-abduction ratio

*Acute knee injury refers to any acute ligament, meniscus or cartilage injuries.

Muscle strength test characteristics

ROC curve analyses revealed an area under the curve (AUC) of 0.46 and 0.45 for quadriceps concentric strength at 300 ^{0}/s (any lower extremity injury) and 60 ^{0}/s (overuse injury), respectively, and 0.56 for the adductor squeeze test, indicating a failed combined sensitivity and specificity of the strength variables identified as significantly associated with injury risk.

DISCUSSION

The main finding of this large 2-year prospective cohort study on male professional soccer players, was that only two strength variables (out of 20 examined) - greater quadriceps concentric muscle strength at (i) high and (ii) low speed - were associated with an increased risk of lower extremity injury. In addition, a greater bilateral adductor strength adjusted for body mass was associated with a lower risk for a knee injury, a finding not previously reported in soccer.

Association between muscle strength and lower extremity injury

Thigh strength. Our finding of an association between greater quadriceps concentric peak torque strength at high (300^{0}/s) and low (60^{0}/s) speed and risk of injury (lower extremity injury and overuse injury) (Table 4), extends with two other reports to suggest that greater quadriceps strength increases risk of lower extremity injury (particularly for a thigh muscle injury).[19, 49] Despite the statistically significant association, the HR demonstrated merely a 0.4% to 0.5% increase in injury risk per 1-unit increase in concentric quadriceps strength (mean difference of 3.4 Nm [136.6 vs 133.2 Nm] and 8.0 Nm [240.6 vs 232.6 Nm], respectively). This finding, in addition to the small group difference in strength between the injured and uninjured players (2.5 % and 3.4% strength difference, respectively), means it is essentially impossible to distinguishing the injured and uninjured groups clinically. Furthermore, the smallest detectable difference (SDD) for concentric quadriceps peak torque is about 20%,[39] so the difference in strength between the injured and uninjured groups is equivalent to test-retest variability. It may be argued that intrinsic risk factors, such as muscle strength, are more relevant for non-contact than for contact injuries. Interestingly, the association between greater quadriceps concentric peak torque strength at high speed (300^0/s) remained the same (weak) when contact injuries were excluded, suggesting that the clinical value of this finding remains limited.

We found no association between any of the 13 isokinetic strength variables evaluated and the risk of acute lower extremity injuries or knee injuries, which argues against using isokinetic quadriceps and hamstring strength as an injury prediction tool. Our study extends those of a prospective study on acute ACL injury risk in male military academy cadets.[47]

Hip strength. We found no association between any of the hip strength variables examined (eccentric adductor and abductor strength, as well as bilateral isometric adductor strength) and risk of all lower extremity injury, nor acute or overuse injuries. In contrast, low adductor strength proved a risk factor for groin injuries in two recent meta-analyses on athletes in field-based sports.[42, 51] A plausible explanation for the apparent discrepancy may be that while low hip adductor strength may be associated with greater risk of groin injuries specifically, this effect may be diluted when looking at lower extremity injuries in general, even if muscle injuries comprised almost 50% of the injuries included in the current study (of which 28% were adductor-related injuries). Our results lend no support using these hip strength variables to identify the player at risk of lower extremity injury.

Interestingly, we identified greater bilateral adductor strength, adjusted for body mass, as a protective factor for any knee injury, decreasing injury risk by 23% per 1 N/kg increase in strength (which represents a 6% increase in strength relative to the group mean). This has previously not been described as an independent risk factor for knee injury, and contrasts with previous reports of the association between hip abductor weakness and increased risk of ACL injury and patellofemoral pain.[16, 25] However, although statistically significant, the group difference in bilateral adductor strength between injured and uninjured players was small (3.14 vs 3.34 N/Kg, respectively, corresponding to a mean difference of -0.2 N/Kg). In addition, the SDD for the adductor squeeze test is between 11% to 13%,[28] which most likely renders these findings clinically invaluable.

Muscle imbalance. There was no association between any of the ratios examined in the current study (HQ-ratio and ADD:ABD ratio) and the risk of lower extremity injury, regardless of injury type (lower extremity injury, acute, overuse or knee injury). Although univariate analyses revealed that players with a lower ADD:ABD ratio were at increased risk of lower extremity injury, these findings were not confirmed in the multivariate model. Our findings suggest that muscle imbalance as expressed in a HQ-ratio or ADD:ABD ratio do not identify players at risk of a lower extremity injury. Similar findings have been reported for the HQ-ratio in a meta-analysis on risk factors for hamstring injuries.[19] In contrast to our result, two recent systematic reviews on risk factors for groin injury report ADD:ABD ratio as a significant risk factor.[42, 51]

The predictive ability of muscle strength testing

In addition to demonstrating an association with injury, a valid screening test to predict sports injury should distinguish athletes at high risk of injury from those who are not.[1] The ROC curve analysis revealed an AUC of < 0.50 (0.46 for quadriceps concentric strength at 300°/s and 0.45 for quadriceps concentric at 60°/s) for strength variables identified as potential risk factors for lower extremity injury, confirming that these variables are no better than chance (or flipping a coin) in predicting the player at risk of lower extremity injury.[35] This inability to predict injury is substantiated by the small association and group difference in strength between the injured and uninjured players for these two strength variables; there was no cut-off point on the horizontal (bilateral adductor strength score) axis that would allow us to distinguish injured and uninjured players. Similarly, the ROC curve analysis for bilateral adductor strength revealed an AUC of 0.56, confirming that the ability of the strength variable to predict the player at risk of knee injury was also poor.

Should muscle strength tests be used to screen for injury risk in professional soccer?

While our results suggest that muscle strength testing is not useful as a screening test to identify the individual players at risk, it does not necessarily mean clinicians should not use muscle strength testing in pre-season screening. Such testing may identify current conditions that require further assessment or treatment.[4] It is possible to intervene with strength training to reduce lower extremity injuries in soccer.[3, 44] For example, implementation of eccentric hamstring strength, the Nordic hamstring exercise, reduces the risk of acute hamstring injuries by at least 50%. [3, 40, 48] Specific adductor strength training can prevent groin injuries in sub-elite soccer players.[23] Based on our results, such prevention programs should be implemented at a group level (i.e. team) rather than on the individual level based on screening tests.

In addition, strength testing may also be a useful baseline measure as a reference point for a future return to play decision and perhaps also as a measure of the effect of strength training programs to prevent injury. Injuries generally result from a complex interaction of multifactorial factors;[33] a player's injury risk is probably dynamic and subject to frequent changes in external factors (heavy training load, congested playing schedule or psychological factors).[33, 34] Multiple assessments (or monitoring) of the player throughout the sport season may represent a more suitable strategy to prevent injury.[20] Wollin et al[52] recently reported clinically meaningful isometric adductor strength reduction during periods of match congestion in elite youth soccer players compared to baseline, when players were monitored daily for adductor strength.

Methodological considerations

To detect strong to moderate associations in a prospective cohort study, 30 to 40 injury cases are required,[2] whereas 200 injury cases are required to detect small to moderate associations.[2] The large number of participants and injured players represents a strength in the current study (n=294 injured players).

The organization of sports medicine care in Qatar, with all club medical doctors being part of the centrally regulated National Sports Medicine Program (NSMP), allowed for standardization of injury and exposure recording.

Limitations to the present study include that the team medical staff responsible for the injury and exposure reporting were not blinded to the muscle strength score. Also, we did not control for preventive measures that may have been implemented based on the player´s strength test score during the study period. Given the high number of injuries recorded during the two seasons (n=538), we believe these factors represent a low risk of bias.

We acknowledge that the strength tests examined in the current study are commonly used to identify risk of muscle injury to the thigh, particularly to hamstring strain and groin injuries, and not for identifying the risk of lower extremity injury in general. However, these tests are frequently used in the assessment of other injury types (i.e. knee injury) than hamstring strain and groin injuries. For this reason, we performed sub-analysis for acute, overuse injuries and knee injury.[5, 7, 16] Given muscle strength is considered an important factor in the injury causation,[7, 34] we believe examining the injury prediction value of these tests for any injury type is valuable.

We measured strength with standard measurement procedures widely used in clinical practice.[32, 51] Other testing protocols may yield different results, particularly for the isokinetic strength testing. Measuring knee extension and flexion strength at different angular velocities provides additional information on quadriceps strength deficits after ACL injury.[12]

Although our sample size was large and allowed for small to moderate association to be detected for lower extremity injuries, overuse and acute injuries,[2] the limited number of knee injuries reduced the statistical power for such subgroup analyses. This may have affected the conclusions drawn, and potential associations may have been masked.

Another limitation is related to the fact that injuries were from different mechanisms (contact or non-contact). We relied on the team doctor to classify the injury as contact or non-contact, but this was often not reported, perhaps because it may be difficult to interpret what happens in an injury situation.[26] As a result, the statistical power to perform sub-group analyses other than for any lower extremity injury was limited.[2]

Finally, our study included male professional soccer players, which limits the generalizability of the findings to other sports, age groups, athletes at lower performance level and females.

CONCLUSION

This study identified only a weak association with the risk of lower extremity injury for two strength variables; quadriceps concentric muscle strength at (i) high and (ii) low speed. These associations were too small to identify the individual player at risk of injury. Therefore, strength testing, as performed in the present study, cannot be recommended as a screening test to predict injury in professional male soccer.

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Paper III

The functional movement test 9+ is a poor screening test for lower extremity injuries in professional male football players: a 2-year prospective cohort study

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The functional movement test 9+ is a poor screening test for lower extremity injuries in professional male football players: a 2-year prospective cohort study

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ABSTRACT

Background The 9+ screening battery test consists of 11 tests to assess limitations in functional movement.
Aim To examine the association of the 9+ with lower extremity injuries and to identify a cut-off point to predict injury risk.
Methods Professional male football players in Qatar from 14 teams completed the 9+ at the beginning of the 2013/2014 and 2014/2015 seasons. Time-loss injuries and exposure in training and matches were registered prospectively by club medical staff during these seasons. Univariate and multivariate Cox regression analyses were used to calculate HR and 95% CI. Receiver operating characteristic (ROC) curves were calculated to determine sensitivity and specificity and identify the optimal cut-off point for risk assessment.
Results 362 players completed the 9+ and had injury and exposure registration. There were 526 injuries among 203 players (56.1%) during the two seasons; injuries to the thigh were the most frequent. There was no association between 9+ total score and the risk of lower extremity injuries (HR 1.02, 95% CI 0.99 to 1.05, p=0.13), even after adjusting for other risk factors in a multivariate analysis (HR 1.01, 95% CI 0.98 to 1.04, p=0.37). ROC curve analysis revealed an area under the curve of 0.48, and there was no cut-off point that distinguished injured from non-injured players.
Conclusion The 9+ was not associated with lower extremity injury, and it was no better than chance for distinguishing between injured and uninjured players. Therefore, the 9+ test cannot be recommended as an injury prediction tool in this population.

INTRODUCTION

Injuries in professional football are common, with injuries to the lower extremity accounting for nearly 90% of all time-loss injuries in senior male professional players.[1–4] Given the negative impact on player performance,[5 6] financial cost[7] and possibly long-term player health,[8 9] there is interest in using screening tools to identify players at risk for injury with a view to prescribing individualised prevention measures.[10–12]

Functional movement tests are popular screening tools within professional football as well as other sports,[8 13] and they all purport to be able to identify players at risk of injury.[14 15] One such tool is the Nine Plus screening battery (9+).[16] This relatively new tool aims to identify limitations in fundamental movement patterns that predispose athletes to injury.[16] The 9+ consists of six tests with modified criteria from the Functional Movement Screen (FMS).[16–18] In addition, Frohm *et al*[16] included five additional tests to fill a gap for tests challenging dynamic trunk flexors, rotation of the spine and knee control and strength.[16 19] Each movement test is scored on a four-point scale (3-0) with a maximum score of 33 points.

The ability of the 9+ to predict injury is unknown. However, studies using the FMS have shown a significantly higher injury risk among individuals with low FMS scores, using a cut-off score of 14 out of 21 possible points.[15] Still, the sensitivity seems to be low; the receiver operating characteristic (ROC) curve indicates that the overall predictive validity of the FMS was only slightly better than chance.[20]

We recently demonstrated that there is substantial intraindividual variability in the 9+ total score between two consecutive seasons, irrespective of injury.[21] We therefore questioned the validity of 9+ as a screening tool to identify the athlete at risk.

The purposes of the present study were to (1) examine the association of the 9+ total score with lower extremity injuries in professional male football players, (2) identify the optimal cut-off point to predict lower extremity injuries and (3) assess the association of the 9+ with the most common injury types in football (hip/groin, thigh, knee, lower leg and ankle injuries).

METHODS

Study design and participants

The present study analysed prospectively collected data from a periodic health evaluation (PHE) of male professional football players in Qatar.[22] All players eligible to compete in the Qatar Stars League (QSL), the professional first division of football in Qatar, were invited to participate as they presented for their annual PHE at the Aspetar Orthopaedic and Sports Medicine Hospital in Doha (Qatar) during the 2013/2014 and 2014/2015 seasons. The PHE was performed mainly during the preseason period (66.6%) (July through September), with a small group completing the tests during the early/mid competition phase (23.8%) (October through December) each year and a minor group postseason (9.7%) (end of April through June) in 2014.

The players performed the 9+ test as part of the musculoskeletal component of the PHE. All players who competed for QSL clubs during the 2013 and 2014 season, did not report a current injury or physical complaint limiting training or match play at the time of testing and completed the entire 9+ were eligible for analysis. Ethical approval was obtained from the Institutional Review Board, Anti-Doping Lab Qatar. All players signed a written informed consent form at inclusion.

Study procedure

Fourteen experienced sports physiotherapists who all worked at the study institution performed the 9+ testing during the study period. Prior to testing, all physiotherapists had to undergo a 2-day course with the inventors of the 9+,[16] in addition to performing the 9+ regularly in their clinical practice.

The 9+ screening battery was performed as described by Frohm *et al*.[16 19] The 9+ comprises 11 functional movement exercises to assess stability, mobility and neuromuscular control in the kinetic chain, demonstrating moderate to good inter-rater reliability (intraclass correlation coefficient [ICC] ranging from 0.68 to 0.80).[16 21] The exercise items are the deep squat, in-line lunge, shoulder mobility, trunk stability push-up, active hip flexion and diagonal lift (all from the FMS with modified criteria) and one-legged squat, deep one-legged squat, drop jump test, seated rotation and straight leg raise. Seven of the 11 tests are assessed bilaterally, looking for asymmetries between left and right. For these tests, the left extremity was tested first, and the lower of the two scores for the left and right side was used for data analysis. Each movement test was scored on a four-point ordinal scale (3–0), with three representing correct completion of the task with no compensatory movements, two correct but with presence of compensatory movement, one incorrect despite compensatory movements and 0 if pain was present. Thus, each player could reach a maximum score of 33 points. A more detailed description of the 9+ movements is provided by Frohm *et al*.[16 19]

All players performed the tests barefoot, with shorts and a t-shirt, except for the drop jump test. As described by Frohm *et al*,[19] the players wore their own training shoes for this test. Due to equipment availability, the participants performed the drop-jump test from a 30 cm box, not a 40 cm box height as described by Frohm *et al*.[19] The physiotherapists gave a standardised verbal instruction and showed the player a photo of the starting and finishing position of an optimally performed exercise. Each player performed each test three times, and the maximum score achieved was recorded and used for evaluation of test performance. Verbal corrections were given during the three trials to achieve the most optimal performance. The complete assessment took 20–30 min to complete.

Player characteristics data (ie, age, date of birth, player position) and previous injury history (lower extremity injury, groin, hamstring, quadriceps femoris, knee and ankle injury) were collected from the FIFA precompetition medical assessment form completed during the medical part of the PHE on the same day as the 9+ test.[22] A previous lower extremity injury was defined as any time-loss injury occurring within 12 months before the PHE. Height and weight were measured before the 9+ assessment.

Injury registration

Injuries and exposure data were obtained from the Aspetar Injury and Illness Surveillance Program (AIISP). The AIISP includes prospective injury and exposure (minutes of training and match play) recording from all 14 QSL teams.[4 23] An injury was recorded if the player was unable to fully participate in football training or match play for at least 1 day beyond the day of injury (time-loss injury).[4 23] The player was considered injured until declared fit for full participation in training and available for match selection by medical staff.

The team physician (or head physiotherapist when no physician was available) for each team recorded all injuries and individual training and match exposure daily throughout the 2013 and 2014 football season (July–May; 44 weeks). For each injury recorded, the team physician/physiotherapist completed a standardised injury card containing information on the body part injured, injury type and specific diagnosis. In addition, the injury card included questions related to re-injury, overuse or acute injury mechanism (contact or collision), as well as information on whether the injury occurred during training or match.[23] Injury severity was determined by the number of days absent from matches or training sessions due to injury and was classified as mild (1–3 days), minor (4–7 days), moderate (8–28 days) or severe (>28 days).[23] Injury and exposure data were requested monthly by the study group, and the accuracy was checked regularly and clarified with the team doctor if needed.

Statistical analyses

Data were analysed with IBM SPSS statistics, V.21.0. Descriptive data are presented as the mean±SD unless otherwise stated. Individual exposure data were calculated as sum of the total number of hours of training and match play from the individual player's screening date to the end of the season for each season or date until the first injury. To examine the relationship between any lower extremity injury (yes/no) with 9+ total score and other potential risk factors (anthropometric data, player position, previous injury and season), we used Cox regression analysis (STATA V.11.0) with each player as the unit of analysis. The 9+ test score for each season was used as a predictor for injury (yes/no) for that respective season. To account for the repeated measures performed over the two seasons, as well as the fact that not every participant had the same number of measurements (ie, some participants would have test results for both seasons, some for only one season), the player ID was used to cluster the related observations when estimating the Cox model.

Similar and separate analyses were performed for assessing relationship between 9+ total score and injuries to the hip/groin, thigh, knee, lower leg and ankle. Injuries to the foot/toe were excluded from these analyses because of the low number of such injuries (n=19).

The HRs presented with 95% CIs are per one unit of change in the independent continuous risk factor (9+ scores, anthropometric data). For categorical variables (season, player position and previous injury history), HR with 95% CIs represents change in risk when compared with the reference category. After the univariate analyses, all factors with a p value of <0.20 were investigated further in a multivariate model. A p value of <0.05 was considered as statistically significant.

ROC curves were calculated to describe the sensitivity and specificity of the 9+ test for each dependent variable. The area under the curve (AUC) indicates how well the 9+ total score would discriminate between injured and uninjured players and was interpreted as excellent (1.00–0.90), good (0.90–0.80), fair (0.80–0.70), poor (0.70–0.60) or fail (<0.60).[24 25] The ROC curve was also used to determine an optimal cut-off point for identifying high- and low-risk players for lower extremity injuries. Identified cut-offs with maximum sensitivity and specificity were further used as a factor in the Cox regression analysis as described above to evaluate differences in injury risk. We also calculated the likelihood ratio (LR). LR is a combination of sensitivity and specificity values reported as a ratio used to

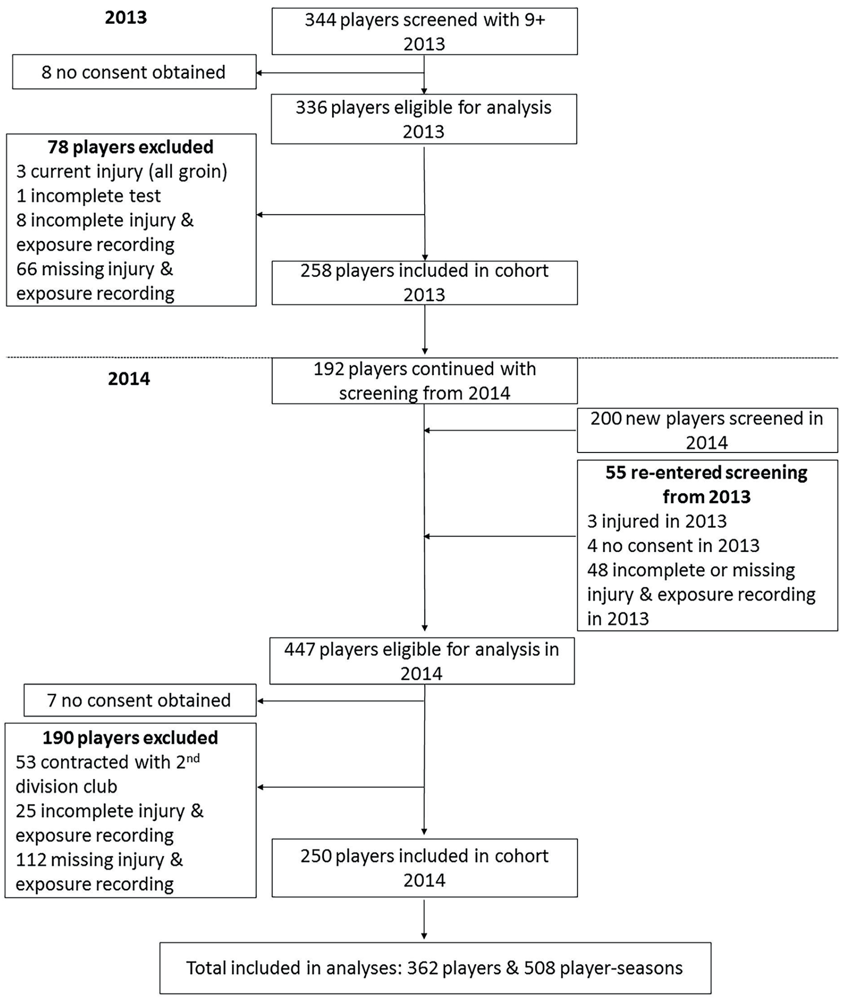

Figure 1 Flow chart demonstrating the movement of players and repeated 9+ between the two seasons.

determine whether a test result usefully changes the probability that a condition exists.[26]

RESULTS

Participants

The inclusion process is shown in figure 1. The final sample included 362 players who provided complete data sets for both 9+ and the prospective injury and exposure registration (age 26.0±4.7 years, height 177±7 cm, weight 72±9 kg, body mass index 23.0±1.9 kg/m^2). The players included participated in a total of 508 player-seasons (n=216 played one season, n=146 two seasons) and represented 42 nationalities, the majority from the Middle East (65.2%). By ethnicity, 54.7% were Arab, 30.7% black, 5.2% Caucasian, 1.7% East Asian, 5.5% Persian and 2.2% other. A history of previous lower extremity injury was reported by 34.5% of the players. Player positions included 40 goalkeepers (11%), 126 (34.8%) defenders, 130 (35.9%) midfielders and 66 (18.2%) forwards. The mean 9+ total score of the players (n=362) was 22.5±4.0, ranging from 13 to 31.

Injury and exposure characteristics

In total, 203 of the 362 (56.1%) players sustained at least one lower extremity injury during the two seasons, and a total of 526 lower extremity injuries were reported. During the 2013 season, 143 of the 258 players included sustained at least one lower extremity injury, while 140 of the 250 players included during the 2014 season experienced at least one lower extremity

Table 1 Characteristics of lower extremity injuries (n=526) related to location and injury type

Injury type (body part injured)	Muscle strain	Muscle cramps/spasm	Sprain/ligament injury	Contusions	Meniscus/cartilage lesion	Tendon injury	Fracture	Other	Total (%)
Hip/groin	69	19	–	2	–	17	–	9	116 (22.0)
Thigh	101	32	–	18	–	9	–	1	161 (30.6)
Knee	–	–	30	16	14	18	–	7	85 (16.2)
Lower leg	23	13	–	8	–	12	3	4	63 (12.0)
Ankle	–	–	55	19	–	1	2	5	82 (15.6)
Foot/toe	–	–	2	7	–		6	4	19 (3.6)
Total (%)	193 (36.7)	64 (12.2)	87 (16.5)	70 (13.3)	14 (2.7)	57 (10.8)	11 (2.1)	30 (5.7)	526 (100)

injury. A muscle strain to the thigh was the most frequent injury type (table 1). More than half of the injuries occurred during training (52.7%, n=277), and the majority of the injuries were moderate (n=207, 39.4%), leading to an absence from football training and match play for 8–28 days.

The mean player exposure was 214±93 hours per season, 189±88 hours of training and 25±16 hours of match play.

9+ and lower extremity injuries

The results of the univariate analyses are shown in table 2. As shown in figure 2, there was substantial overlap in the frequency distribution of the 9+ total score between the injured and uninjured groups. Consequently, there was no association between 9+ total score and the risk of sustaining a lower extremity injury (HR 1.02, 95% CI 0.99 to 1.05, p=0.13). Also, the outcome was the same when hip/groin, thigh, knee, lower leg and ankle injuries were used as the dependent variable in separate univariate analyses (table 3).

Age, player position and season were the only factors associated with an increased risk of lower extremity injury and remained significant in the multivariate model. The 9+ total score remained not significant even after adjusting for other candidate risk factors (table 4).

We also performed similar and separate subanalyses assessing the relationship between 9+ total score and overuse (n=161) and acute (n=201) injuries, respectively. There was no association between 9+ total score and the risk of overuse injuries (HR 1.003, 95% CI 0.97 to 1.04, p=0.85) nor with acute injuries (HR 1.02, 95% CI 0.99 to 1.06, p=0.18) (see online supplementary tables A1 and A2). The outcome remained the same when adjusting for other candidate risk factors in a multivariate analysis (table 4).

Risk factors for hip/groin injuries

A total of 116 hip/groin injuries were recorded in 92 players, mainly adductor strain (n=55, 47.4%). Anthropometric data, age, previous groin injury and player position were not associated with an increased risk of hip/groin injuries (see online supplementary table A3). Since none of the candidate risk factors had a p value of <0.20 in the univariate analysis, no multivariate analysis was performed.

Risk factors for thigh injury

Of the 161 thigh injuries recorded in 120 players, 105 (65.2%) affected the hamstring muscles. Univariate analysis identified only age as a candidate risk factor for a thigh injury (see online supplementary table A4); however, this factor did not remain significant in the multivariate model (table 4).

Risk factors for knee injury

Sixty-nine players sustained at least one knee injury, and 85 injuries were recorded, of which eight were ACL injuries. A

Table 2 Univariate analysis comparing player-seasons with and without lower extremity injury (n=508 player-seasons)

	n	Injured (n=283), mean±SD	Uninjured (n=225), mean±SD	HR	95% CI	p-Value
9+ total score	508	22.9±3.8	22.7±4.1	1.02	0.99 to 1.05	0.13
Age, years	508	27.0±4.8	25.8±4.7	1.04	1.01 to 1.06	0.005
Height, cm	508	177±7	176±7	1.005	0.99 to 1.02	0.59
Weight, kg	508	73±9	72±9	1.01	0.995 to 1.02	0.23
BMI, kg/m^2	508	23.1±2.0	23.0±1.9	1.04	0.98 to 1.10	0.18
Previous lower extremity injury,* n (%)	492	97 (35.0)	76 (35.3)	1.05	0.81 to 1.36	0.72
Player position, n (%)	508					
Goalkeeper†		23 (8.1)	33 (14.7)	1.0	1.0	
Defender		100 (35.3)	76 (33.8)	1.63	1.07 to 2.48	0.02
Midfielder		104 (36.7)	87 (38.7)	1.59	1.05 to 2.42	0.03
Forward		56 (19.8)	29 (12.9)	2.05	1.31 to 3.20	0.002
Season, n (%)	508					
Season 1†		143 (50.5)	115 (51.1)	1.0	1.0	
Season 2		140 (49.5)	110 (48.9)	1.31	1.03 to 1.65	0.02

Data are presented as mean±SD for injured versus uninjured players. HRs per one unit of change for continuous variables (ie, 9+ score) and change in risk when compared with the reference category for categorical variables are presented with 95% CIs and p values from Cox regression analysis accounting for clustering factors (player ID) and using player as the unit of analysis.

*History of previous injury refers to any lower extremity injury occurring within 12 months prior to the 9+ test.

†Reference group in analysis.

BMI, body mass index.

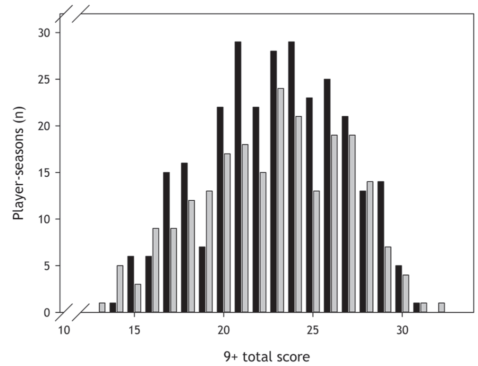

Figure 2 Distribution of 9+ score in the injured (n=283) versus uninjured groups (n=225). Black bars represent the injured group; grey bars, the uninjured group.

previous knee ligament injury and playing in season two were the only factors associated with an increased risk of knee injury (see online supplementary table A5). In the multivariate model, only a previous knee ligament injury was found to increase the risk of a knee injury (table 4).

Risk factors for lower leg

Of the 63 lower leg injuries in 52 players, age and playing in season 2 were the only factors associated with lower leg injuries (see online supplementary table A6); season was also significant in the multivariate analysis (table 4).

Risk factors for ankle injury

Being a defender was the only factor associated with 82 ankle injuries in 75 players (see online supplementary table A7) and remained significant in the multivariate model (table 4).

9+ test characteristic for lower extremity injuries

Analysis of ROC curves revealed an AUC of 0.48 (95% CI 0.43 to 0.54, p=0.53) for lower extremity injuries, indicating a failed combined sensitivity and specificity of the 9+ total score to predict lower extremity injury. The outcome was the same whether hip/groin injuries (AUC 0.53, 0.47 to 0.60, p=0.36), thigh injuries (AUC 0.51, 0.45 to 0.57, p=0.68), knee injuries (AUC 0.46, 0.39 to 0.52, p=0.27), lower leg (AUC 0.45, 0.37 to 0.54, p=0.25), ankle injuries (AUC 0.47, 0.40 to 0.54, p=0.36), overuse injuries (AUC 0.51, 0.45 to 0.56, p=0.82) or acute

Table 3 Univariate analysis for the relationship between 9+ total score and each binary outcome-dependent injury variable (n=508 player-seasons)

Injury location	HR	95% CI	p Value
Hip/groin	0.98	0.93 to 1.03	0.52
Thigh	0.99	0.95 to 1.04	0.84
Knee	1.05	0.99 to 1.10	0.09
Lower leg	1.05	0.98 to 1.12	0.15
Ankle	1.04	0.98 to 1.10	0.21

HR per one unit of change in 9+ scores is presented with 95% CIs and p values from Cox regression analysis accounting for clustering factors (player ID) and using player as the unit of analysis.

Table 4 Multivariate analyses for 9+ total score including all candidate risk factors achieving p<0.20 in the univariate analyses for all dependent variables

	HR	95% CI	p Value
Lower extremity			
9+ total score	1.01	0.98 to 1.04	0.37
Age	1.03	1.01 to 1.06	0.01
BMI	1.04	0.97 to 1.10	0.25
Player position*			
Defender	1.79	1.16 to 2.77	0.01
Midfielder	1.80	1.17 to 2.76	0.01
Forward	2.28	1.44 to 3.61	<0.001
Season†	1.30	1.02 to 1.64	0.03
Thigh			
9+ total score	0.98	0.93 to 1.03	0.39
Age	1.04	0.998 to 1.07	0.06
Previous QF injuries	1.86	0.65 to 5.31	0.25
Player position*			
Defender	1.65	0.76 to 3.60	0.20
Midfielder	1.56	0.72 to 3.40	0.26
Forward	1.89	0.82 to 4.37	0.14
Season†	1.39	0.96 to 2.01	0.08
Knee			
9+ total score	1.03	0.97 to 1.09	0.34
BMI	1.11	0.96 to 1.28	0.16
Previous knee injury	2.15	1.10 to 4.21	0.02
Season†	1.44	0.86 to 2.38	0.16
Lower leg			
9+ total score	1.02	0.95 to 1.10	0.51
Age	1.06	0.999 to 1.13	0.05
Season†	2.07	1.21 to 3.54	0.01
Ankle			
9+ total score	1.04	0.98 to 1.10	0.21
Player position*			
Defender	2.82	1.05 to 7.58	0.04
Midfielder	2.42	0.90 to 6.51	0.08
Forward	1.34	0.42 to 4.24	0.62
Overuse			
9+ total score	1.005	0.97 to 1.04	0.81
Player position*			
Defender	2.25	1.15 to 4.42	0.02
Midfielder	1.68	0.86 to 3.26	0.13
Forward	2.71	1.35 to 5.46	0.005
Acute			
9+ total score	1.005	0.97 to 1.04	0.77
Age	1.04	1.01 to 1.07	0.01
Player position*			
Defender	1.37	0.86 to 2.19	0.19
Midfielder	1.58	0.99 to 2.53	0.06
Forward	1.59	0.96 to 2.63	0.07
Season†	1.69	1.26 to 2.25	<0.001

HRs per one unit of change for continuous variables (ie, 9+ score) and change in risk when compared with the reference category for categorical variables are presented with 95% CIs and p values from Cox regression analysis accounting for clustering factors (player ID) and using player as the unit of analysis.
Since none of the candidate risk factors had a p value of <0.20 in the univariate analysis for hip/groin injuries, no multivariate analysis was performed.
*Reference category for player position: goalkeeper.
†Reference category: season 1 (2013).
BMI, body mass index; QF, quadriceps femoris.

Table 5 Univariate analysis 9+ total score and lower extremity injury risk using a cut-off ≤23 derived from the ROC curve analysis

9+ score	Injured (n=283),	Uninjured (n=225),	HR	95% CI	p Value
≤23	152	126	0.84	0.66 to 1.07	0.17
>23	131	99	1.0		

HR per one unit of change in 9+ scores is presented with 95% CIs and p values from Cox regression analysis accounting for clustering factors (player ID) and using player as the unit of analysis.

injuries (AUC 0.48, 0.43 to 0.54, p=0.57) were used as main outcomes.

Although the intention of the study was to determine the optimal cut-off point for lower extremity injury risk screening, the ROC curve analysis could not provide a point that maximised specificity and sensitivity. However, derived from the ROC curve, we examined a cut-off of ≤23 points, which provided the best maximum sensitivity and specificity as a predictor for lower extremity injury. The corresponding sensitivity and specificity were 0.54 (95% CI 0.48 to 0.60) and 0.44 (95% CI 0.37 to 0.51), respectively, with a positive LR (LR+) of 0.96 (95% CI 0.82 to 1.12) and negative LR (LR−) of 1.05 (95% CI 0.92 to 1.21). There was no increased risk of lower extremity injury for those who scored ≤23 points compared with those who scored >23 points (table 5). The same results were found in the multivariate model when adjusting for all candidate risk factors listed in table 2 (HR 0.90, 95% CI 0.71 to 1.15, p=0.41 compared with the >23).

DISCUSSION

In this large prospective cohort study on professional football players, the 9+ total score was consistently not associated with an increased risk of lower extremity injury, even after adjusting for other potential risk factors in a multivariate analysis. There was considerable overlap in 9+ scores between injured and uninjured players, and ROC analyses revealed no cut-off point to identify the at-risk player, as shown in figure 2, indicating a complete failure in discriminating between injured and uninjured players based on the 9+ total score.

9+ test and predicting injury in professional male football players

The lack of association between 9+ total score and risk of lower extremity injury argues against the use of the 9+ test as an injury prediction tool.[27] Although a direct comparison of the test batteries and study methodologies cannot be made, comparable findings were reported in recent studies on the FMS among football players.[28–32] Two recent meta analysis on the FMS drew similar conclusions that the FMS does not allow clinicians to predict injuries[20 33]

We also found no association between 9+ total score and hip/groin, thigh, knee, lower leg and ankle injuries. Compared with the FMS, the 9+ comprises three additional tests that assess knee control and strength. Excessive knee valgus motion is a key feature of the mechanisms of ACL injury, particularly in the female athlete population.[34–36] The added tests are frequently used in return-to-sport decision making, to measure treatment response and as screening tools for knee injuries (ACL and patellofemoral pain); however, their usefulness for injury prediction is debated.[27 37–39] Given this, and the relatively low number of knee injuries and poor reliability identified for these three tests in our population,[21] our analyses should be interpreted with caution.

It is argued that decreased movement quality (as assessed on the 9+ and FMS) resulting from decreased range of motion and reduced neuromuscular control increases the risk of overuse injury.[40 41] However, we found no association between 9+ total score and overuse injuries nor with acute injuries. Comparable findings have been reported in studies on FMS among college athletes.[42 43]

For a screening test to predict sports injury, in addition to demonstrating an association with injury, it also needs to identify the athlete at high risk of injury compared with those who are not.[27] The ROC curve analysis revealed an AUC of only 0.48, indicating that the 9+ test is no better than chance in predicting lower extremity injuries. This inability to predict injury is substantiated by the complete overlap and similar distributions of the 9+ total scores for the injured and uninjured groups; there is no cut-off point we could place on the horizontal (9+ score) axis which would allow us to separate injured and uninjured players. Comparably low AUCs have also been reported in other studies on the FMS.[20 28 32 44] Examining specific injury subgroups, we also observed a similarly low AUC for hip/groin, thigh, knee, lower leg and ankle injuries. Therefore, the 9+ test has poor accuracy as an injury prediction tool for any of these most common injury types in football.

Frohm *et al*[16] in their reliability study of the 9+ on elite football players hypothesised that a 9+ total score below 67% (22 points) was the threshold at which players were predisposed to injury. Our ROC curve analysis could not identify a clinically useful cut-off point. A cut-off of ≤23 (≤69.7% of the possible maximum of 33 points) provided the best fit for sensitivity and specificity, comparable to the recently debated cut-off point of 67% (≤14 points of possible 21) of the FMS.[11 14 15 20] Nevertheless, this cut-off provided a sensitivity and specificity of 0.54 and 0.44, respectively, demonstrating that the discriminatory ability is only slightly above chance.[45] Therefore, it is not surprising that there was no increased risk of lower extremity injury for those who scored ≤23 compared with those who scored >23. The LR+ of 0.96 further demonstrates that when the test is positive, the athlete is slightly less likely to suffer an injury in the subsequent season. Although the LR+ 95% CI crossed one (0.82 to 1.12), the post-test probability of an injury is altered to an insignificant degree, if at all, by the 9+ test. Comparable findings were reported in a recent meta-analysis on the FMS.[20]

Clinical implications

Functional movement tests, including the 9+, are growing in popularity as an injury screening tool putatively as they provide clinicians with information about an individual's risk of injury.[8 15] The validity of the FMS as an injury prediction tool has been scrutinised recently and with conflicting results. Wright *et al*[11] in an editorial concluded that because of this inconsistency in findings and low accuracy (sensitivity and LR−), the FMS cannot confidently be used as an injury prediction tool. The 9+ appears to exhibit similar properties. Based on our results, the 9+ total score should not be used to screen the athlete at risk for lower extremity injuries. Although our results show that using the 9+ total score to predict injury is no better than flipping a coin, this does not necessarily mean that clinicians should stop using functional movement tests. They may still hold value to detect deficits or asymmetries that could require further assessment or treatment.[22]

Methodological considerations

The large number of participants and injured players represents a strength of the current study. Bahr and Holme[46] suggested that 30–40 injury cases would be needed to detect strong to moderate associations and that 200 injury cases are needed to find small to moderate associations. Also, the organisation of sports medicine care in Qatar with all club medical doctors and physical therapists being part of the centrally regulated National Sports Medicine Programme (NSMP) allowed for standardisation of injury and exposure recording. The present study was performed in a professional athlete setting, using multiple testers. This provides good generalisability but might have also adversely influenced the inter-tester reliability. We found only moderate reliability between our testers in a recent study on the inter-season variability of the 9+ test.[21]

Limitations to the present study include that the team physician or physiotherapist responsible for the injury and exposure reporting was not blinded to the 9+ test score. Also, we did not record if any prevention interventions occurred in the teams based on the player's 9+ test score. Given the high number of injuries recorded during the study period (n=526 injuries), we believe that it represents a low risk of bias.

Finally, we acknowledge that as our study included a group of male professional football players, this limits the generalisability of the findings to other sports, age groups and women. This study should be repeated in other athlete populations, including female athletes, other age groups and athletes at lower performance levels.[27]

SUMMARY AND CONCLUSION

This study could not identify any association between 9+ total score and risk of lower extremity injury in professional male football players, even after adjusting for other risk factors. The 9+ total score was no better than chance for distinguishing between injured and uninjured players. Therefore, the 9+ test cannot be recommended as an injury prediction tool in this population.

What are the findings?

- The 9+ total score was not associated with the risk of lower extremity injuries or any of the most common injury types in professional male football players (hip/groin, thigh, knee, lower leg, ankle injuries).
- The 9+ total score was no better than chance for distinguishing players who would sustain an injury and those who would not.

How might it impact on clinical practice in the future?

- The 9+ test is not recommended as an injury prediction tool in male professional football players.

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Contributors AB designed the study, contributed in data collection, analysed and interpreted the data, and drafted the article. RB designed the study, interpreted the data, revised the article and approved the final revision of the article. AF and RW contributed in data analysis, interpreted the data, revised the article and approved the final revision of the article. KMK, ST, TB, CE and JLT interpreted the data, revised the article and approved the final revision of the article.

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Ethics approval Institutional Review Board, Anti-Doping Lab Qatar (ADLQ), Doha, Qatar.

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Supplement

Table A1. Univariate hazard ratios for the risk of an overuse injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

		Injured (n=161)	**Uninjured (n=347)**			
	N	Mean ± SD	Mean ± SD	HR	95% CI	P value
9+ total score	508	22.8 ± 3.9	22.8 ± 3.9	1.003	[0.97-1.04]	0.85
Age (y)	508	26.7 ± 4.6	26.3 ± 4.8	1.02	[0.98-1.05]	0.28
Height (cm)	508	177 ± 7	177 ± 7	0.998	[0.97-1.02]	0.90
Weight (kg)	508	72 ± 9	72 ± 9	1.002	[0.98-1.02]	0.85
BMI (kg/m^2)	508	23.1 ± 2.0	23.1 ± 2.0	1.02	[0.95-1.10]	0.61
History of previous injury, n	492					
Lower extremity injury (yes/no)*		57/99	116/220	1.06	[0.77-1.47]	0.72
Player position, n (%)	508					
Goalkeeper**		10 (6.2)	46 (13.3)	1.00	1.00	
Defender		62 (38.5)	114 (32.9)	2.25	[1.15-4.42]	0.02
Midfielder		54 (33.5)	137 (39.5)	1.68	[0.86-3.27]	0.12
Forward		35 (21.7)	50 (14.4)	2.71	[1.34-5.47]	0.005
Seasons	508					
Season 1**		90 (55.9)	168 (48.4)	1.00	1.00	
Season 2		71 (44.1)	179 (51.6)	0.96	[0.71-1.30]	0.81

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.
Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category
*History of previous injury refers to any lower extremity injury occurring within 12 months prior to the 9+ test.
**Reference group in analysis

Table A2. Univariate hazard ratios for the risk of an acute injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

	N	Injured (n=201) Mean ± SD	Uninjured (n=307) Mean ± SD	HR	95% CI	P value
9+ total score	508	23.0 ± 3.6	22.7 ± 4.1	1.02	[0.99-1.06]	0.18
Age (y)	508	27.1 ± 4.9	26.0 ± 4.6	1.04	[1.01-1.07]	0.01
Height (cm)	508	177 ± 7	176 ± 7	1.01	[0.99-1.03]	0.46
Weight (kg)	508	73 ± 9	72 ± 9	1.01	[0.99-1.02]	0.32
BMI (kg/m^2)	508	23.2 ± 2.0	23.0 ± 1.9	1.03	[0.96-1.11]	0.37
History of previous injury, n	492					
Lower extremity injury (yes/no)*		70/128	103/191	1.09	[0.82-1.46]	0.56
Player position, n (%)	508					
Goalkeeper**		18 (9.0)	38 (12.4)	1.00	1.00	
Defender		69 (34.3)	107 (34.9)	1.29	[0.81-2.05]	0.28
Midfielder		77 (38.3)	114 (37.1)	1.49	[0.94-2.38]	0.09
Forward		37 (18.4)	48 (15.6)	1.46	[0.88-2.42]	0.14
Seasons	508					
Season 1**		91 (45.3)	167 (54.4)	1.00	1.00	
Season 2		110 (54.7)	140 (45.6)	1.71	[1.29-2.27]	<.001

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.

Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category

*History of previous injury refers to any lower extremity injury occurring within 12 months prior to the 9+ test.

**Reference group in analysis

Table A3. Univariate hazard ratios for the risk of a hip/groin injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

		Injured (n=92)	**Uninjured (n=416)**			
	N	Mean ± SD	Mean ± SD	HR	95% CI	P value
9+ total score	508	22.5 ± 3.9	22.9 ± 3.9	0.98	[0.93-1.03]	0.52
Age (y)	508	26.7 ± 4.5	26.4 ± 4.8	1.01	[0.97-1.05]	0.51
Height (cm)	508	177 ± 7	177 ± 7	0.996	[0.97-1.03]	0.81
Weight (kg)	508	73 ± 10	72 ± 9	1.01	[0.98-1.03]	0.61
BMI (kg/m^2)	508	23.2 ± 2.1	23.0 ± 1.9	1.05	[0.95-1.17]	0.36
History of previous injury	492					
Groin injury (yes/no)*		11/80	34/367	1.39	[0.75-2.61]	0.30
Player position, n (%)	508					
Goalkeeper**		9 (9.8)	47 (11.3)	1.00	1.00	
Defender		28 (30.4)	148 (35.6)	0.99	[0.47-2.11]	0.99
Midfielder		37 (40.2)	154 (37.0)	1.28	[0.61-2.67]	0.51
Forward		18 (19.6)	67 (16.1)	1.40	[0.62-3.13]	0.41
Seasons	508					
Season 1**		50 (54.3)	208 (50.0)	1.00	1.00	
Season 2		42 (45.7)	208 (50.0)	1.10	[0.73-1.64]	0.65

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.

Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category.

*History of previous injury refers to any groin injury occurring within 12 months prior to the 9+ test.

**Reference group in analysis

Table A4. Univariate hazard ratios for the risk of a thigh injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

		Injured (n=120)	**Uninjured (n=388)**			
	N	Mean ± SD	Mean ± SD	HR	95% CI	P value
9+ total score	508	22.7 ± 4.0	22.9 ± 3.9	0.99	[0.95-1.04]	0.84
Age (y)	508	27.2 ± 4.5	26.2 ± 4.8	1.04	[1.00-1.07]	0.047
Height (cm)	508	177 ± 8	177 ± 6	1.005	[0.97-1.04]	0.77
Weight (kg)	508	73 ± 9	72 ± 9	1.01	[0.99-1.02]	0.56
BMI (kg/m^2)	508	23.1 ± 2.0	23.0 ± 1.9	1.03	[0.95-1.13]	0.48
History of previous injury	492					
Hamstring injury (yes/no)*		9/109	31/343	0.84	[0.43-1.68]	0.63
Quadricep femoris (yes/no)*		6/112	9/365	2.11	[0.82-5.39]	0.12
Player position, n (%)	508					
Goalkeeper**		9 (7.5)	47 (12.1)	1.00	1.00	
Defender		46 (38.3)	130 (33.5)	1.78	[0.82-3.87]	0.14
Midfielder		42 (35.0)	149 (38.4)	1.52	[0.70-3.32]	0.29
Forward		23 (19.2)	62 (16.0)	1.89	[0.83-4.30]	0.13
Seasons	508					
Season 1**		60 (50.0)	198 (51.0)	1.00	1.00	
Season 2		60 (50.0)	190 (49.0)	1.28	[0.91-1.82]	0.16

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.
Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category
*History of previous injury refers to any thigh (hamstring and quadricep femoris) injury occurring within 12 months prior to the 9+ test.
**Reference group in analysis

Table A5. Univariate hazard ratios for the risk of a knee injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

		Injured (n=69)	**Uninjured (n=439)**			
	N	Mean ± SD	Mean ± SD	HR	95% CI	P value
9+ total score	508	23.4 ± 3.2	22.7 ± 4.0	1.05	[0.99-1.10]	0.09
Age (y)	508	26.6 ± 4.7	26.4 ± 4.8	1.01	[0.97-1.06]	0.64
Height (cm)	508	177 ± 7	177 ± 7	1.003	[0.97-1.04]	0.85
Weight (kg)	508	73 ± 10	72 ± 9	1.02	[0.99-1.05]	0.20
BMI (kg/m^2)	508	23.4 ± 2.2	23.0 ± 1.9	1.12	[0.98-1.28]	0.10
History of previous injury	492					
Knee injury (yes/no)*		11/55	32/394	2.30	[1.22-4.33]	0.01
Player position, n (%)	508					
Goalkeeper**		8 (11.6)	48 (10.9)	1.00	1.00	
Defender		21 (30.4)	155 (35.3)	0.82	[0.37-1.83]	0.62
Midfielder		23 (33.3)	168 (38.2)	0.87	[0.39-1.93]	0.73
Forward		17 (24.6)	68 (15.5)	1.50	[0.65-3.45]	0.34
Seasons	508					
Season 1**		30 (43.5)	228 (51.9)	1.00	1.00	
Season 2		39 (56.5)	211 (48.1)	1.62	[1.01-2.61]	0.045

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.
Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category
*History of previous injury refers to any knee injury occurring within 12 months prior to the 9+ test.
**Reference group in analysis

Table A6. Univariate hazard ratios for the risk of a lower leg injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

	N	**Injured (n=52)** Mean ± SD	**Uninjured (n=456)** Mean ± SD	HR	95% CI	P value
9+ total score	508	23.4 ± 4.0	22.8 ± 3.9	1.05	[0.98-1.12]	0.15
Age (y)	508	27.9 ± 5.3	26.3 ± 4.7	1.07	[1.005-1.14]	0.03
Height (cm)	508	177 ± 6	177 ± 7	1.01	[0.98-1.05]	0.48
Weight (kg)	508	72 ± 8	72 ± 9	.995	[0.97-1.02]	0.74
BMI (kg/m^2)	508	22.8 ± 1.8	23.1 ± 2.0	0.94	[0.83-1.06]	0.31
History of previous injury						
Lower extremity injury (yes/no)*	492	18/34	155/285	1.01	[0.57-1.78]	0.98
Player position, n (%)	508					
Goalkeeper**		4 (7.7)	52 (11.4)	1.00	1.00	
Defender		21 (40.4)	155 (34.0)	1.70	[0.59-4.91]	0.32
Midfielder		17 (32.7)	174 (38.2)	1.35	[0.45-4.00]	0.59
Forward		10 (19.2)	75 (16.4)	1.78	[0.55-5.70]	0.33
Seasons	508					
Season 1**		19 (36.5)	239 (52.4)	1.00	1.00	
Season 2		33 (63.5)	217 (47.6)	2.21	[1.30-3.77]	0.003

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.
Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category
*History of previous injury to refers to any lower extremity injury occurring within 12 months prior to the 9+ test.
**Reference group in analysis

Table A7. Univariate hazard ratios for the risk of an ankle injury during the study period, calculated from Cox regression analyses accounting for that the player was the unit of analysis and clustered for player id.

		Injured (n=75)	**Uninjured (n=433)**			
	N	Mean ± SD	Mean ± SD	HR	95% CI	P value
9+ total score	508	23.2 ± 3.8	22.8 ± 3.9	1.04	[0.98-1.10]	0.21
Age (y)	508	26.9 ± 4.9	26.4 ± 4.7	1.02	[0.97-1.07]	0.41
Height (cm)	508	177 ± 7	177 ± 7	1.01	[0.97-1.04]	0.67
Weight (kg)	508	72 ± 9	72 ± 9	.999	[0.97-1.02]	0.94
BMI (kg/m^2)	508	23.0 ± 1.9	23.1 ± 2.0	0.97	[0.87-1.08]	0.61
History of previous injury, n	492					
Ankle injury (yes/no)*		7/66	26/393	1.60	[0.72-3.55]	0.25
Player position, n (%)	508					
Goalkeeper**		4 (5.3)	52 (12.0)	1.00	1.00	
Defender		33 (44)	143 (33.0)	2.82	[1.05-7.55]	0.04
Midfielder		30 (40.0)	161 (37.2)	2.44	[0.91-6.56]	0.08
Forward		8 (10.7)	77 (17.8)	1.34	[0.42-4.22]	0.62
Seasons	508					
Season 1**		41 (54.7)	217 (50.1)	1.00	1.00	
Season 2		34 (45.3)	216 (49.9)	1.05	[0.66-1.67]	0.84

The classification injured and uninjured reflects the number of athletes being injured during the study period, where each player was the unit of analysis, including both continuous (mean ± SD) and categorical (yes/no) independent variables.
Results are presented as mean ± SD for injured versus uninjured players. Hazard ratio (HR) per 1-unit of change for continuous variables (i.e. 9+ scores) are presented with 95% confidence intervals (CI) and p-values. For categorical variables (i.e. previous injury history), HR with 95% CI and p-values represent change in risk when compared to the reference category
*History of previous injury to ankle refers to any injury occurring within 12 months prior to the 9+ test.
**Reference group in analysis

Paper IV

Interseason variability of a functional movement test, the 9+ screening battery, in professional male football players

British Journal of Sports Medicine

Interseason variability of a functional movement test, the 9+ screening battery, in professional male football players

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ABSTRACT

Background The Nine Plus screening battery test (9+) is a functional movement test intended to identify limitations in fundamental movement patterns predisposing athletes to injury. However, the interseason variability is unknown.

Aim To examine the variability of the 9+ test between 2 consecutive seasons in professional male football players.

Methods Asymptomatic Qatar Star League players (n=220) completed the 9+ at the beginning of the 2013 and 2014 seasons. Time-loss injuries in training and matches were obtained from the Aspetar Injury and Illness Surveillance Program. No intervention was initiated between test occasions.

Results A significant increase in the mean total score of 1.6 points (95% CI 1.0 to 2.2, p<0.001) was found from season 1 (22.2±4.1 (SD)) to season 2 (23.8±3.3). The variability was large, as shown by an intraclass correlation coefficient (ICC) of 0.24 (95% CI 0.11 to 0.36) and a minimal detectable change (MDC) of 8.7 points. Of the 220 players, 136 (61.8%) suffered a time-loss injury between the 2 tests. There was an improvement in mean total scores in the injured (+2.0 ±0.4 (SE), p<0.001) group but not in the uninjured group (+0.9±0.5, p=0.089). The variability from season 1 to season 2 was large both in the injured (ICC 0.25, 0.09 to 0.40, MDC 8.3) and uninjured (ICC 0.24, 0.02 to 0.43, MDC 9.1) groups.

Conclusions The 9+ demonstrated substantial intraindividual variability in the total score between 2 consecutive seasons, irrespective of injury. A change above 8 points is necessary to represent a real change in the 9+ test between seasons.

INTRODUCTION

Injuries in football are common, causing substantial morbidity, and may have long-term health consequences on the player.[1–3] One strategy to prevent injuries is the use of a periodic health evaluation (PHE) or screening examination to identify the athlete at risk for injury, with a view to implementing targeted prevention measures.[4] For a PHE to be effective in detecting injury risk or be clinically useful, it is essential that the screening tools or tests used are reliable, valid and reproducible, and have acceptable measurement error.[5–9]

Functional movement tests have become popular components of musculoskeletal screening examinations, and are also used for clinical assessments to determine treatment response and assist in return to play decision-making.[10] The Nine Plus screening battery test (9+) is a functional movement test attempting to identify limitations in fundamental movement patterns predisposing athletes to injury.[11] This relatively recently developed tool comprises six tests with modified criteria from the functional movement screen (FMS; deep squat, in-line lunge, shoulder mobility, trunk stability push-up, active hip flexion and diagonal lift); in addition, Frohm *et al*[11] included five additional tests (one-legged squat, deep one-legged squat, drop jump test, seated rotation and straight leg raise) to fill the gap for tests challenging dynamic trunk flexors, rotation of the spine, and knee control and strength.[11 12]

There is limited evidence for the measurement properties of the 9+. An initial study by Frohm *et al*[11] found good inter-rater (intraclass correlation coefficient (ICC) 0.80) and intra-rater (ICC 0.75) reliability of the 9+ in a sample of elite football players. The validity of the 9+ in predicting injury is still unknown. However, athletes with scores below 67% of the total score on the FMS have shown a significantly higher injury risk compared with athletes who score above 67%.[13] For 9+ to be clinically useful as a potential predictor, it is important to document the normal variation, in the absence of any intervention or injury, to be able to meaningfully interpret differences in a test result.[14]

Therefore, we aimed to examine the season-to-season variability of the 9+ in a group of professional male football players. We hypothesised that in the absence of any prevention or performance intervention or injury, the 9+ score would be stable (ie, low variability) between seasons.

METHODS

Study design and participants

We analysed prospectively collected data from a PHE of professional male football players in Qatar.[15] All players eligible to compete in the Qatar Stars League (QSL), the professional first division of football in Qatar, were invited to participate as they presented for their annual PHE at Aspetar Orthopaedic and Sports Medicine Hospital in Doha (Qatar) at the beginning of the 2013 and 2014 seasons, which the majority (66.6%) completed during the preseason period (July through September). A smaller group (23.8%) completed the tests during the early/mid competition phase (October through December 2013 or 2014) and a few (9.7%) did the testing during the 2014 post-season (May through June).

As part of the musculoskeletal component of the PHE, all players underwent the 9+ test in the rehabilitation department of the hospital each year. Players presenting with 9+ data from both season examinations (2013 and 2014) were included for analyses. Players reporting a current injury or physical symptom limiting training or match play at the time of testing were excluded from analyses. Ethical approval was obtained from the Institutional Review Board, Anti-Doping Lab Qatar. All players signed a written informed consent form at inclusion, allowing their data to be used for research.

Examiners

The 9+ was performed by experienced sports physiotherapists working at the study institution. In total, 14 physiotherapists were involved in performing the 9+ testing during the study period (7 performed in both seasons, 7 in one of the two seasons only). Prior to testing, all physiotherapists underwent a 2-day course with the inventors of the 9+,[11] in addition to performing the 9+ in their clinical practice.

We measured the intertester reliability of the 14 physiotherapists in a subgroup of 63 randomly chosen players during the screening setting in the 2014 season. The intertester reliability for the total score and each of the tests was examined with two testers from a randomly selected pool of 8 of the 14 physiotherapists (4 of these were involved in testing both seasons, 4 in the 2014 tests only). The testers were blinded for each other's 9+ score.

Procedures

The 9+ screening battery was performed as described by Frohm *et al*[11 12] on both test occasions (2013 and 2014). The 9+ consists of 11 functional and complex movement exercises to assess stability, mobility and neuromuscular control in the kinetic chain. Each player performed the 11 tests and they completed each test in the same order on both test occasions. Seven of the 11 tests are assessed bilaterally, looking for asymmetries. For these tests, the left extremity was tested first and the lower of the two scores for the left and right sides was used for data analysis. Each movement test was scored on a four-point scale (3–0), with 3 representing correct completion of the task with no compensatory movements, 2 correct but with the presence of compensatory movements, 1 not correct despite compensatory movements and 0 if pain was present. Thus, the player could reach a maximum score of 33 points. A more detailed description of the 9+ movements is provided by Frohm *et al*.[11 12]

All players performed the tests barefoot, with shorts and a t-shirt, except for the drop jump test. As described by Frohm *et al*,[12] the players wore their own training shoes for this test. Owing to equipment availability, the participants performed the drop jump test from a 30 cm box, in contrast to a 40 cm box height as described by Frohm *et al*.[12] The physiotherapists gave a standardised verbal instruction, and showed the player a photo of the starting and finishing positions of an optimally performed exercise. Each player performed each test three times, and the maximum score achieved was recorded and used for evaluation of test performance. Verbal corrections were given during the three trials in order to achieve the most optimal performance. All testers and participants were blinded to the player's score from test occasion 1 on test occasion 2. The 9+ took 20–30 min to complete.

Between-season data collection

After the completion of the initial 9+ in 2013, a report form with the total 9+ score along with the results from the other PHE tests was given to the respective team doctor.[15] Other than that, no specific intervention was advised based on the 9+ score from test 1. Data on injuries in training and matches during the intervening football season were obtained from the Aspetar Injury and Illness Surveillance Program (AIISP).[2]

The AIISP is based on prospective injury recording from all 14 QSL teams. An injury was recorded if the player was unable to fully participate in future football training or match play (time-loss injury).[2 16] The player was considered injured until declared fit for full participation in training and available for match selection by medical staff.

The team physician (or head physiotherapist when no physician was available) for each team recorded all injuries daily throughout the intervening season. For each injury recorded, the team physician/physiotherapist completed a standardised injury card containing information on the body part injured, injury type and specific diagnosis. In addition, the injury card included questions related to reinjury, overuse or trauma, injury mechanism (contact or collision), as well as information on whether the injury occurred during training or match play. Injury severity was determined by the number of days absent from matches or training sessions due to injury and was classified as mild (1–3 days), minor (4–7 days), moderate (8–28 days) or severe (>28 days). Injury data were requested from the clubs every month. We maintained regular communication with the clubs to encourage timely and accurate reporting.

Statistical analyses

Data were analysed with IBM SPSS statistics, V.21 (IBM Corp, Armonk, New York, USA). We used a paired t-test to assess for systematic differences in the 9+ total score between test occasions. Significance level was set at $p<0.05$. The variability (random error) of the 9+ total score between tests was assessed using the $ICC_{1.1}$ with 95% CIs, and SE of measurement (SEM).[17 18] The SEM was calculated from the square root of the mean square of the residual term derived from the analysis of variance (ANOVA). The minimal detectable change (MDC) with 95% certainty was calculated as $SEM\times1.96\times\sqrt{2}$.[17 19]

Systematic differences and the variability of each movement test between test occasions were also examined. Since each movement test is measured on an ordinal scale, a non-parametric test (Wilcoxon signed-rank test) and weighted κ (κ_w) were used. The weighted κ was calculated using STATA (V.11.0, StataCorp, College Station, Texas, USA).

The intertester reliability for the total score was analysed using $ICC_{1.1}$ with scores between 0.75 and 1.00 interpreted as good, 0.50–0.74 as moderate, and those below 0.50 as poor.[20] The κ_w was used to analyse the intertester reliability for each movement test with scores interpreted as follows: <0.20 as poor, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial and 0.81–1.00 as excellent.[21]

Data are presented as means with SDs or 95% CI unless otherwise stated.

RESULTS

Participants

A total of 247 male footballers completed the 9+ during both the 2013 and 2014 seasons. Of these, 27 players were excluded from analyses because of current injury, no consent or missing injury registration (figure 1). Thus, the final sample included 220 players (age 25.3±4.6 years; height 176±7 cm; body mass 71±9 kg; body mass index 22.8±2.0 kg/m^2). The players represented 35 nationalities, the majority from the Middle East (71.8%). By ethnicity, 57.7% were Arabic, 29.5% black,

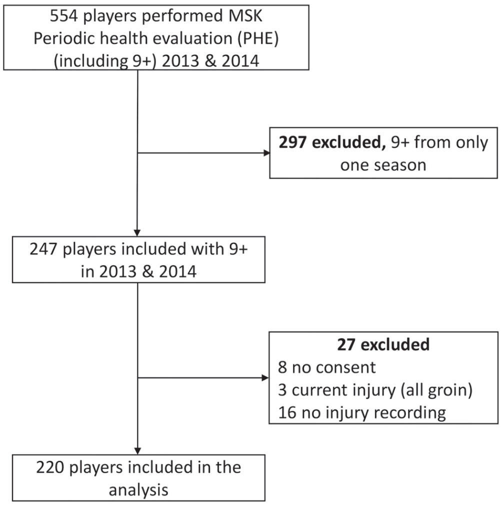

Figure 1 The flow of players included in the study. MSK, musculoskeletal.

Caucasian 3.6%, East Asian 0.9%, Persian 6.8% and 1.4% other. There were no missing items of the 9+ among any of the players included in the interseason variability and intertester reliability analyses.

Examiner intertester reliability

The intertester reliability for the total score was moderate (ICC=0.68), while the intertester reliability for each test ranged from fair to excellent (κ_w=0.31 to 0.81; table 1). For 8 of the 11 exercises (72%), reliability was fair or moderate.

Interseason variability of the 9+

The mean time between the two 9+ test scores was 359.7 ±65.4 days. We observed a statistically significant increase in the mean total score of the 9+ test of 1.6 (95% CI 1.0 to 2.2, p<0.001) from season 1 (22.2±4.1) to season 2 (23.8±3.3). However, the variability was large (ICC 0.24, 95% CI 0.11 to 0.36; figure 2 and table 2).

Among the 220 players, 136 (61.8%) players had a ≥1 time-loss injury between the two 9+ tests, predominantly to the lower extremity (n=124, 91.2% of all injured players). We observed a consistent improvement in the 9+score across all subgroups, which tended to be greater for the injured than the uninjured group, as seen in table 2. The variability between season 1 and season 2 was large across all injured (ICC=0.13–0.25) and uninjured groups (ICC=0.23–0.27). Players with a severe injury (>28 days absence) displayed the greatest increase in mean total score between season 1 and season 2 (2.9±0.7, p<0.001). Again, the variability was large in this group (ICC=0.13–0.16), as illustrated in figure 3.

The SEM for the total score was large (3.0–3.4 points) across all groups, irrespective of injury and severity. The clinical applicability of the 9+ total score is limited, as indicated by the magnitude of the MDC (8.3–9.5 points), again irrespective of injury and severity (table 2).

We performed a subanalysis of players with a mean time between the 9+ test of <1SD (294.2 days, n=32) and >1SD (425.1 days, n=27) than the average, and observed similar findings as described above. There was a significant increase in the mean total score for the >1SD group of 2.1 (95% CI 0.40 to 3.82, p=0.017) from season 1 (21.3±3.8) to season 2 (23.4 ±4.2), whereas there was no significant increase in the mean total score for the <1SD group (0.21±0.8, p=0.79) from season 1 (22.8±4.2) to season 2 (23.0±2.8). However, the variability was again large for both the >1SD group (ICC=0.35, 95% CI −0.03 to 0.64, SEM=3.1) and the <1SD group (ICC=0.19, 95% CI −0.16 to 0.50, SEM=3.2).

Table 1 Intertester reliability for each movement test of the 9+ (n=63 athletes tested by 8 physiotherapists)

	κ_w (95% CI)	Strength of agreement
Deep squat	0.52 (0.30 to 0.69)	Moderate
One-legged squat	0.38 (0.12 to 0.59)	Fair
Deep one-legged squat	0.36 (0.11 to 0.56)	Fair
In-line lunge	0.31 (0.10 to 0.54)	Fair
Active hip flexion	0.81 (0.69 to 0.91)	Excellent
Straight leg raises	0.57 (0.38 to 0.76)	Moderate
Push-up	0.47 (0.19 to 0.73)	Moderate
Diagonal lift	0.39 (0.13 to 0.64)	Fair
Seated rotation	0.68 (0.51 to 0.84)	Substantial
Shoulder mobility	0.81 (0.67 to 0.92)	Excellent
Drop jump	0.46 (0.20 to 0.70)	Moderate

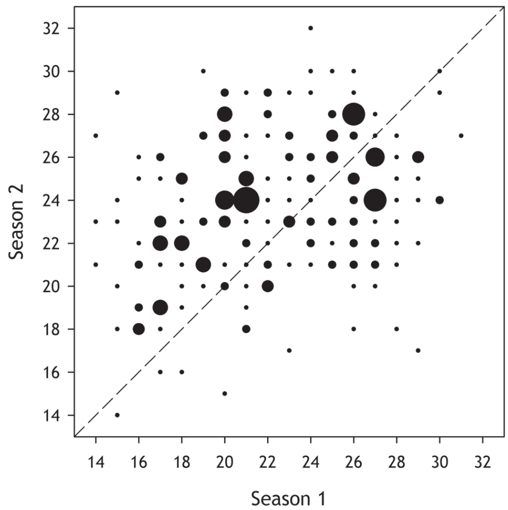

Figure 2 Bubble plot presenting the total score for all players (n=220) in season 1 (test 1) and season 2 (test 2). The bubble size depicts the number of players with an identical total score; the smallest points represent one player, the largest seven players. The hatched line represents the identity line.

Interseason variability of each movement test

There was a significant increase in score for each movement test between season 1 and season 2, apart from the one-legged squat, deep one-legged squat, seated rotation and shoulder mobility (table 3). However, the variability was large for all movement tests (κ_w=−0.003 to 0.63), irrespective of injury and severity.

Table 2 Interseason characteristics of the 9+ total score (0–33) for all players and for injured versus uninjured groups*

	n	Mean±SD Test 1	Mean difference test 2 to test 1 (95% CI)	ICC (95% CI)	SEM†	MDC†
All	220	22.2±4.1	1.6 (1.0 to 2.2)‡	0.24 (0.11 to 0.36)	3.1	8.7
Any injury						
Yes	136	22.1±4.0	2.0 (1.3 to 2.7)‡	0.25 (0.09 to 0.40)	3.0	8.3
No	84	22.4±4.3	0.9 (−0.1 to 1.9)	0.24 (0.02 to 0.43)	3.3	9.1
Lower extremity injury						
Yes	124	22.1±4.1	2.0 (1.2 to 2.7)‡	0.25 (0.08 to 0.41)	3.1	8.5
No	96	22.3±4.2	1.1 (0.1 to 2.0)‡	0.23 (0.03 to 0.41)	3.2	8.8
Any severe injury						
Yes	40	21.5±4.1	2.9 (1.4 to 4.4)‡	0.16 (−0.15 to 0.45)	3.3	9.1
No	180	22.3±4.1	1.3 (0.6 to 1.9)‡	0.27 (0.13 to 0.40)	3.1	8.5
Severe lower extremity injury						
Yes	36	21.6±4.2	3.0 (1.3 to 4.6)‡	0.13 (−0.20 to 0.44)	3.4	9.5
No	184	22.3±4.1	1.3 (0.7 to 1.9)‡	0.27 (0.14 to 0.40)	3.0	8.4

Severe injury: >28 days absence.
*Mean±SD for test 1 (season 1), mean interseason difference and ICC with 95% CI, and measurement error (SEM and MDC) from test 1 (season 1) to test 2 (season 2) are reported.
†Expressed in the same unit as the measurement (9+ points).
‡Significant at p<0.05 (paired t-test).
ICC, intraclass correlation coefficient;
MDC, minimal detectable change; SEM, SE of measurement.

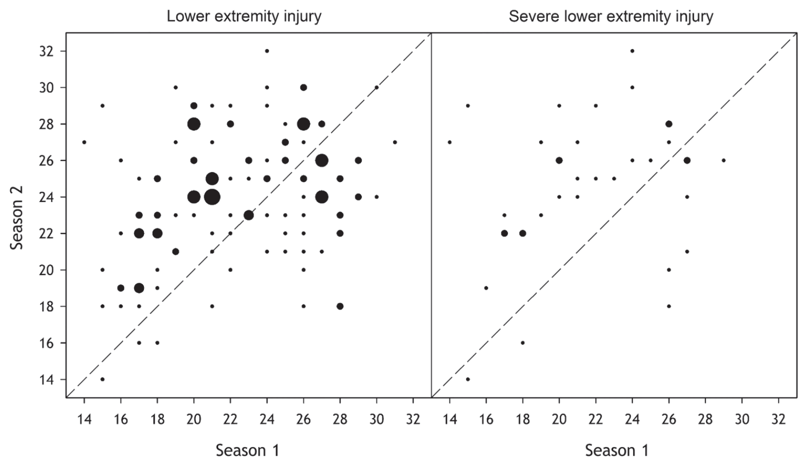

Figure 3 Bubble plot presenting the total score for players with a lower extremity injury (n=124) and severe lower extremity injury (n=36) in season 1 (test 1) and season 2 (test 2). The bubble size depicts the number of players with an identical score; the smallest points represent one player, the largest five players. The hatched line represents the identity line.

DISCUSSION

The main finding of this study was that there was a substantial intraindividual variability in the 9+ mean total score between the two consecutive seasons, irrespective of injury and severity status, and the MDC was high across all groups. The intertester reliability was moderate. Additionally, there was a small but systematic improvement from one season to the next across all injured and uninjured groups.

The variability of the 9+ test

Frohm *et al*[11] examined the inter-rater and intra-rater reliability among eight trained observers of the 9+ in a group of male elite football players (n=26). They reported good intra-rater reliability (ICC 0.75, based on data from 18 players) with no systematic change when players were retested after 7 days, indicating that player and tester performance was stable across test sessions. Similarly, good ICC scores have also been reported in several studies investigating the intra-rater and test–retest reliability of the FMS in physically active populations and college athletes retested after 2–7 days.[22–24]

We therefore assumed that in the absence of any intervention or injury, the 9+ total score would be stable (ie, low variability) between seasons. The remarkably low ICC observed in our study, across injured and uninjured groups, suggests that the ability of the 9+ test to detect changes in functional movement patterns is very limited, largely because of the sizeable measurement error. A similar tendency was also observed for each movement test, displaying consistently poor κ_w for all tests across all injured and uninjured groups.

Table 3 Weighted κ for each movement test for test 1 (season 1) to test 2 (season 2) of the 9+ for all players, and for injured versus uninjured groups†

	All	Any injury		LE injury		Severe any injury		Severe LE injury	
		Yes	No	Yes	No	Yes	No	Yes	No
Exercises	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)	κ_w (95% CI)
Deep squat	*0.16* (0.07 to 0.26)*	*0.15* (0.03 to 0.28)*	0.18 (0.02 to 0.35)	*0.16* (0.04 to 0.30)*	*0.16* (0.00 to 0.31)*	*0.11* (−0.04 to 0.27)*	*0.19* (0.07 to 0.30)*	*0.14* (−0.02 to 0.35)*	*0.17* (0.05 to 0.28)*
One-legged squat	0.24 (0.13 to 0.34)	0.25 (0.09 to 0.40)	*0.24* (0.10 to 0.40)*	0.26 (0.11 to 0.41)	0.21 (0.05 to 0.35)	0.12 (−0.15 to 0.38)	0.26 (0.14 to 0.39)	0.11 (−0.14 to 0.40)	0.26 (0.15 to 0.38)
Deep one-legged squat	0.26 (0.16 to 0.36)	0.19 (0.06 to 0.32)	*0.37* (0.22 to 0.54)*	0.20 (0.07 to 0.33)	*0.34* (0.20 to 0.48)*	0.15 (−0.05 to 0.37)	0.28 (0.18 to 0.39)	0.15 (−0.08 to 0.36)	0.28 (0.18 to 0.38)
In-line lunge	*0.11* (0.01 to 0.20)*	*0.10* (−0.02 to 0.21)*	*0.12* (−0.02 to 0.29)*	0.10 (−0.04 to 0.23)	*0.12* (−0.02 to 0.27)*	*0.06* (−0.10 to 0.26)*	*0.12* (0.01 to 0.22)*	*0.08* (−0.10 to 0.30)*	*0.11* (0.001 to 0.21)*
Active hip flexion	*0.34* (0.24 to 0.43)*	*0.39* (0.27 to 0.50)*	0.24 (0.07 to 0.41)	*0.38* (0.26 to 0.52)*	0.27 (0.11 to 0.42)	*0.31* (0.10 to 0.49)*	0.34 (0.24 to 0.44)	*0.29* (0.10 to 0.50)*	0.34 (0.24 to 0.45)
Straight leg raises	*0.32* (0.22 to 0.43)*	0.39 (0.25 to 0.53)	*0.20* (0.04 to 0.37)*	*0.35* (0.21 to 0.50)*	0.26 (0.10 to 0.40)	0.51 (0.26 to 0.74)	*0.27* (0.16 to 0.40)*	0.63 (0.39 to 0.84)	*0.25* (0.14 to 0.37)*
Push-up	*0.08* (−0.02 to 0.19)*	*0.14* (0.02 to 0.27)*	0.003 (−0.18 to 0.18)	*0.12* (−0.01 to 0.25)*	0.03 (−0.12 to 0.20)	*0.24* (0.08 to 0.47)*	*0.05* (−0.07 to 0.16)*	*0.23* (0.07 to 0.46)*	*0.06* (−0.06 to 0.17)*
Diagonal lift	*0.08* (−0.01 to 0.18)*	*0.07* (−0.04 to 0.19)*	0.10 (−0.06 to 0.28)	*0.03* (−0.06 to 0.15)*	0.14 (−0.01 to 0.30)	*0.11* (−0.06 to 0.32)*	*0.08* (−0.02 to 0.19)*	*0.09* (−0.08 to 0.32)*	*0.08* (−0.02 to 0.20)*
Seated rotation	0.35 (0.24 to 0.46)	0.41 (0.27 to 0.56)	0.25 (0.09 to 0.44)	0.41 (0.27 to 0.57)	0.27 (0.09 to 0.49)	0.25 (0.01 to 0.49)	0.37 (0.24 to 0.49)	0.25 (−0.04 to 0.52)	0.37 (0.24 to 0.49)
Shoulder mobility	0.37 (0.28 to 0.49)	0.33 (0.20 to 0.45)	0.45 (0.28 to 0.61)	0.34 (0.20 to 0.47)	0.42 (0.26 to 0.57)	0.20 (−0.04 to 0.43)	0.42 (0.30 to 0.52)	0.26 (0.02 to 0.49)	0.40 (0.29 to 0.52)
Drop jump	*0.19* (0.08 to 0.30)*	*0.26* (0.12 to 0.40)*	*0.07* (−0.10 to 0.24)*	*0.25* (0.13 to 0.39)*	*0.11* (−0.05 to 0.25)*	0.13 (−0.07 to 0.38)	*0.20* (0.08 to 0.31)*	0.17 (−0.08 to 0.41)	*0.19* (0.08 to 0.32)*

Significant results ($p<0.05$) are marked with '* and italics'.
†Weighted κ (κ_w) with 95% CI from test 1 to test 2 is reported with significant results ($p<0.05$) from Wilcoxon signed-rank test.
LE, lower extremity.

An error in a measurement includes both rater variation, variation by chance and between-session variability in player performance.[25] The intertester reliability of our testers (overall ICC 0.68) was lower on all of 9+ movement tests than those reported by Frohm *et al*,[11] except for seated rotation and shoulder mobility. Frohm *et al*[11] examined the intertester reliability in a small group of male football players (n=26) in a controlled research setting, using eight physiotherapists who were all experienced on the 9+. Our results may differ from those of Frohm *et al*,[11] given that our testing was undertaken in a busy clinical screening setting using multiple testers (n=14) with less 9+ experience (than in Frohm *et al*'s study). However, studies on the FMS have reported good intertester reliability for testers with varying experience.[22–24 26–28] It is possible that in our screening setting some of the detailed movement criteria may have been missed, although all of our testers received the same initial 9+ training, and had similar clinical and 9+ experience. On the other hand, this increases the external validity of our findings.

The SEM in this study was large, ranging from 3.0 to 3.4 points across all groups independent of injury status, indicating that the 9+ total score has a normal variation (measurement error) of 3–4 points from season to season. Furthermore, the MDC ranged from 8.3 to 9.5 points, indicating that a minimum improvement of 8–10 points is required to represent a real change in the 9+ test, again irrespective of injury and severity. Given our large SEM and MDC, it suggests that the 9+ total score interseason variation is too large for the 9+ to detect change attributed to injury or clinical interventions.[19 29] In other words, the large variability in the 9+ is mainly attributed to variability in player performance and chance rather than variability between testers.[17 19] This view is substantiated by the difference in ICC values, which for the total score was 0.68 for between testers but only 0.24 between seasons.

There are several potential sources of random error that may help explain the observed variability in the 9+, including the motivation of the player, interpretation of the test instructions by the player or a learning effect.[30] Another possible explanation may be the ambiguity of the scoring criteria. The difficulty in assessing and performing the more complex tests involving multiple joints and complex physical qualities such as balance, coordination and core stability (ie, the diagonal lift, in-line lunge, one-legged squat test) makes scoring and performance uncertain, and subsequently will cause variability in athlete performance and in the scoring (tester variability).[11 27]

Clinical implications

Functional movement tests, including the 9+, are growing in popularity as an injury screening tool. Our results show that there is a large variability in the 9+ total score and a change of above 8 points is necessary to represent a real change in a player's 9+ test between seasons. Practitioners should consider this when interpreting the 9+ or similar FMS scores. Our intertester reliability, using multiple testers, was moderate and practitioners are advised to perform their own reliability tests on their target population before considering the 9+ for clinical use.

The ability of the 9+ to predict injury is still unknown. However, the validity of the FMS as an injury prediction tool has been scrutinised recently, and with conflicting results.[8 13 31 32] Based on the initial study by Kiesel *et al*[33] on the FMS in professional American football players, a total score below 67% was believed to represent an increased risk of injury.[33] However, a recent meta-analysis revealed that a cut-off of 67% only provided a sensitivity of 24.7% and a specificity of

85.7%, with an area under the curve of 0.58, indicating that the overall predictive validity of the FMS is only slightly better than a 50/50 chance.[32]

Nevertheless, based on the study by Kiesel *et al*, a 9+ score below 67% (22 points) has been suggested as a possible cut-off point for identifying players at increased risk of injury.[11] Given our SEM of 3–4 points, a player may be considered at risk in one season and not the next season without any injury or intervention occurring. We therefore anticipate that the 9+ test will have limited value in predicting injury. Practitioners should therefore exercise caution using a 67% cut-off value when interpreting the 9+ total score as an injury screening tool. Further studies are needed to confirm (or refute) the predictive validity of the 9+ test.

Methodological considerations

A major strength of this study was that it was undertaken in a real clinical athlete screening setting with a large group of professional male football players in one sports medicine hospital. A further strength of our study was the use of multiple testers. This provides good generalisability, but also might have influenced the intertester reliability adversely.

Limitations include that we did not record any prevention interventions occurring between the two test occasions. Also, this study was performed in a multinational and multilanguage setting. Although most of our testers spoke the same language as the players and we used pictures of the tests as described by Frohm *et al*,[11] it is possible that players did not understand the instructions given. This may have influenced the variability in the player performance of the 9+ score.[30] Finally, our study participants consisted of a homogeneous group of professional male football players in a specific setting which limits the generalisability of the findings to other sports, settings, age groups or women.

CONCLUSION

There was a substantial intraindividual variability of the 9+ total score between two consecutive seasons, irrespective of injury and severity status. A change above 8 points between seasons is necessary to represent a real change in the 9+ test. Additionally, there was a small but systematic improvement from one season to the next across all injured and uninjured groups.

Correction notice This paper has been amended since it was published Online First. In the methods section, the name of the authors' ethical review organisation was incorrectly changed to the Anti Doping Lab Qatar. The correct name is Anti-Doping Laboratory Qatar. Also, on page 4, the first sentence should have been deleted. This has now been done.

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Contributors AB designed the study, contributed in data collection, analysed and interpreted the data, and drafted the article. RB designed the study, interpreted the data, revised the article and approved the final revision of the article. AF and RW contributed in data analysis, interpreted the data, revised the article and approved the final revision of the article. KMK, ST, TB, CE, JLT and EW interpreted the data, revised the article and approved the final revision of the article.

Competing interests KMK is Editor in Chief of *BJSM* and was at arm's length (and blinded) from the review process in *BJSM*.

Ethics approval The study has been reviewed and approved by the Institutional Review Board, Anti-Doping Laboratory Qatar (ADLQ), Doha, Qatar.

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Appendix

Approval letters from the Institutional Review Board, Anti-Doping Lab Qatar (ADLQ)
(Ethical approval)

Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
Fax: 44132997
Email: ADLQ-RO@adlqatar.com

IRB SCH Registration: SCH-ADL-070
SCH Assurance: SCH-ADL-A-071

APPROVAL NOTICE

Date: 18/08/2013
PI: Dr. Stephen Targett
IRB Number: E2013000003
Protocol Title: **The benefits of periodic health examination (PHE) in athletes - a prospective cohort study from athlete screening in a Middle Eastern setting.**
Submission Type: Initial Application
Review Type: Expedited Review
Approval Period: 18/08/2013 – 17/08/2014

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.
As the Principal Investigator of this research project, you are responsible for:

- Ethical Compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval (i.e., with regards to obtaining prior approval of any deviation of protocol, reporting of unanticipated events, and submission of progress reports).
- To inform the ADLQ-RO of the date of commencement of the research*.

The activities under this protocol will be performed as a part of the awarded grant:

Sponsor: Aspetar Sports Hospital
Grant Title: The benefits of periodic health examination (PHE) in athletes - a prospective cohort study from athlete screening in a Middle Eastern setting.
Grant/Contract PI: Dr. Stephen Targett

ADLQ- IRB Chair
Dr. Sittana ElShafie

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

**For Commencement of Research, Protocol Deviation Reporting, Unanticipated Problem Reporting & Research Progress Annual Report, please contact - Education & Research Office, Anti-Doping Lab Qatar.*

Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
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IRB SCH Registration: SCH-ADL-070
SCH Assurance: SCH-ADL-A-071

APPROVAL NOTICE

Date	23/09/2014
Lead Principal Investigator	**Dr Stephen Targett**
IRB Application #	E2013000003
Protocol Title	**The benefits of periodic health examination (PHE) in athletes - a prospective cohort study from athlete screening in a Middle Eastern setting.**
Submission Type	**Ethical Approval Extension**
Review Type	**Expedited Review**
Approval Period	23/09/2014– 22/09/2015

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.
As the Principal Investigator of this research project, you are responsible for:

- Ethical Compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval (i.e., with regards to obtaining prior approval of any deviation of protocol, reporting of unanticipated events, and submission of progress reports).
- To inform the ADLQ-RO of the date of commencement of the research*.

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

Director – ORS/ADLQ (Office of Research Support)
Ms. Noor AlMotawa

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Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
Fax: 44132997
Email: ADLQ-RO@adlqatar.com

IRB SCH Registration: SCH-ADL-070
SCH Assurance: SCH-ADL-A-071

APPROVAL NOTICE

Date: 04/08/2013
PI: Mrs. Andrea Mosler
IRB Number: F2013000003
Protocol Title: **Intrinsic and extrinsic risk factors for hip, groin and hamstring pain in elite footballers: a prospective study**
Submission Type: Initial Application
Review Type: Full Board Review
Approval Period: 22/07/2013 – 21/07/2014

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.
As the Principal Investigator of this research project, you are responsible for:

- Ethical Compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval (i.e., with regards to obtaining prior approval of any deviation of protocol, reporting of unanticipated events, and submission of progress reports).
- To inform the ADLQ-RO of the date of commencement of the research*.

The activities under this protocol will be performed as a part of the awarded grant:

Sponsor: Aspetar Sports Hospital
Grant Title: Intrinsic and extrinsic risk factors for hip, groin and hamstring pain in elite footballers: a prospective study
Grant/Contract PI: Mrs. Andrea Mosler

ADLQ- IRB Chair
Dr. Sittana ElShafie

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

***For Commencement of Research, Protocol Deviation Reporting, Unanticipated Problem Reporting & Research Progress Annual Report, please contact - Education & Research Office, Anti-Doping Lab Qatar.*

Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
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IRB SCH Registration: SCH-ADL-070
SCH Assurance: SCH-ADL-A-071

APPROVAL NOTICE

Date	23/09/2014
Lead Principal Investigator	**Intrinsic and extrinsic risk factors for hip, groin and hamstring pain in elite footballers: a prospective study**
IRB Application #	**F2013000003**
Protocol Title	**Mrs. Andrea Mosler**
Submission Type	**Ethical Approval Extension**
Review Type	**Full Board Review**
Approval Period	**23/09/2014– 22/09/2015**

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.
As the Principal Investigator of this research project, you are responsible for:

- Ethical Compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval (i.e., with regards to obtaining prior approval of any deviation of protocol, reporting of unanticipated events, and submission of progress reports).
- To inform the ADLQ-RO of the date of commencement of the research*.

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

Director – ORS/ADLQ (Office of Research Support)
Ms. Noor AlMotawa

** For Commencement of Research, Protocol Deviation Reporting, Unanticipated Problem Reporting & Research Progress Annual Report, please contact - Education & Research Office, Anti-Doping Lab Qatar.*

Arnhild Bakken // The benefits of periodic health evaluation in professional football