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Dustin Nabhan

Preventive medicine in elite sport: the role of the periodic health evaluation

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"There should be instituted, as a custom, a system of periodical examination, to which all persons should submit themselves, and to which they should submit their children…The examination should be reported in writing; and, after due consideration, such advice must be given as careful judgement may dictate, for the future conduct, pursuits and habits of the patient, with a view to correcting any defects, or tendency to defects, in the organism.

Such a system of examination and advice as I propose, if properly carried out, must strike at the root of these evils, and would at the same time reduce the miserable over-crowding of the hospital waiting-rooms, and the enormous expenses incurred for the drugs."

-Dr. Horace Dobell

Lectures on the Germs and Vestiges of Disease, and on the Prevention of the Invasion and Fatality of Disease by Periodical Examinations, 1861

Summary

Health problems are an occupational hazard for elite athletes. Medical surveillance by the International Olympic Committee reveals that up to one in six athletes are injured and one in ten experience an illness during the period of an Olympic Games. These health problems range from the common cold to catastrophic, disabling injuries, and death. In addition to health consequences, the financial and performance impacts of injury and illness can be significant to both the athlete and their team. Protecting athletes from injury and illness is an important task for all sport organizations.

Preventive medicine reduces the impact of health problems by stopping them from occurring and reducing their burden. In elite sport, one aspect of preventive medicine is the periodic health evaluation (PHE). The objectives of the PHE are to comprehensively review of an athlete's health status, assess for risk of future health problems, serve as an entry point into the healthcare system, and to monitor health over time. Several approaches to the PHE have been described, with varying levels of clinician-patient engagement, necessary resources, and clinical complexity. Despite widespread adoption, whether PHEs improve the health and wellness of athletes is unknown. Better understanding of the PHE can result in improved health for athletes, more efficient resource allocation for sport organizations, and will guide other areas of athlete health promotion research and practice.

The aim of this dissertation is to describe current PHE practices in elite athlete populations and assess the value of specific elements of the PHE: the health history, iron screening, and screening for conditions that are difficult to diagnose in primary care (sleep, mental health, and allergies).

Paper I: The PHE practices of the top performing National Olympic Committees (NOCs) are not known. We aimed to learn more about current practice by surveying NOCs finishing in the top eight for medal count at the 2016 Rio Olympic Games or 2018 PyeongChang Olympic Games. The survey included four sections: 1) PHE staff composition and roles, 2) beliefs regarding the PHE, 3) a ranking of risk factors for future injury, and 4) details on the elements of the PHE. All 14 NOCs with top 8 finishes at the 2016 Rio Olympic Games or 2018 PyeongChang Olympic Games completed the survey. NOCs included a median of 7 staff specialties in the PHE, with physicians and physiotherapists having the highest level of involvement. There was agreement that PHEs are effective in identifying current health conditions (13/14) and that athletes should receive individualized action plans after their PHE (14/14), but less agreement (6/14) that PHEs can predict future injury. The top three risk factors for future injury were thought to be previous injury, age, and training experience. The practices of NOCs were diverse and often specific to the athlete population being tested, but always included the patient's health history, laboratory studies, cardiovascular screening, and assessments of movement capacity. Among the top performing NOCs, the PHE is a comprehensive, multidisciplinary process aimed to identify existing conditions and provide baseline health and performance profiles in the event of future injury.

Paper II: Patient health history information is commonly collected by interview or questionnaire. However, there is no research that compares these techniques directly. We aimed to do this by performing a retrospective chart review of health history data collected by questionnaire and interview in a cohort of 142 athletes who participated in a PHE with the United States Olympic & Paralympic Committee. The main outcome measure was number of injuries reported by either interview or written questionnaire. 626 injuries were reported by interview and 157 by questionnaire. The mean number of injuries reported was 4.4 ± 4.2 by interview and 1.1 ± 1.3 by questionnaire (difference: 3.3, $p<.001$). Capture rate by method was similar across sex and for both Olympic and Paralympic athletes. More injuries were reported by interview than questionnaire for all injury categories, except for concussions and surgeries. Patient interviews capture four times as many past or current injuries than electronic questionnaires. Questionnaires provide incomplete health history information.

Paper III: Athletes encounter many health conditions that are difficult to diagnose in the primary care setting. We aimed to assess the value of including validated screening tools for allergies, anxiety, depression, sleep apnoea, and sleep quality into an electronic patient health history questionnaire to determine if this practice may identify these conditions as part of the PHE. In this descriptive study we reviewed electronic health records of Olympic and Paralympic athletes who completed health screenings, which included validated screens for allergies (Allergy Questionnaire for Athletes), anxiety (GAD-2), depression (PHQ-2), sleep apnoea (Berlin Questionnaire), and sleep quality (Pittsburgh Sleep Quality Index) using established criteria for a positive screen. We reported the prevalence of positive tests and the associations between positive screening outcomes. A total of 683 Olympic and 257 Paralympic athletes (462 male, 478 female) completed the health history between May and September of 2019. At least one positive screen was reported by 37% of athletes training for the Olympics and 48% of athletes training for the Paralympics. More than 20% of all athletes screened positive for allergies and poor sleep quality. Athletes training for the Paralympics had a significantly higher percentage of positive screens for anxiety, depression, poor sleep quality and sleep apnoea risk. Females had significantly more positive screens for allergy and poor sleep quality. The addition of standardized screening tools to an electronic health history resulted in the identification of potential mental health, sleep, and allergy problems in both Olympic and Paralympic athletes. Strong associations between mental health and sleep disorders suggest these problems should be considered together in health screening programs.

Paper IV: It is not uncommon for athletes to be diagnosed with iron deficiency, yet there remains uncertainty whether the prevalence of suboptimal iron status in elite athletes differs from the normal population or warrants routine screening. The purpose of this study was to compare the distribution of serum ferritin (SF) in a cohort of elite athletes to that of the general population. Electronic health records of 1085 elite adult athletes (570 women, 515 men) from 2012–2017 were examined retrospectively. SF values were compared to published general population data. The proportion of athletes meeting criterion values for iron deficiency or initiation of treatment was examined. SF distributions in male athletes were significantly lower than normal males aged 20 to <24 years and aged 24 to <28 years. SF status was similar in female athletes and normal women aged 20 to <24 years or aged 24 to <28 years. Using 35 ng/ml as the criterion value for stage one iron deficiency, 15% of male athletes and 52% of female athletes displayed suboptimal iron status. Male athletes have a significantly lower population distribution of SF values as compared to normative data on healthy males, with 15% of male athletes having suboptimal SF status. The distribution of SF values in elite female athletes did not differ from population values; however, approximately half of women athletes were iron deficient. These data suggest that iron screening should be considered in both male and female athlete populations.

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Dustin Nabhan

List of papers

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

I. Nabhan D, Taylor D, Lewis M, Bahr R. Protecting the world's finest athletes: periodic health evaluation practices of the top performing National Olympic Committees from the 2016 Rio or 2018 PyeongChang Olympic Games. *Br J Sports Med* 2021:bjsports-2020-103481.

II. Nabhan D, Taylor D, Hedges A, Bahr R. The value of the patient history in the periodic health evaluation: Patient interviews capture 4 times more injuries than electronic questionnaires. *J Orthop Sports Phys Ther;* 2021;**51**:46–51.

III. Nabhan D, Lewis M, Taylor D, Bahr R. Expanding the screening toolbox to promote athlete health: how the US Olympic & Paralympic Committee screened for health problems in 940 elite athletes. *Br J Sports Med* 2021;**55**:226–30.

IV. Nabhan D, Bielko S, Sinex JA, Surhoff K, Moreau WJ, Schumacher YO, Bahr R, Chapman R. Serum ferritin distribution in elite athletes. *J Sci Med Sport* 2020;**23**:554–8.

Abbreviations

ACL	Anterior cruciate ligament
AQUA	Allergy questionnaire for athletes
Berlin	Berlin sleep apnoea questionnaire
ECG	Electrocardiogram
GAD	Generalized anxiety disorder questionnaire
IOC	International Olympic Committee
FIFA	Federation Internationale de Football Association
NOC	National Olympic Committee
PHE	Periodic health evaluation
PHQ	Patient health questionnaire
PSQI	Pittsburgh sleep quality index
ROM	Range of motion
SF	Serum ferritin
USOPC	United States Olympic & Paralympic Committee
USPSTF	United State Preventive Service Task Force
WHO	World Health Organization

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Introduction

The burden of health problems in elite athletes

Health problems are an occupational hazard for elite athletes. Medical surveillance from the International Olympic Committee (IOC) reveals that during the period of an Olympic Games athletes will sustain between 9.6 to 14.0 injuries and 5.4 to 8.9 illnesses per 100 athletes (Soligard et al., 2019). When injury rates in professional soccer are compared to occupational health safety standards, the health risks of soccer are considered unacceptable (Drawer & Fuller, 2002). In addition to high injury risk, athletes have a high prevalence of general medical issues, including mental health problems (Reardon et al. 2019), asthma, and upper respiratory infections (Carlsen et al., 2008).

Sports injuries are usually described in terms of their short-term impact; however, the health effects of elite sport participation can persist long after an athlete retires. There is a balance of long-term risk and benefit to sport participation that appears to be organ system and sport dependent (Kujala et al., 2003). Elite athletes tend to have better health than the general population; they are more physically active, hospitalized less frequently, have fewer disabilities, and live longer than non-athletes (Kontro et al., 2018). However, former athletes frequently suffer from osteoarthritis, with reported prevalence of hip and knee osteoarthritis as high as 60% and 95%, respectively (Gouttebarge et al., 2015; Roos, 1998). This can result in chronic pain and disability, with one-third of former Olympians reporting chronic pain secondary to injuries sustained during their sporting career (Palmer et al., 2021). Former elite athletes also suffer from a high prevalence of mental health problems (Gouttebarge et al., 2019), and there has been speculation that future development of neurocognitive disease and depression may be associated with history of sport-related head injury (Kerr et al., 2014; Mackay et al., 2019; Manley et al, 2017).

In addition to health consequences, these problems have significant financial and performance implications for athletes and their teams. In individual sports, every week lost from training due to health problems reduces the chance of athletes meeting their performance goals by 25% (Raysmith & Drew, 2016), and in team sport, injuries have been found to influence a team's chance of competitive success (Hägglund et al., 2013). The financial impact of health problems in professional sport is staggering. A single hamstring injury is thought to cost over $40,000 AUS in Australian rules football (Hickey, et al. 2013), one concussion results in an average of $292,000 US per year of lost salary for a National Hockey League player (Navarrao, et al. 2018), and the average Premier League football team loses £45M US annually due to injury-related costs including the associated performance decrement of injured athletes (Eliakim, et al. 2020).

Protecting athletes from injury and illness is an important task for all of sport. The IOC, Federation Internationale de Football Association (FIFA), National Football League and National Basketball Association have programs for health promotion—these include best practice sharing, mandatory medical screenings, policy changes, and developing novel clinical resources for injury and illness prevention. The lessons learned from PHEs of elite athletes have the potential to benefit those participating in all levels of sport.

Preventive medicine in elite sport

The aim of *preventive medicine* is the absence of disease, either by preventing the occurrence of a disease or by halting a disease and averting resulting complications after its onset (Clarke, 1974). Preventive medicine uses three strategies to reduce the impact of health problems (Katz & Ali, 2009). *Primary prevention* describes interventions provided to healthy patients before any signs or symptoms of a disease are present. This strategy focuses on eliminating the cause of the health problem (often by reducing exposure by laws or environmental change) or increasing resistance to the risk factor (e.g., vaccination). Primary prevention can be provided for all members of a population (e.g., water purification for a city) or for targeted groups known to be at risk due to their demographic characteristics, for example the requirement of helmets in American football to prevent traumatic brain injury. *Secondary prevention* describes the treatment of a condition in an early phase before symptoms present. This is accomplished by screening to identify risk factors, followed by treatment for those determined to be at elevated risk or with latent disease. Any prevention program that includes a test to stratify risk (e.g., blood pressure, flexibility, strength) is considered secondary prevention. *Tertiary prevention* refers to the treatment of a symptomatic health problem after diagnosis. The goal of tertiary prevention is to reduce the burden of a condition after it occurs, including prevention of recurrence. For instance, managing the return to play of an athlete who has sustained an injury so that the total amount of time lost due to that injury is minimized is part of tertiary prevention. Examples of prevention programs for infectious disease and sports injuries are detailed in **Table 1**.

Table 1 Example preventive medicine approaches for infectious disease and injury.

	Primary	**Secondary**	**Tertiary**
Influenza	Seasonal vaccination for entire population	Anti-viral medication to exposed individuals who have not yet displayed symptoms	Anti-viral medication for symptomatic patients to reduce symptoms and risk of transmission
ACL*	Neuromuscular training program for all athletes at risk (e.g., FIFA 11+†)	Neuromuscular training program for all athletes with a known risk factor (e.g., dynamic valgus during drop jump landing)	Injury rehabilitation and prevention exercises after ACL reconstruction.

*ACL= anterior cruciate ligament †FIFA 11+ see Thorborg et al., 2017

Unfortunately, the terminology used in preventive medicine has been inconsistent (Froom & Benbassat, 2000) and differs from accepted injury prevention terminology. Injury prevention literature defines primary prevention as interventions used to prevent an injury from occurring or preventing an event from leading to an injury, secondary prevention as rapid diagnosis and appropriate treatment, and tertiary prevention as the process of improving the outcome, such as rehabilitation and reducing long term complications (Holder, 2004). In this thesis I will use the preventive medicine definitions, as this model best describes the methodology of prevention through screening programs and periodic health evaluations (PHEs).

Epidemiology is the foundation for preventive medicine

Epidemiology is the basic science that underpins preventive medicine (Clarke, 1974). Epidemiological research is necessary to identify the health problems that are most important in a population and the risk factors associated with their onset and prolonged burden. In sport, injury and illness surveillance forms the foundation for this work (Bahr et al., 2020).

Depending on the setting and resources, the methods used to classify and describe health problems may include formal health surveillance research programs, reviews of medical records and federation injury/illness reports, or literature reviews. The IOC has published a consensus statement with best practices in elite athlete health surveillance (Bahr et al., 2020). In this statement, the authors recommend that surveillance programs include detailed reports for each health condition identified, including the mode and mechanism of onset, affected body region, classification of diagnosis, frequency (incidence and/or prevalence), severity (days lost from full sport participation), and burden (the product of incidence and severity) (Bahr et al., 2020). This type of reporting allows researchers to understand the burden and natural history of each condition.

Etiology research guides preventive medicine

The preventive medicine model relies on the identification of risk factors for secondary prevention. This parallels the sport injury prevention research model, in which once the most important health problems are identified, risk factor identification research is the next step (van Mechelen, 1992). This facilitates the development of interventions that can then be implemented and studied to determine their impact on the burden of disease in a population.

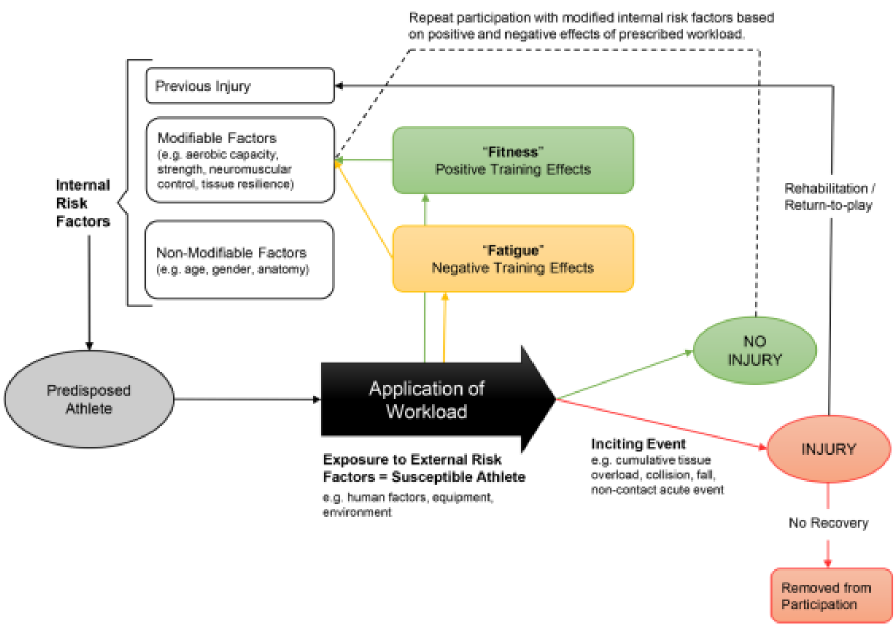
Identifying and managing risk factors for injury and illness in sport is difficult, due to the number of factors that may lead to a health condition, intrinsic differences between athletes, and the dynamic nature of sport and human life (Bahr & Holme, 2003; Meeuwisse et al., 2007). Risk factors have been classified as internal to an athlete (e.g., age, sex, strength) or external to the athlete (e.g., environment, rules, equipment); some risk factors can be changed and are deemed modifiable (e.g., strength), while others are non-modifiable (e.g., age). There has been considerable theoretical work in the field of sports medicine to propose how these risk factors interact with circumstance to cause an injury.

Several models have been proposed to describe the etiology of sports injury. The first sport injury causation model to propose that injury is the result of interactions between multiple risk factors came from Meeuwisse in 1994 (Meeuwisse, 1994). Meeuwisse's model described injury as the result of complex interactions between internal (e.g., shoulder flexibility) and external risk factors (e.g., playing against an aggressive opponent) that predispose an athlete to injury if they are exposed to a potential inciting event (e.g., a rugby tackle) that exceeds a tissue's capacity to withstand biomechanical forces (e.g., shoulder dislocation). This model was expanded upon by

Bahr and Holme (2003), who proposed more robust definitions of internal and external biomechanical risk factors and described how the interactions of these factors during the inciting event cause an injury. They called for improvements in research methods to account for documentation and analysis of how risk factors relate to injury events and described minimal sample sizes and the most appropriate statistical techniques for multivariate injury causation models.

In 2007, Meeuwisse et al. revised the multifactorial sports injury causation model to account for physiological adaptations to sport specific stimuli. The recursive nature of this model described injury susceptibility as constantly changing due to adaptations to modifiable risk in response to sport exposure. Windt and Gabbett later expanded on this model by introducing the fitness-fatigue relationship to training in which recent, "acute," training leads to fatigue that may increase risk in the short term, while past "chronic" training loads theoretically increase work capacity and offer a protective effect due to positive physiologic adaptations (Windt & Gabbett, 2016). This model emphasized the importance of careful planning of training due to its theoretical influence on fitness, fatigue, and injury risk (See **Figure 1**).

Figure 1 The workload—injury aetiology model, from Windt & Gabbett, 2016.



As British statistician George Box famously wrote, “All models are wrong, some are useful” (Box, 1976). The multifactorial and dynamic nature of sports injury has not allowed for the development of accurate risk factor-based injury prediction methods. Advanced statistical techniques designed for multiple, dynamic variables, such as neural networks and machine learning have been presented as promising applications for this field (Kakavas et al., 2020). Given the current state of risk factor-based injury prediction research, it has been declared that it is unlikely that screening for risk factors will ever be an effective method of injury prevention (Bahr, 2016). However, these models still are useful, as they form a theoretical framework for research and practice.

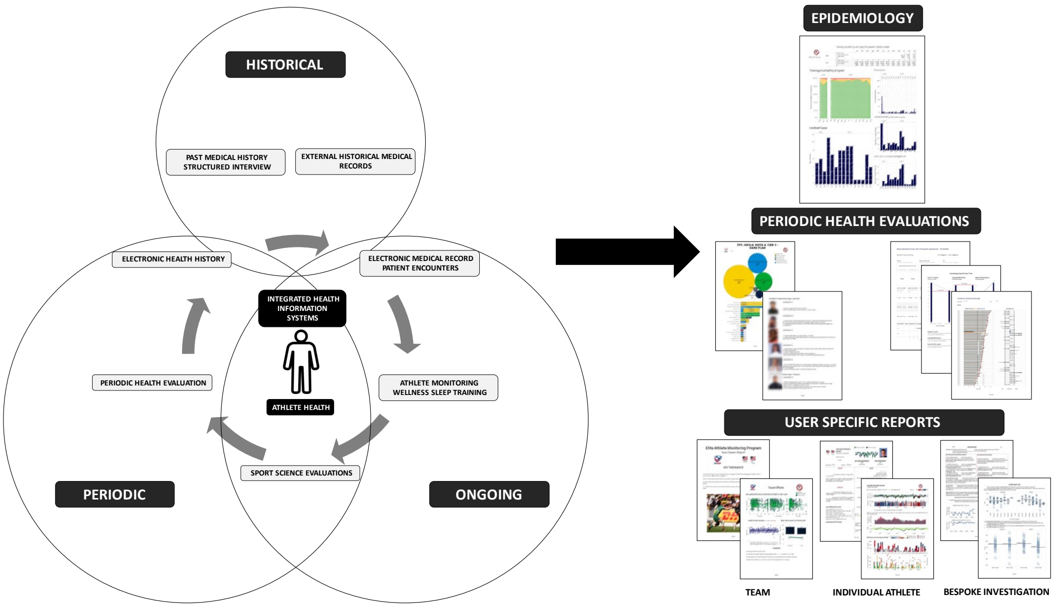
Risk management in elite sport—from theory to practice

The practice of preventive medicine in elite sport has been described as an element of risk management programs (Fuller & Drawer, 2004). Risk management programs evaluate the health consequences of sport participation, identify risk factors, and incorporates education and preventive interventions to manage risk. Although the scope of risk management plans may differ depending on setting, there are several components of these programs that should be considered by sports medicine teams hoping to promote athlete health (adapted from McIntosh & Bahr, 2009):

- Implement an injury and illness surveillance system
- Analyze injury trends in relation to events that occurred during the season (e.g., schedule, environment, etc.)
- Perform pre-season screening of health problems and functional limitations
- Monitor modifiable risk factors
- Educate athletes and coaches on injury prevention and management
- Develop and practice emergency action plans
- Audit and improve risk management plans based on new scientific evidence
- Coordinate the risk management program

Data are critical to the planning and management of a risk management program. **Figure 2** provides a real-world example of how one National Olympic Committee (NOC) uses a health information system to turn data into information that informs risk management efforts. In this example, medical histories are collected from structured patient interviews and available medical records. Current or new injuries are documented in the electronic health record. Risk factors are monitored with tools such as biomechanical testing, daily wellness, or sleep questionnaires. PHEs are used as comprehensive evaluations of health status at pre-determined time intervals. This information is aggregated and used to create summary reports of team health, periodic reports for risk evaluation, and bespoke individual or group reports for data informed risk management projects.

Figure 2 Example of health information use in a risk management program (from Nabhan et al., 2021)



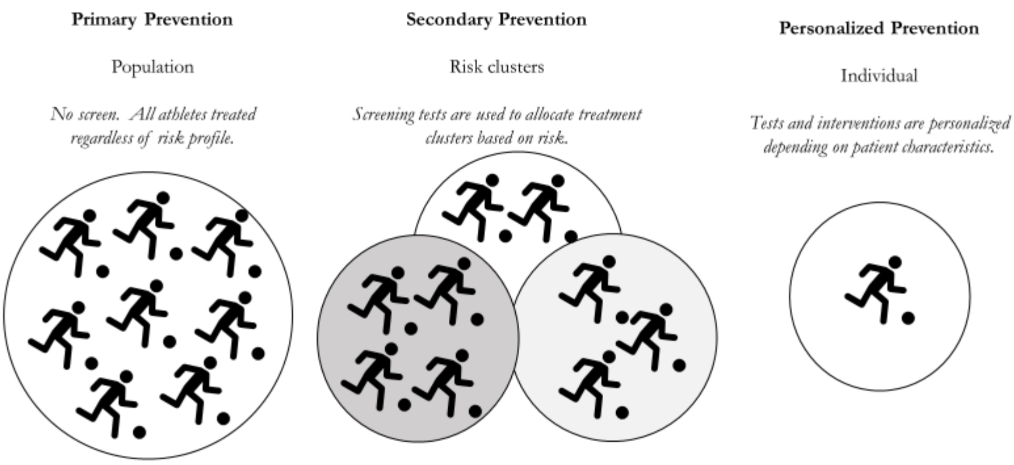
Personalized medicine as preventive medicine

Preventive medicine programs that use screening (secondary prevention) or treat affected patients (tertiary prevention) target the patients most likely to respond positively to an intervention. Two strategies can be used for this: 1) stratified clustering based on risk or 2) a personalized approach. If clusters of patients with similar risk factors are prescribed a treatment, this is stratified clustering. For example, athletes with a known risk factor for future injury, such as history of hamstring strain, could be prescribed hamstring eccentric strength exercises as part of their strength and conditioning program. There is evidence that this strategy is effective in specific contexts, with the best example being an 86% reduction in hamstring injury when preventive exercises were provided to athletes with previous hamstring injury, as compared to a 50% reduction of injury in the uninjured population (Peterson et al., 2011).

Researchers focus on the outcomes of a cohort or population. However, clinicians work with individual patients with unique histories, risk factors, lifestyles, and goals. *Personalized medicine* is defined as "the ability to classify individuals into subpopulations that differ in their susceptibility to a particular disease or their response to a specific treatment" (Report on the Presidents Council, 2008). The objective of personalized medicine is to better prescribe preventive or therapeutic interventions to the patients they will benefit, reducing expenses and side effects of ineffective treatments for probable non-responders (DiSanzo et al., 2017).

Personalized medicine describes the development of a customized intervention for an individual, based on all risk factors that an individual is found to possess. In theory, personalization may be the most effective method to protect health by addressing an individual's current health state, medical history, environmental and societal exposures, and family history/genetics. This information could be used to better manage risk by accounting for individual differences in health status and their likely response to care (**Figure 3**). A proof-of-concept model has been published that provides evidence for personalized preventive care in general practice (Taskler et al., 2013), but there is no real-world evidence that this approach improves outcomes in either the general or elite athlete populations. Before considering the personalized approach, the benefits of bespoke interventions must be weighed against the costs of program implementation.

Figure 3 Population, clustered and personalized prevention models (adapted from Roe, 2017)



The Periodic Health Evaluation

The history of screening

The promotion of modern medical screening programs is credited to Horace Dobbell, a London physician at the Royal Hospital for Chest Diseases (Raffle, 2019). Dobell advocated for systematic medical evaluations of healthy patients, with a goal of identifying risk factors for health problems and prescribing preventive treatments to reduce the burden of disease. Dobell's work eventually spread, and by 1922 the practice of PHEs as a preventive medicine measure was endorsed by the American Medical Association and became common practice by the 1950s.

Dobell's model of preventive screening was adopted with optimism. However, problems with screening quickly appeared. Patients and clinicians became frustrated with methodological flaws in screening systems, and identified missed diagnoses, over-diagnosis, and excessive cost as drawbacks of screening (Raffle, 2019). The World Health Organization (WHO) addressed these issues by commissioning England's Principal Medical Officer JMG Wilson and G Jungner of Sahlgren's Hospital in Gothenberg, Sweden, to write "Principles and Practice of Screening for Disease." This monograph described the theoretical rationale and evidence base for medical screening, discussed problems associated with screening, and recommended best practices for developing new programs (Wilson & Jungner, 1968). Since Wilson and Jungner's critical review, the roles of medical screening and PHEs as prevention tools have been controversial, as there is still limited evidence that PHEs have efficacy or result in cost savings (Boulware, 2007).

Despite the challenges with screening, there are many examples of medical screening programs that are effective. The US Preventive Service Task Force (USPSTF) currently grades 25 screening topics as Grade A or B, indicating moderate to high certainty of net benefit (United States Preventive Services Taskforce, 2021). Examples include bi-annual low dose computed-tomography screening for adults 50 to 80 years old with a 20 pack-year smoking history within the last 15 years, one-time ultrasound screening of abdominal aortic aneurysm for males, and hepatitis B screening for pregnant women in their first prenatal visit. These programs each have a high benefit to risk profile, acceptable test properties (e.g., cost, feasibility), and result in a net health improvement for participants. Many of these programs target patients in a certain demographic or stratify eligibility based on risk exposure, a strategy that reduces costs and improves the diagnostic yield as compared to screening entire populations.

There are also many screening programs that have proven to be ineffective or harmful after implementation. There are 14 clinical topics that the USPSTF rates as Grade D, meaning there is moderate to high certainty of no benefit, or the harms outweigh the benefit, and 38 in which there is not yet enough evidence to make a recommendation. Some of these programs caused more harm than benefit because they were adopted before evidence of efficacy. An often-cited example comes from early cervical cancer screening programs, which led to many inappropriate cancer diagnoses, unnecessary invasive and harmful treatments, increased risk of pre-term delivery for many mothers, and escalation of healthcare costs and strain on medical systems (Casper & Clarke, 1998).

Sometimes screening is performed for reasons other than effectiveness. Drivers of early adoption of screening include the need to support research, economic savings, professional empowerment, developing physician-patient relationships and administrative efficiency (Raffle, 2019). However, the impetus for screening is not always patient centered; for example, when screening tests become newly available to clinicians with low barriers to use, or financial incentives are attached to incorporating screening, clinicians often implement screening before evidence justifies it (Raffle, 2019). Due to the controversy surrounding the risks and benefits of these programs, future research is needed on screening and its impact on patients, clinicians, and society.

PHEs in sport

The practice of evaluating an athlete's health prior to training or competition has existed for centuries. The first known record of this comes from ancient India in 600 BC, where a physician named Susruta implemented pre-exercise evaluations of patients, and then carefully prescribed exercise based on their health (Tipton, 2014). Spartans screened the health of children to be future warriors, and terminated or ostracizing those deemed unfit (Mitchell, 1985). Hippocrates evaluated the health of athletes in advance of their participation in ancient Olympic Games, and the Gladiators of Pegamum were given medical evaluations prior to combat (Gwathmey et al., 2011).

The PHE is now a standard aspect of sports medicine practice (Brukner, et al., 2004). The rationale and recommended format of the PHE has been described by expert consensus, most notably by an IOC position statement for the PHE for elite athletes in 2009 (Ljungqvist et al., 2009). Many sport organizations now require an athlete to gain medical clearance via a PHE prior to participation.

In North America, the current standard of care is described by the 5th edition of the Preparticipation Examination Monograph (Bernhardt & Roberts, 2019). This monograph, which primarily targets the screening of adolescents prior to sports participation, has been endorsed by medical societies such as the American Academy of Pediatrics, American Academy of Family Physicians, American College of Sports Medicine, American Medical Society for Sports Medicine, American Orthopedic Society for Sports Medicine, and American Osteopathic Academy for Sports Medicine. Other guidelines include FIFA's Pre-Competition Medical Assessment (Dvorak, et al., 2009), the Australian College of Sports Physicians Statement (Brukner et al., 2004), and the National Athletic Trainers Association Position Statement (Conley et al., 2014). Despite these endorsements, the sports administration and medical communities are largely unaware of published guidelines (Madsen et al., 2014), and the practice patterns of the sport and exercise community are unknown. In Paper 1, we aimed to describe the PHE practices in elite sport by surveying the top performing NOCs on their current practice patterns.

Objectives of the PHE

The objectives and practice patterns for the PHE vary depending on the setting, resources, and priorities of the organization. Current guidelines describe the purposes of the PHE as: a comprehensive review of an athlete's health status, an assessment for risk of future health problems, an entry point into a healthcare system, and an opportunity to monitor health over time (Ljungqvist et al., 2009). While recommendations from medical societies focus on screening for health, high performance sport organizations also include screening for factors that may impair performance and the collection of data as a baseline for diagnostic or return to play decision making (Brukner et al., 2004; Bernhardt & Roberts, 2019). In youth sport, the PHE is often the entry point into the healthcare system and may be only health promotion opportunity for adolescent athletes who do not have access to regular medical care (Bernhardt & Roberts, 2019). Medico-legal and insurance requirements and regional standards of care also have a strong influence on the practice of the PHE. A list of commonly referenced objectives for the PHE is included below in **Table 2**.

Table 2 Objectives of the PHE

Current symptomatic health problems	Determine general physical and psychological health Determine eligibility for sport participation Ensure current health problems are managed appropriately
Occult health problems	Screen for silent medical conditions, with an emphasis on identifying conditions associated with sudden cardiac death
Risk factor identification	Identify risk factors for future injury Introduce prevention strategies for athletes at risk Document and review the past medical history
Performance	Identify barriers to performance Performance analysis in sport science disciplines (nutrition, biomechanics, physiology, psychology)
Baseline data collection	Collect baseline data to use as a diagnostic tool in the event of future injury Collect baseline data to use as a benchmark for return to play decision making in the event of future injury
Education & Relationships	Develop relationships between athletes and medical staff Serve as a portal of entry into the healthcare system Opportunity to provide education on health topics and available resources
Medicolegal & Anti-doping	Satisfy requirements of sport federations, local government, and regional standards of care for periodic screening of athletes/employees Review medications and vaccination history for medical and anti-doping risk management

Elements of the PHE

Despite the numerous consensus and best practice documents designed to guide the PHE, little is known about how PHEs are performed in elite sport. What is known comes from surveys of sport organizations that suggest PHEs vary in breadth and depth, but often include a comprehensive health history, physical examination, cardiovascular exam, laboratory studies, musculoskeletal exam and focused work ups for conditions requiring further evaluation (Fuller et al., 2007; McCall et al., 2015). Factors that affect the structure of the PHE are the setting, objectives and perceived risks of the organization requiring the PHE, region or federation specific regulations, medico-legal concerns, and clinician interpretation of standard of care (Fuller et al., 2007). The following section describes some of the most common elements of the PHE, the rationale and the evidence base for their use.

Health history

The health history is the cornerstone of the PHE. Understanding a patient's health history is critical for health care providers and clinical researchers—it has been shown that the history alone identifies 90% of health problems discovered during the PHE (Gomez, 1993) and history of prior injury is the strongest predictor of future injury (Hägglund, 2006). The health history can be used as a type of injury surveillance and to identify athletes with risk factors for future injury, such as insufficient rehabilitation of prior injures. The patient interview also allows the clinician to develop a working relationship with an athlete and educate them on sports medicine topics and how to utilize medical resources.

Several methods are used to identify the current and prior health conditions in an individual or population. In sport, these often include patient interviews, written and electronic questionnaires and surveys, medical record reviews and sport federation injury reports. These methods each have strengths and limitations, including the accuracy and completeness of data collected, likelihood of compliance from athletes and medical staff, and the resources required to incorporate them. Clinicians have historically used guided patient interviews as the primary means of understanding the patient's current and past health status and to create a professional relationship with a new patient. The capture rate of these health history methods depends on the setting and population, and the best approach for the elite sports medicine setting is not yet known (Bjørneboe et al., 2011; Flørenes et al., 2011). In Paper II, we addressed this research question by comparing the use of patient interviews and electronic questionnaires to identify history of current or previous significant injury in a cohort of elite athletes at an Olympic and Paralympic Training Center.

General medical

A limited general physical exam is a routine element of the PHE. This exam usually includes assessment of height, weight, vital signs and physical examination of the eyes, ears, chest, nose, throat, neurologic, pulmonary and vascular systems, skin, and abdomen. Focused and comprehensive examinations should then be performed as indicated by the patient history (Conley et al., 2014). Regular physical examinations have been shown to improve delivery of preventive services, and may decrease patient worry (Boulware et al., 2007). Consensus statements on the PHE provide guidelines for the general medical exam that can be used as checklists for quality assurance and as a template for documenting the encounter (Ljungqvist et al., 2009: Bernhardt & Roberts, 2019).

Cardiovascular

Cardiovascular events are the leading cause of death during sports participation (Harmon et al., 2014; Dennis et al., 2018), and as a result cardiovascular screening is the most studied element of the PHE. Cardiovascular screening of athletes is controversial. Screening advocates highlight the ability of screening programs to identify risk factors for cardiovascular events, while opponents provide arguments regarding the lack of evidence for long-term benefits, evidence that athletes may not be a high enough risk population for screening to be necessary, and limitations in interpretation of screening findings (Bahr, 2010; Drezner et al., 2016).

There is abundant evidence that cardiac screening programs identify athletes with physiologic or anatomic findings associated with high risk for sport-related cardiac events (Pellicia & Corrado, 2010; Magalski et al., 2011; Malhotra et al., 2011; Wilson et al., 2012). The sensitivity of these programs can be improved with the addition of an ECG (Baggish, 2010). However, with increased sensitivity, there is a loss of specificity. There have been improvements in ECG interpretation guidelines that have resulted in false positive rates dropping from as high as 40% to as low as 2% (Malhotra et al., 2011). Despite this, there remains a high rate of false positives (10%) in athletes with African descent, the population known to have the highest prevalence of cardiac pathology (Wilson et al., 2012).

Most of the literature used to justify cardiovascular screening comes from cross-sectional studies, which have limited value as they cannot report long-term outcomes. Prospective cohort studies provide a better indication of the value of a screening program, as they allow for determination of false-negative screens. There are only two cohort studies (both from professional football) with adequate follow up to determine if screening identifies future cases. The first was a retrospective review of the English Football Association Registry, in which 11,168 athletes were screened from 1996-2016 (Malhotra et al., 2018). In this cohort there were eight deaths due to cardiac-related disease, and six of the eight had negative cardiac screens. The second is an eight-year cohort of 595 soccer players with retrospective identification of cases via media report; in this cohort six athletes with negative cardiac screens (including ECG and echocardiography) suffered severe cardiac events during the follow up period (Berge et al., 2019). These findings suggest that current cardiac screening programs may be ineffective in identifying athletes at risk for future cardiac events.

The cardiovascular screening debate presents a dilemma for clinicians performing PHEs. Current guidelines and best practices vary, with most organizations recommending a minimum of a history and physical examination, many including ECG, and some adding echocardiography and/or exercise stress tests. The effectiveness of these programs cannot be assessed with current evidence, and clinicians are left to make their own judgements regarding the scope of cardiovascular screening in the PHE (Drezner et al., 2016).

Laboratory

Laboratory studies are a common element of the PHE in the general population, where they are used to identify risk for cardiovascular disease, metabolic syndrome, and hematologic disorders (Kermott et al., 2012). The risk profile for these conditions is different in athletic populations, and so is the approach to laboratory screening. Recommended laboratory panels range from the use of a complete blood count, metabolic panel, lipid panel, immunologic studies, sexually transmitted disease screening, iron, and vitamin D (Dvorak et al., 2009; Ljungqvist et al., 2009; Hennrikus et al., 2010; Conway et al., 2018), to recommendations not to use laboratory screens unless clinically indicated (Fallon, 2008).

Iron deficiency is the most prevalent nutritional disorder in the world (Marx, 1997). Elite athletes have high rates of iron deficiency when compared to the general population. Iron deficiency associated with exercise is thought to occur from several mechanisms, which include increased iron utilization, iron loss, and reduced iron absorption due to inflammatory and exercise-mediated hepcidin bursts (Clenin et al., 2015). Female athletes have higher risk of iron deficiency than males due to blood loss from menstruation (Chatard et al., 1999; Peeling et al., 2007; Pedlar et al., 2018).

In addition to its importance for normal physiologic function, iron status affects sports performance. In its most severe form, severely depleted iron stores affect oxygen carrying capacity (iron deficiency anemia); however, iron deficiency without anemia also alters oxidative enzyme and aerobic capacity in athletes (Burden et al., 2015). As a result, screening and monitoring iron status for performance purposes has become common practice in elite sport settings (Chapman et al., 2017). The PHE provides a convenient opportunity to do this, and consequently laboratory studies are often included in the PHE.

Serum ferritin (SF) is the preferred biomarker for evaluating for low iron status, due to its sensitivity and specificity, and the fact that SF is not as vulnerable to plasma changes as hemoglobin (Cavill, 1999). Screening female athletes for SF is recommended by most guidelines, and a few also recommend screening male athletes. However, the yield of SF screening has not been reported in large populations of elite athletes. In Paper IV, we compared the distribution of SF measures in a large cohort of elite athletes, to a normal, non-athletic population to determine if there is justification for iron screening of athletes.

Vitamin D is a steroid hormone involved in many essential bodily functions. Vitamin D is produced in response to sun exposure and to a lesser extent absorbed through dietary intake. Insufficient vitamin D has been hypothesized to contribute to poor bone health, sub-optimal muscle function and increased risk of upper respiratory infections (Shuler et al., 2012; He et al., 2013). Elite athletes are at risk for inadequate vitamin D and this risk may increase in athletes of African descent or those who have inadequate sun exposure (Bauer et al., 2019). Vitamin D deficiency is readily treatable with supplementation, a cheap and accessible intervention for affected athletes (Heaney et al., 2003). These factors suggest that screening for vitamin D is reasonable, especially in high-risk populations.

Laboratory screening for infectious disease risk may benefit some athletes. Many athletes do not have immunity to preventable diseases, and mass screening to identify athletes in need for immunization has a good yield in elite athletes for measles, mumps, rubella, varicella (Conway et al., 2018) and hepatitis B (Bakken et al., 2016). In the general population, routine screening for sexually transmitted disease has been recommended in some countries. The addition of chlamydia screening to the PHE identifies many asymptomatic cases, up to 10% in some athlete groups (Hennrikus et al., 2010). Screening for blood borne pathogens, such as human immunodeficiency virus or hepatitis is not recommended as a universal requirement for sports participation as there are no known cases of sport-related transmission (McGrew et al., 2020).

Mental Health

Athletes suffer from mental health problems; however, the prevalence in elite athletes is not well understood (Goutebarge et al., 2020). This topic is an area of focus in the sports medicine community and new tools are being developed to determine the impact of mental health problems on athletes and help screen for their presence. For example, the IOC released the Sport Mental Health Assessment Tool 1 and Sport Mental Health Recognition Tool 1 in 2020

(Gouttebarge et al., 2020). There is an established need for mental health screening programs due to known relationships between mental health, performance, injury, re-injury, and illness risk (Reardon, 2019). Access to mental health services can be difficult in the elite athlete population, due to a stigma that reduces athlete motivation to seek treatment, insufficient mental health resources, a lack of awareness of symptoms and treatments, and reports of athletes having poor experiences interfacing with mental health providers (Henriksen et al., 2020).

In the general population, mental health screening for adults is recommended as a standard of care (Siu et al., 2016). Screening questionnaires improve the identification of these conditions, as mental health problems are known to be difficult to diagnose in a primary care setting in the absence of structured screening programs (Davidson, 2010; Williams, 1999). However, there is not much evidence guiding decisions on optimal timing or frequency for screening (Siu et al., 2016). The USPSTF recommends screening all adults who have not been previously screened, and to use clinical judgement to determine if screening for co-morbidities associated with mental health problems (e.g., substance abuse) is indicated (Siu et al., 2016).

Musculoskeletal

Musculoskeletal injuries are the most prevalent health problem in elite athletes (Soligard et al., 2019). The musculoskeletal assessment portion of the PHE usually includes injury-specific history questions, a focused musculoskeletal physical exam, and functional tests such as strength, range of motion (ROM), or movement quality assessments. The objectives of these tests are to identify any current conditions that are untreated, assess for inadequate rehabilitation of previous injuries, to collect baseline data in the event of a new injury, and screen for risk factors of future injury.

PHEs include elements designed to identify musculoskeletal conditions that require further attention. In a pilot study of FIFA's standardized PHE, the "pre-competition medical assessment", orthopedic conditions were identified in more athletes than all other types of health problems combined (Dvorak et al., 2009). A PHE program of professional football players, which included a musculoskeletal exam, strength, and ROM tests, found a musculoskeletal condition requiring further follow-up or treatment in one-third of the participants (Bakken et al., 2016).

Musculoskeletal screening programs facilitate tertiary prevention by streamlining the identification and appropriate treatment of existing problems. Population normative and athlete specific data collected during screening can be used to develop benchmarks during rehabilitation in the event of future injury. This information can also contribute to risk factor identification research and inform risk management programs.

The next frontier in injury prevention has been proposed to be injury or prognosis prediction (Myer et al., 2010; Hughes et al., 2018). However, to date, musculoskeletal screening has failed to identify risk factors that are strong enough to predict ACL (Krosshaug et al., 2016), hamstring (van Dyk et al., 2017), or shoulder (Andersson et al., 2018) injuries in large prospective cohort studies. This begs the question as to whether the tests used for musculoskeletal screening have value for secondary prevention.

Do PHEs meet the recommended criteria for screening programs?

Wilson and Junger's "Principles and Practice of Screening for Disease" provided guidelines for the development of preventative screening programs (Wilson & Jungner, 1968). These guidelines are designed to help policy makers determine what conditions may be better managed with screening programs, which tests to include in screening, and how to manage results to optimize effectiveness. Wilson and Jungner's principles that are relevant to the use of the PHE as an opportunity for screening include:

- The condition must be an important health problem
- There should be an accepted treatment
- There should be a recognizable latent stage
- There should be a suitable test or examination
- The natural history of the condition should be adequately understood

In elite able-bodied athletes, the most important health problems are musculoskeletal injuries (greatest burden) (Soligard et al., 2019) and the leading cause of death during sport participation is cardiovascular events (most severe) (Dennis et al., 2018). These topics are the most studied components of the PHE; however, there is not prospective evidence for improved outcomes after PHEs in either of these clinical domains. To evaluate whether PHEs meet the criteria of screening tests, the test properties of PHE elements for these conditions must be considered.

Table 3 critiques the appropriateness of screening using Wilson and Jungner criteria for cardiovascular and musculoskeletal conditions in elite athlete populations.

Table 3 Select analysis of Wilson & Jungner criteria in the PHE

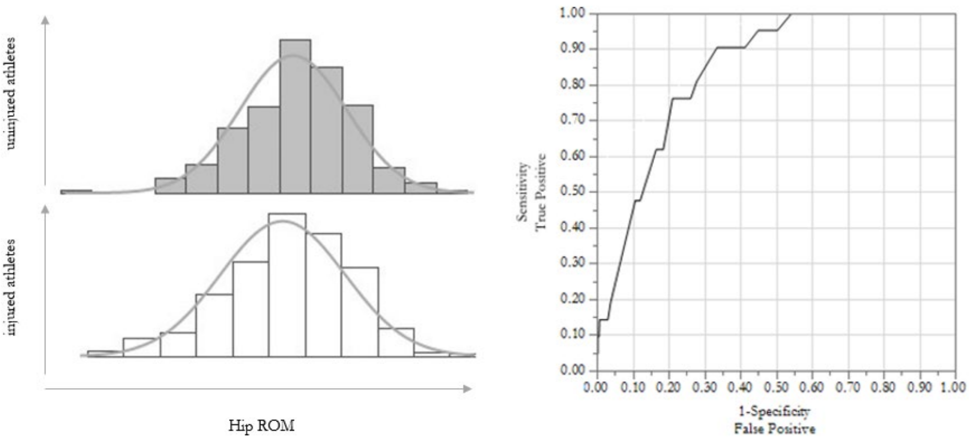
Wilson & Jungner Criterion	**Cardiovascular**	**Musculoskeletal**
Is the condition an important health problem?	Rare, but severe.	Yes.
Is there an acceptable treatment?	Depends—for some conditions, the only treatment is disqualification from sport, which may be reasonable. Others can be treated.	Unknown—prevention programs are effective when broadly implemented, but there is no evidence screening for risk improves outcomes.
Is there a latent stage?	Potentially—there are known pathologies, but the best designed study on the topic shows screening may miss cases.	Unknown.
Is there a suitable test or examination?	Controversial—the existing tests miss cases and result in false positives.	No—existing screening tests can not identify athletes at risk for injury with acceptable sensitivity and specificity.
Is the natural history well understood?	Partially—understanding of these conditions is improving.	No.

Developing suitable screening tests- the 'borderline problem'

Screening programs depend on the development of appropriate tests. Properties of tests include validity, reliability, yield, cost, acceptance, and access to follow up services (Wilson & Jungner, 1968). Screening programs have struggled to be effective due to the difficulty in developing tests that are valid, reliable, and have a high yield.

The sensitivity and specificity of a test are inversely related. Therefore, for many conditions it is difficult to create cut-points for tests that result in a high yield and a low rate of false positives. The "borderline problem," as described by Wilson and Jungner (Wilson & Jungner., 1968), describes this statistical dilemma for when a risk factor measured as a continuous variable with a normal distribution cannot be dichotomized with a cut score that effectively determines risk. Risk factors that have been deemed statistically significant in cohort studies may not be useful in case management of individuals. For example, prospective screening based on muscle strength, ROM and motor control have failed to produce clinically significant cut scores that clearly differentiate high risk from low-risk athletes (Bahr, 2016). **Figure 4** provides a fictional example of a screening test for a continuous variable that is statistically significant but not clinically useful predicting risk in an individual.

Figure 4 The "borderline" problem for normally distributed risk factors. An example using fictional data demonstrates the relationship between sensitivity and specificity when risk factors are normally distributed in two groups that are statistically different ($p<.01$). The top histogram (grey bars) represents the distribution of a risk factor in a population that does not sustain an injury, and the bottom (white bars) for the athletes that sustain a future injury. The graph on the right displays a receiver operator characteristic curve for a risk factor with am area under the curve of 0.87. This curve provides an example of the trade-off between sensitivity (y-axis) and specificity (x-axis is 1-specificity).



Considering this issue, it has been recommended that screening for risk factors should not be confused with injury prediction (Bahr, 2016). Bahr's critical review of this topic provides a strong rationale for providing prevention programs for all athletes in a target population regardless of individual risk, as the efficacy of exercise-based injury prevention programs is well established (Lauersen et al., 2014). Bahr argues that until the criteria of screening are met by the PHE, these programs should focus on other purposes as outlined in the IOC Consensus Statement on the Periodic Health Evaluation of Elite Athletes (Ljungqvist et al., 2009).

Does PHE practices address all important aspects of athlete health?

The WHO defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Constitution of the World Health Organization, 1946). *Evidence-based health promotion* uses information derived from formal research and systematic investigation to identify causes and contributing factors to health needs and the most effective health promotion actions to address these in given contexts and populations (Smith et al., 2006).

PHEs contribute to evidence-based health promotion by identifying athletes with current health conditions, risk factors for future conditions and serving as a portal of entry for athletes into clinical programs dedicated to health promotion. To accomplish this, the scope of these programs must expand beyond sport related injuries and take a holistic approach to address all aspects of athlete health.

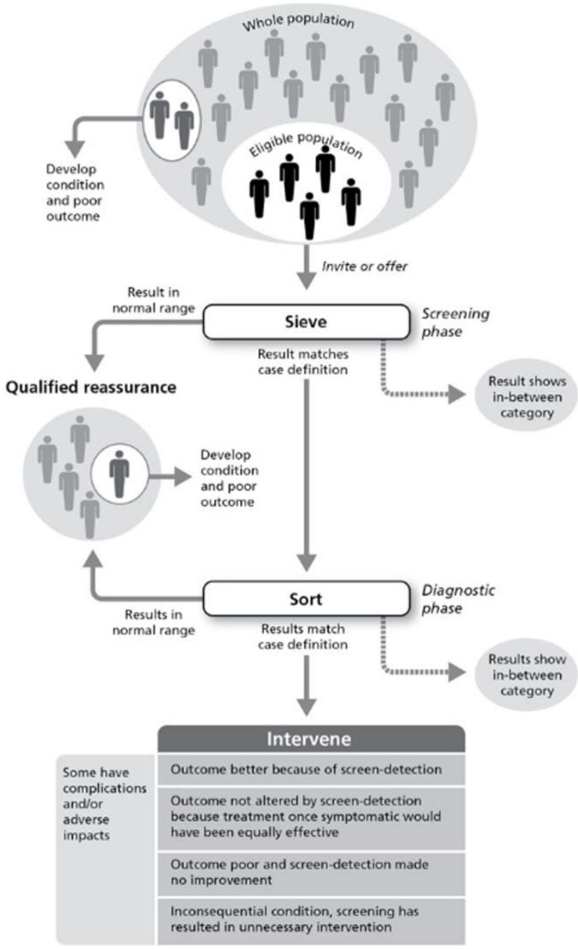
The traditional structure of the PHE may not capture many non-sport related conditions that elite athletes encounter. These include common and significant health conditions that are frequently missed in routine clinical practice, such as anxiety (Plummer et al., 2016), depression (Manea et al., 2016), allergies (Bonini et al., 2009) and sleep disorders (Buysse et al., 1989; Netzer et al., 1999). Integrating screening questionnaires into PHEs may improve the recognition of sleep, allergy, and mental health problems. However, this approach has not been described in the elite sport setting. In Paper III, we developed an electronic health history questionnaire that included screening tools for mental health, sleep, and allergies. We aimed to implement this questionnaire as part of a PHE program for Olympic and Paralympic athletes and report the prevalence of positive findings for each screening tool.

The benefits of the PHE

Despite widespread adoption, whether PHEs improve the health and wellness of athletes is unknown (Ljungqvist et al., 2009). There are no studies that support the premise that mandatory PHEs protect athlete health in terms of long-term outcomes (e.g., deaths, days missed from training, injury incidence), and there is no evidence that screening programs in the PHE predict future injury (Bahr, 2016). However, the WHO's definition of health implies that finding a treatable diagnosis protects health. Under this theory, PHE programs have the potential to improve athlete health through the identification of existing health problems.

The process to establish that identifying health problems or risk factors during a PHE leads to improved health is three-fold. First, it would have to be proven that the problems identified would not have been addressed by usual care. Second, the identified problems would have to be significant enough to have a negative impact on the individual. Third, early treatment must change the trajectory of the problems. Some conditions are diagnosed at a latent stage but will never progress enough to harm the patient, and others have a set trajectory that cannot be changed by early screening. **Figure 5**, from Angela Raffle's *Screening: Evidence and Practice,* illustrates the outcomes that may result from the identification of a condition during a screening program (Raffle, 2019). Raffle's model provides a framework for the evaluation of elements of the PHE.

Figure 5 Potential outcomes of medical screening programs, from Raffle 2019



In addition to identification of health problems, there are other benefits of the PHE that are not captured by this model. The PHE is more than a screening program—*it is a system* that provides education, captures baseline data for risk factor identification and tertiary prevention projects, identifies existing conditions that require further care and facilitates an interaction between the medical staff and athletes that fosters positive working relationships. A well-designed PHE could potentially accomplish all these objectives contributing to the implementation of preventive medicine in the sports medicine setting.

Aims

The aim of this PhD project is to evaluate the current PHE methods for elite athletes and investigate the value of new methods where there are gaps in current practice.

The specific aims were:

I. To describe the periodic health evaluation practices of the top performing National Olympic Committees.

II. To compare the use of patient interviews and electronic questionnaires to identify history of previous significant injury in a cohort of elite athletes at an Olympic and Paralympic Training Center.

III. To assess the value of including validated screening tools for allergies, anxiety, depression, sleep apnoea and sleep quality into an electronic patient health history questionnaire.

IV. Determine the distribution of serum ferritin measures in a large cohort of elite athletes, for comparison to the normal, non-athletic population.

Methods

This dissertation is based on two research projects. Project One (Paper I) is a survey of the medical screening practices of NOCs finishing in the top 8 of the medal count at either the 2016 Rio Summer Olympic Games or the 2018 PyeongChang Winter Olympic Games.

Project Two (Papers II-IV) reports findings from the health promotion programs of the United States Olympic and Paralympic Committee (USOPC). These papers retrospectively analyze data from PHEs of athletes training for the Olympic and Paralympic Games. The topics covered in these papers are health history data collection methods, the use of validated screening questions as part of the PHE, and iron screening.

Project One (Paper I)

Population

We invited NOCs who finished in the top 8 of the total medal count at either the 2016 Rio Summer Olympic Games or 2018 PyeongChang Winter Olympic Games to participate. Two NOCs placed in the top 8 of both Games, resulting in 14 invitations.

Recruitment

We emailed requests for participation to each NOC's Chief Medical Officer, Medical Director or other parties identified as responsible for the PHE. The invitation included the purpose of the study, outlined the survey questions, described anticipated outcomes, how data would be used, and provided a link to the survey website. The survey landing page allowed the participant to opt out of the survey or proceed with consent to use their anonymous data for research purposes.

Participants were asked to respond on behalf of their NOC and collect contributions from others within their organization as necessary, as the survey included questions pertaining to many disciplines of sports medicine and science. Each NOC was allowed one survey response. Periodic reminder emails were sent to NOCs that did not complete the survey 2 weeks after the initial invitation. The dates of survey collection were from August 24, 2019, to August 20, 2020.

Survey instrument

The authors developed a new survey instrument for this project. We shared a draft with six external international experts in the PHE prior to distribution. Several changes were made based on their feedback.

The survey included 4 sections: 1) questions on PHE staff composition and roles, 2) beliefs regarding the PHE, 3) a ranking of risk factors for future injury, and 4) details on the elements of the PHE. For the section on beliefs, participants were asked to rate their agreement with statements on a 5-point Likert scale. The statements addressed the following topics: screening program effectiveness in identifying current health conditions, risk factors for injury, predicting who will get injured in the future, improving training availability, team action plans, individual action plans and preference to aggregate scores from multiple tests versus single test results.

Sections of the PHE were stratified into 11 categories (history/demographics, strength, movement competency, movement capacity, cardiopulmonary, laboratory studies, fitness, mental health, body composition/nutrition, musculoskeletal health, and neurocognitive health/concussion). If a respondent indicated use of an element in a category their selection was followed with second level questions.

Because the focus of this project was to learn how organizations evaluate athletes on their current roster, we asked respondents not to report on medical evaluations of prospective athletes, such as "contract medical evaluations" or "combine/pre-selection evaluations." Additionally, we asked respondents to only describe periodic (pre-season/post-season) examination practices and exclude medical/sports performance monitoring such as daily or weekly wellness, training load, or strength/ROM) evaluations.

Project Two (Papers II-IV)

Population (Papers II-IV)

In Project Two, we used de-identified medical records from usual care performed at the USOPC to answer our research questions. All athletes gave consent for evaluation and treatment. The USOPC Sports Medicine Division provides medical services to athletes determined to be 'elite' as defined by their national governing body. Criteria for elite status most commonly require making a senior level national team or world team. The athlete populations for each paper are described below.

In Paper II, a data set including age, sport, and health history information was extracted from the medical record for Olympic and Paralympic athletes who had completed both a clinician-guided oral interview of their medical history and an electronic health history questionnaire within 4 weeks of each other. This produced a data set of 142 athletes, which was de-identified and used for final analysis.

In Paper III, we performed a retrospective analysis of data collected between May 2019 and September 2019 by a web-based health history questionnaire developed for clinical use by the USOPC. Athletes who chose to participate in medical screenings at USOPC clinics, resident athletes at USOPC training centers and athletes who registered for international games completed a pre-participation health history questionnaire.

In paper IV, we analyzed de-identified medical records for all laboratory studies that included evaluation of serum ferritin in adult athletes over a five-year period from 2012 to 2017.

Patient interview & electronic health history process (Papers II and III)

The PHE at USOPC facilities includes two methods of health history collection, a structured patient interview and an electronic health history. These health histories were used to identify current or prior medical conditions that require treatment, preventative measures, or monitoring as part of ongoing efforts to maintain optimal health.

The structured patient interview was performed by a sports medicine clinician (physician, chiropractor, physical therapist, athletic trainer) in a private clinic setting. The interview included questions regarding the patient's ongoing medical conditions, cardiac history, past health history, family history, medications, and allergies. The clinician recorded the interview in a free-text narrative in the patient chart within the electronic health record. Diagnoses identified during the interview were then coded and entered in the patient medical record.

The electronic health history was collected via a web-based questionnaire within an encrypted electronic health record patient portal (Docusign, San Francisco CA USA). The questionnaire included many items from widely distributed health history forms, including the PPE Monograph 4th edition (AAFP, 2010) and the IOC Periodic Health Examination health history form (Ljungqvist et al., 2009). The format of the questionnaire included yes/no, multiple choice and free-text items. The questionnaire took approximately 20 minutes to complete.

A standard question in both the patient interview and electronic health history was: "Please list every injury that has kept you from participating in sport for two weeks or more." This question was chosen to designate "serious sports injuries" as per usual practice at the USOPC. Within the electronic health history there were free text spaces that allowed athletes to enter information regarding each injury. Clinicians recorded these injuries in a bullet-point list format and included a written narrative with additional information on each injury.

Screening tools included in the electronic health history process (Paper III)

Patients were emailed a hyperlink to the health history questionnaire via an encrypted website (Qualtrics). The questionnaire included items from widely distributed health history forms, including the PPE Monograph 4th edition (AAFP, 2010), the IOC Periodic Health Examination health history form (Ljungqvist et al., 2009), the Allergy Questionnaire for Athletes (AQUA) (Bonini et al., 2009) the Berlin Sleep Apnoea Questionnaire (Berlin) (Netzer et al., 1999), the Patient Health Questionaire-2 (PHQ-2) (Manea et al., 2016), the General Anxiety Disorder-2 (GAD-2) (Plummer et al., 2016) and the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989). The questionnaire incorporated logic to present items relevant to the patient. Screening tools that utilized entry or exit questions such as the GAD-2 and PHQ-2 were programmed with questionnaire logic to reduce unnecessary questions and minimize questionnaire burden.

Statistical methods

Paper I

Counts and proportions were used to describe responses. We scored the section of beliefs regarding medical screening on a five-point Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree), with a score of 1 for "strongly disagree" and 5 for "strongly agree." The sum of Likert scale points was used to represent the strength of belief in each statement, and percentage of responses in Likert scale categories described categorical trends in responses. Respondents were asked to rank the top five risk factors for injury from a list. We assigned a numerical value of five points to the highest ranked factor, four for the second, three for the third, two for fourth and one for the fifth, and zero for any factor that was not ranked. We added the point totals for each risk factor and ranked them accordingly.

Paper II

A data analyst counted the number of serious sports injuries reported by each athlete by interview and questionnaire methods in a spreadsheet. Injuries were stratified into several categories for secondary analysis. Any health condition not associated with sport participation was excluded. Data were analyzed in JASP (0.8.2, Amsterdam, The Netherlands) and JMP (v14.0 Carey, NC, USA) using paired t-tests to compare data collection methods.

Paper III

Data sets were stratified by sex and sport. Screening tools were scored and dichotomized as positive or negative according to thresholds defined in the literature, with the following criteria for a positive score: AQUA≥5, Berlin ≥2, GAD-2 ≥3, GAD-7≥10, PHQ-2≥3, PHQ-9 ≥10, PSQI ≥5.

A chi-squared test of independence (R Studio, chisqu.test package) was run to identify statistically significant differences in proportions of positive screening responses in sex and Olympic vs Paralympic sport populations. Cohen's kappa was calculated in JMP 15.1 (SAS, Carey, North Carolina, USA) to evaluate the level of agreement between screening tools. Prevalence ratios were calculated in Microsoft Excel for the prevalence of being flagged for one screening tool (consequent) if positive for an alternate screening tool (antecedent), as compared to being screened positive for the consequent and negative to the antecedent.

Paper IV

Distributions of SF results were calculated for each athlete and stratified by sex. To compare athletes to the general population, we utilized the data set of Custer et al (Custer et al., 1995). Custer et al. stratified the SF data into four-year age bins. SF distributions from the 20 to <24 yr. old age group (720 men, 1711 women) and 24 to <28 yr. old age group (1085 men, 2175 women) were compared to the elite athlete distributions, as these age ranges best matched the athlete ages. Counts in distribution bins were compared using Pearson's chi-squared test for independence (R Studio, chisq.test package). We then assigned the percentages of athletes and the normal population to each bin using the following thresholds:

1. <12 ng/mL: This SF value has been correlated with depleted bone marrow iron stores (Ali et al., 1978) and is commonly used as the lower bound of the normal range by clinical testing laboratories. This also is the SF component threshold of stage three iron-deficient anemia, as defined originally by Bothwell et al. (Bothwell et al., 1980), and updated by others (Peeling et al., 2007).
2. <20 ng/mL: This matches the stage two iron-deficient erythropoiesis SF threshold (Bothwell, 1980; Peeling et al., 2007).
3. <35 ng/mL: This matches the stage one iron depletion threshold (Bothwell et al., 1980; Peeling et al., 2007) and the iron deficiency threshold recommended by several other authors for treatment in athletic populations (Nielsen & Nachtigall, 1998; Govus et al., 2015).
4. <50 ng/mL: This matches the threshold recommendation of Custer et al. for men, as well as the SF threshold used for inclusion by many researchers in examining iron treatments for patients presenting with fatigue (Vaucher et al., 2012). This threshold has also been recommended as a minimum level for adult athletes preparing to train at altitude (Clenin et al., 2015).

Ethics

Both projects were approved by Southern California University of Health Sciences. Participants in Project One consented to participation through a voluntary consent process. Project Two analyzed previously collected health information previously collected as part of usual care. A waiver of written consent was granted for the use of this de-identified data for research purposes.

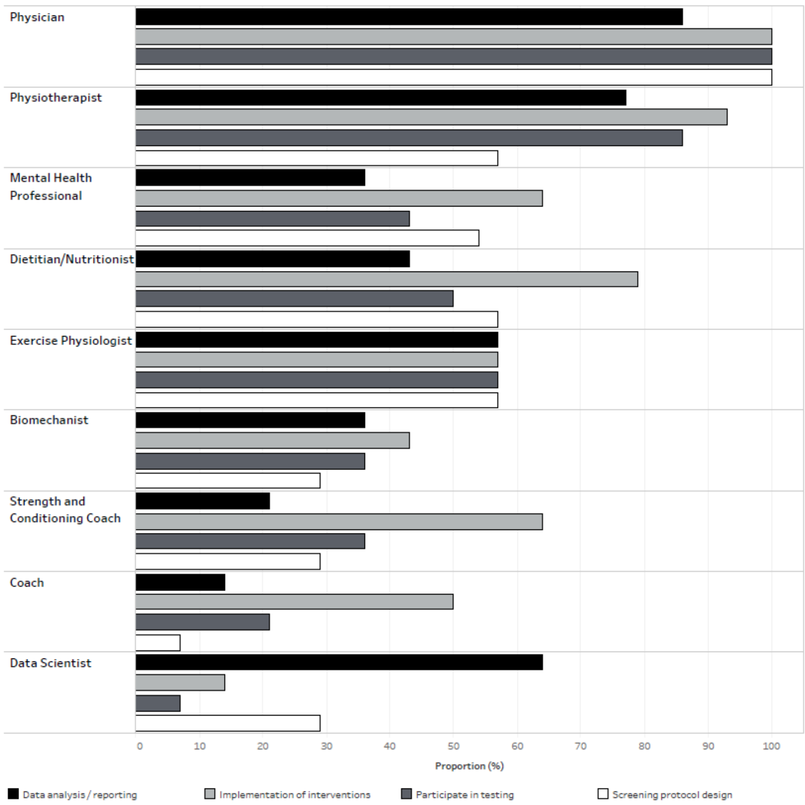
Results and discussion

The PHE practices of top performing NOCs (Paper I)

Staff roles in PHE

The multidisciplinary nature of the PHE at the NOC level has not previously been described. Although many specialists participate in the PHE (a median of seven specialties per NOC), few are included in the planning process. Physicians and physiotherapists plan the majority of the PHE, while other specialties including dietitians, biomechanists, strength and conditioning specialists, and coaches are often asked to implement interventions based on findings (see **Figure 6**). We see potential to improve the PHE through the integration of the entire medicine and science team into PHE planning, which may facilitate athlete-specific interventions that emerge from the evaluation.

Figure 6 Roles of medical, science and coaching staff in the PHE



Why do NOCs perform the PHE?

Figure 7 displays the survey responses to the seven belief statements included in the survey, and **Table 4** provides the results to the risk factor rankings. Our results demonstrate that NOCs believe the PHE prioritizes identification and management of current health conditions, with secondary objectives of profiling baseline characteristics and predicting future health problems. However, while there is good agreement that the PHE identifies current health conditions, there is a lack of agreement for the use of the PHE for profiling or injury prediction. Future research is needed to investigate if the PHE prevents injury.

Figure 7 Beliefs regarding the PHE. The x-axis represents the percentage of responses to each Likert scale category for the seven belief statements.

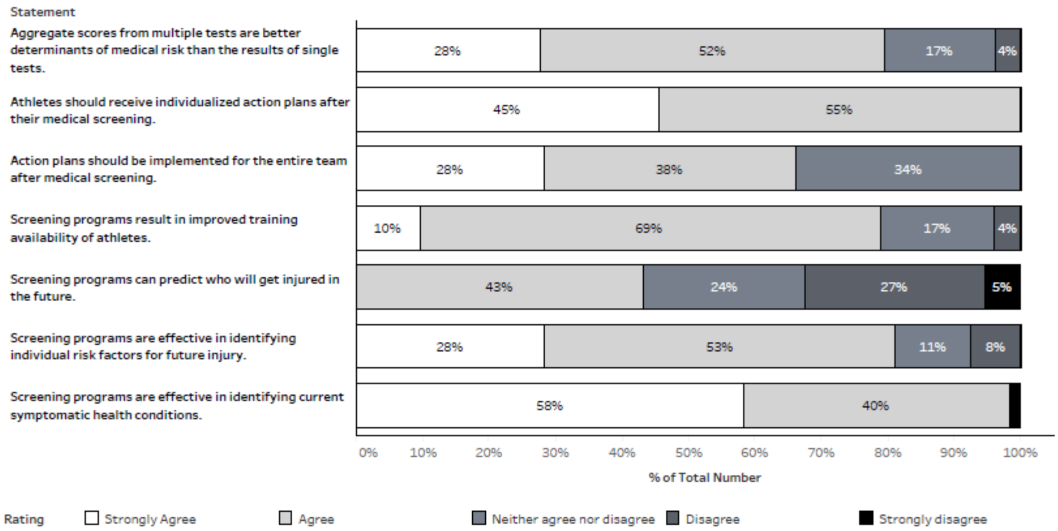


Table 4 The top 14 risk factors for future injury as ranked by NOCs.

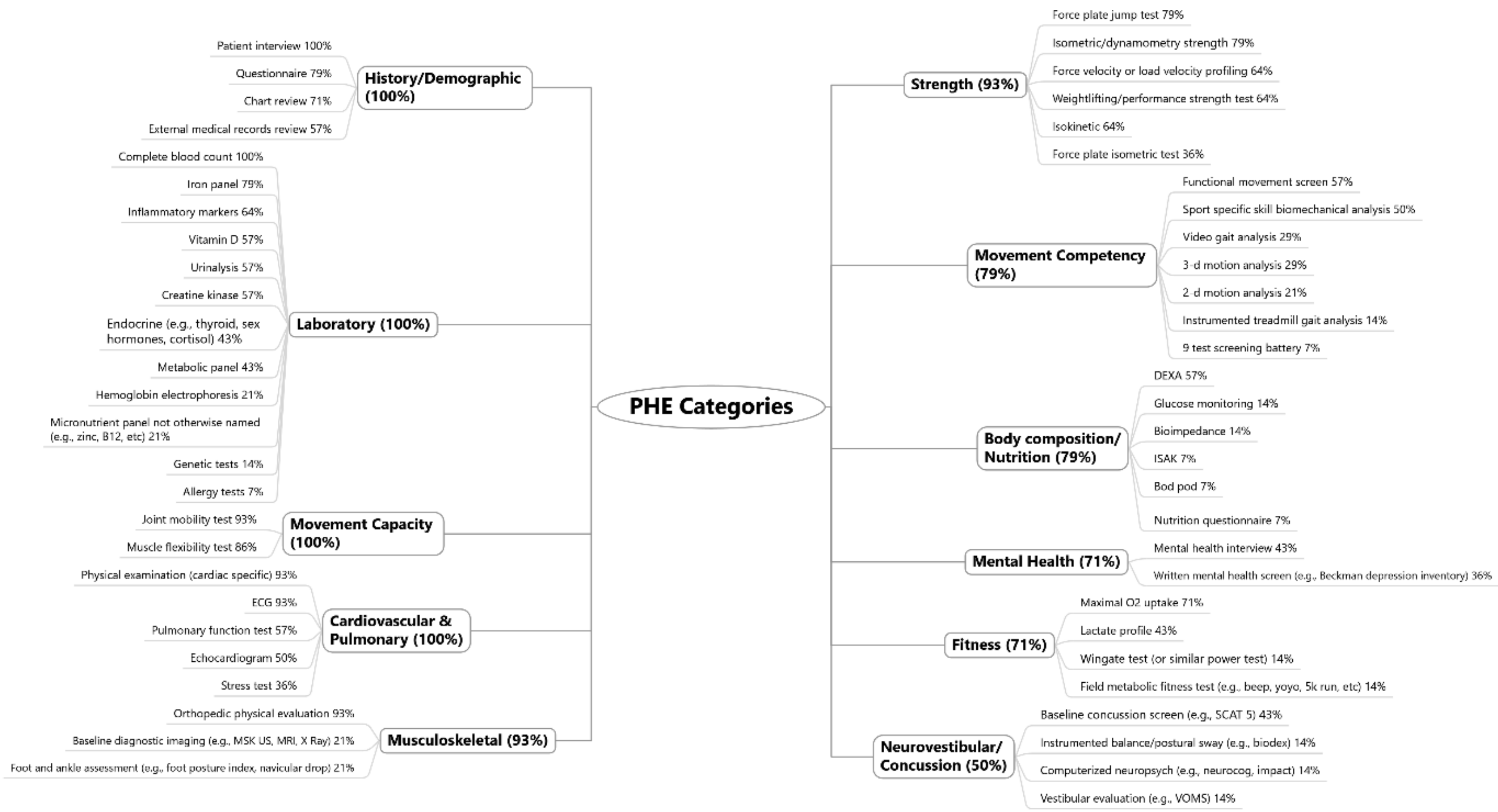
Ranking	Risk factor	Ranking points
1	Previous injury	58
2	Age	37
3	Training experience/training age	24
4	Psychological factors	17
5	Strength imbalance	14
6	Nutrition	10
7	Anatomy & morphology	9
8	Strength symmetry	8
9	Sleep	8
10	Movement competency	6
11	Genetics	6
12	Joint mobility	5
13	Flexibility	5
14	Aerobic fitness	3

When developing PHE programs, organizations should first define their objectives based off what they believe the role of the PHE is and the risk factors most important to the population they are working with. This step may help identify experts from disciplines in sport science and medicine that can contribute to the planning process. Prioritizing the objectives of the PHE will help sport organizations choose which parts of the PHE to focus on and may eliminate unnecessary or costly tests from the PHE process.

Elements of the PHE

Figure 8 illustrates the proportion of NOCs that reported using each of the 55 PHE elements identified, organized into 11 categories. The mean number of elements included by NOCs was 25 (range 17 – 34); however, many NOCs noted that PHEs are customized for specific teams or individual athletes depending on factors such as timing of testing, sport, and historical/demographic factors. Table 2 of Paper I describes the frequency, purpose, population tested, description of how risk was defined, and how actions were taken after testing in each category.

Figure 9 Elements used in each category of the PHE, reported as the % of total responses in each category



History/demographic

Some NOCs reported using continuous health monitoring instruments such as the Oslo Sports Trauma Research Centre questionnaire to capture all health problems and facilitate communication between athletes and medical staff (Clarsen et al., 2020). The high rank of previous injury as a risk factor suggests that optimizing methods for accurate and detailed injury surveillance may improve the effectiveness of health promotion programs while identifying the most common health conditions associated with the sport.

The preventive medicine model is based on identification of risk through analysis of historical data. Future risk in a population can be identified through aggregated injury reports. At the individual athlete level, previous injury has been shown to be the best predictor of future injury (Hägglund et al., 2006). These factors suggest that PHEs should prioritize collecting historical health information to use as a basis for future prevention efforts and should consider incorporating continuous health monitoring tools to manage future risk.

Cardiopulmonary

Most NOCs included a history, physical examination, and ECG in the PHE; some also included additional studies such as echocardiograms or stress tests. This finding is consistent with previous surveys of NOCs at the Summer Olympic Games (Toresdahl et al., 2018). Current guidelines recommend periodic cardiac screening that includes a history, physical examination, and ECG to identify pathologic cardiac conditions in elite athletes; however, there are no evidence-based guidelines supporting imaging or stress tests for screening asymptomatic athletes (Riding et al., 2015; Mont et al., 2016).

Half of NOCs included pulmonary function assessments in the PHE, and these were often specifically prescribed for endurance athletes. The wide variety of pulmonary functions tests used suggests there is not widespread adoption of a single test or battery in this domain. This finding may also be reflective of the need for individualized assessment of pulmonary function based on patient specific factors.

Mental health

Just over half of NOCs had mental health professionals involved in PHE design and one in three did not screen for mental health conditions. Due to the relationship between mental health, general health, and performance, sport organizations should consider inclusion of collaborative mental health teams and standardized screening tools into PHE programs (Hennriksen et al., 2020).

It is not yet known which mental health screening tools are most appropriate in sport. The IOC's Sport Mental Health Assessment Tool 1 has been introduced as a triage tool designed to identify athletes who may benefit from more specific mental health screening (Gouttebarge et al., 2020). If athletes are identified as potentially at risk in the triage phase of this questionnaire are then assessed with specific validated questionnaires: the GAD-7, PHQ-9, Athlete Sleep Screening Questionnaire, Alcohol Use Disorders Identification Test Consumption, Cutting Down, Annoyance by Criticism, Guilty Feeling and Eye-openers Adapted to Include Drugs, and the Brief Eating Disorder in Athletes Questionnaire. The validity of the SMHAT 1 triage tool has not been assessed in large populations, however the accompanying questionnaires are tools that have been validated in non-athletes. Given the prevalence of mental health problems in elite athletes, mental health screening should be considered as part of the PHE. However, in the absence of validated screening tools for athletes, validated screening methods of screening for the general population should be the cornerstone of this portion of the PHE.

Body composition/nutrition

Most NOCs included a nutrition element in the PHE. However, only just over half of teams included a nutrition professional in the design process. The most used modality in the nutrition category was dual energy x-ray absorptiometry to assess body composition (Lambert et al., 2012; Nana et al., 2015). Although many screening methods have been developed for disordered eating, NOCs did not report consistent use of any single validated instrument.

Body composition is associated with both health and performance (Ackland et al., 2012). Low body mass relative to competitors has been associated with performance in endurance, gravitational, aesthetic and weight class sports (Ackland et al., 2012). However, low body mass, low energy availability and fluctuations in body mass have been associated with health problems such as low bone density, disordered eating, menstrual dysfunction, nutrient deficiencies, illness and injury risk (Mountjoy et al., 2018). Screening for these risk factors can involve the use of eating behavior questionnaires (such as the Relative Energy Deficiency in Sport Clinical Assessment Tool) or evaluation of body composition with DEXA or skin fold studies. Whether these programs result in improved athlete health is still not yet known. However, given the higher prevalence of nutrition- and body composition-related health problems in some sport populations, it may be prudent to assess bone density, body composition, and eating behavior in high risk groups.

Laboratory studies

There was wide variation in the utilization of laboratory tests. While most NOCs evaluated for iron and vitamin D status, there was heterogeneity in reporting of endocrine studies, hemoglobin electrophoresis, metabolic panels, micronutrient panels, genetic and allergy tests. The panels used by NOCs often were tailored to the athlete group being evaluated, rather than using standard panels for all NOC athletes.

Laboratory screening is a common part of the PHE in the general population and is commonly used to identify risk for cardiovascular disease, metabolic syndrome, and hematologic disorders (Kermott et al., 2012). The athletic population has different risks than the general population, and so does the approach to laboratory screening. For example, elite athletes have been shown to be at higher risk for iron deficiency than the general population, and so iron screening is warranted in both male and female athletes (as seen in Paper IV). Hemoglobin type screening has been proposed as a standard for the identification of sickle cell trait in some geographic regions, due to the risk of sickle cell crisis during exercise in asymptomatic heterozygous carriers (Harmon et al., 2012). Outside of these studies there is limited evidence supporting the use of these tests in the PHE for asymptomatic athletes (Darche et al., 2019; Fallon, 2007).

Musculoskeletal health

Musculoskeletal physical examinations were utilized by 93% of NOCs. These were accompanied with baseline imaging (e.g., musculoskeletal ultrasound, magnetic resonance imaging, plain radiographs) by some NOCs, primarily during shoulder evaluations for overhead throwing sports. One NOC noted that baseline radiographic imaging is not legal in their country, eliminating this as an option in the PHE.

The musculoskeletal portion of the PHE can be used to identify current symptomatic conditions and previous conditions that are not fully rehabilitated. There is no evidence supporting the use of diagnostic imaging as a screening tool for asymptomatic patients. However, the identification of musculoskeletal issues during a history and physical examination may lead to investigation with secondary evaluations, such as functional tests or diagnostic imaging.

Neurocognitive health/concussion

The least utilized test category in our survey was neurocognitive and concussions tests (50%), with only 43% of NOCs performing baseline concussion tests. This is consistent with the most recent International Concussion Consensus, which did not recommend baseline screening (McCrory et al., 2017).

Baseline neurocognitive and concussion evaluations may result in the identification of athletes with subclinical symptoms associated with previous injury, can identify underlying issues that may affect performance on future concussion tests, and can be used to develop individual and population normative data (Tucker et al., 2020). However, these assessments have suboptimal reliability, limiting their effectiveness as screens and baseline measures (Chin et al., 2016; Walton et al., 2018). As a result, there is heterogeneity in practice patterns for baseline neurocognitive testing as part of the PHE.

Strength

Strength and muscle power tests were used by nearly every NOC, with most using a combination of isometric dynamometry, isokinetic testing, force plate jump testing and weightlifting performance evaluations. Our results suggest that strength tests are chosen for specific populations to create athlete-specific baseline data in the event of future injury, and to evaluate current health status. Prospective collection of strength data in the PHE may help determine its role as an injury risk factor.

Absolute strength deficits and strength asymmetries have been associated with injury risk for injuries such as hamstring strain in football players (Timmins et al., 2015), shoulder injuries in handball players (Clarsen et al., 2014), and all cause musculoskeletal injury (Malone et al., 2018a). However, these associations are generally weak, and are not able to effectively identify athletes at risk for development of future health problems (Andersson et al., 2018; van Dyk et al., 2017). The practices of NOCs are consistent with the evidence that strength testing is not used as a screening tool, but to collect information for future use as a baseline or normative profile of function.

Movement competency

Movement competency evaluations, which we categorized as subjective or objective assessments of functional or sport-specific movements, were used by most NOCs. This category had the highest reported percentage of elements used for injury prediction. Paradoxically, the Functional

Movement Screen, which does not predict injury, was the most reported movement competency test (Dorrell et al., 2015; McCunn et al., 2016; Moran et al., 2017). This mismatch of current practices with supportive evidence has been observed in professional football and raises the question as to whether elite sport organizations understand the predictive value of these tests and limits of injury prediction (McCall et al., 2014). Other explanations for the widespread use of movement screens include a rationale that they help guide coaches on decisions for individual exercise prescription.

The other most used elements were biomechanical analyses, such as sport-specific movement analysis, two-dimensional and three-dimensional motion analysis, and gait analysis. Personalization was a common theme in this category; elements were usually prescribed for special populations, athlete-specific change was commonly reported as a risk factor definition for these tests, and results were always acted upon with personal interventions. Personalization of the PHE to adjust screening protocols, analysis and interventions to the individual athlete may be a luxury available to elite athletes that is not feasible at lower levels of sport.

Movement capacity

Deficits in flexibility and joint mobility are perceived to be risk factors for injury, although evidence for this hypothesis is weak (Nuzzo, 2020; McCall et al., 2014). Every NOC reported using movement capacity tests, even though this was not a highly ranked risk factor. Mobility deficits were almost always treated with athlete-specific interventions; however, there was not a consistent approach to defining risk. Conflicting literature on movement capacity as a risk factor for injury makes the predictive value of this type of screening unclear (Nuzzo, 2020; Pozzi et al., 2020). Although reduced ROM may be a risk factor for injury in some populations, screening is unlikely to identify athletes at risk due to small differences in at-risk populations and poor properties of ROM measures (Bahr, 2016; Tak et al., 2017). In sports where ROM is known to change with activity, regular monitoring to evaluate changes that occur during a competitive season may be preferable to pre-season screens (Fiesler et al., 2015; Freehill et al., 2011). This practice appears to be adopted by some NOCs, as this category had the highest frequency of use.

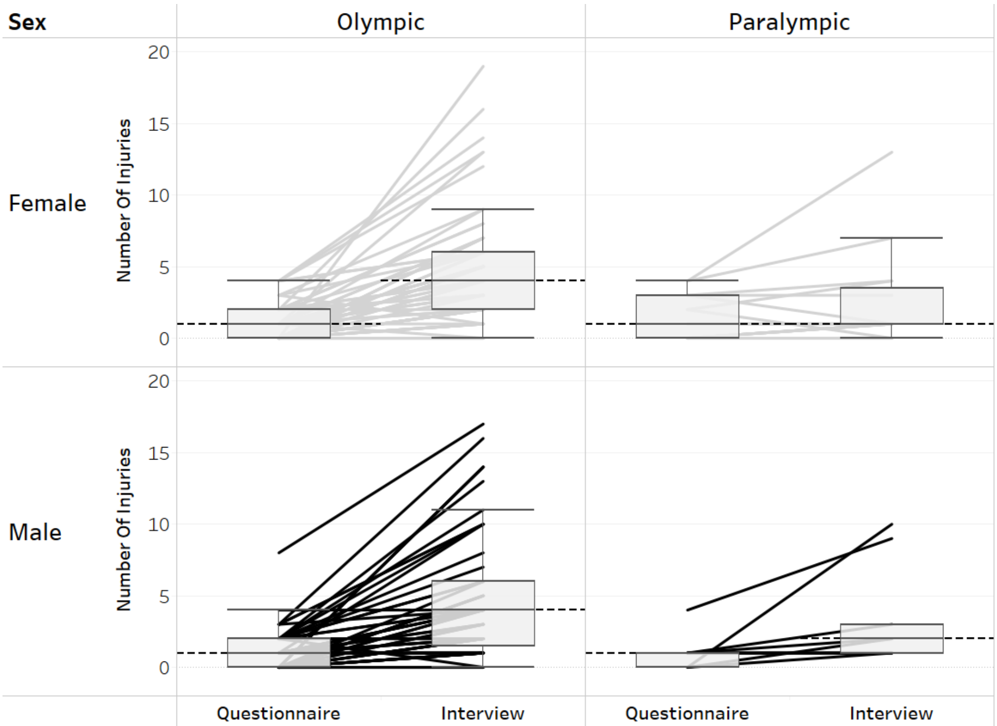
Cardiorespiratory fitness

Fitness is an indicator of health, and lower fitness may be a risk factor for injury in specific populations (Malone, 2017; Malone, 2018a; Malone, 2018b). Despite this, we questioned whether fitness assessments are performed as part of the PHE. We learned that some NOCs include fitness assessments in the PHE, mostly maximal oxygen uptake tests and lactate profiles for select athlete populations. More information is necessary to see understand how fitness assessments fit into the health promotion data ecosystem as an outcome measure or independent measure of risk.

Patient interviews capture 4 times more injuries than electronic questionnaires (Paper II)

A guided patient interview recorded four times more past or present injuries than an electronic health history questionnaire in a cohort of 117 Olympic and 25 Paralympic athletes (**Figure 10**). The only injury types that did not differ between reporting methods were concussions and surgeries. The difference in reporting was consistent across both sexes and was similar for athletes training for the Olympics and Paralympics.

Figure 10 Number of injuries reported by survey method in Olympic & Paralympic athletes



The patient interview

Our findings suggest there may be advantages to the interview that results in more complete health history data collection. Patient interviews have been deemed “the core of clinical interaction and the clinician’s most important and intimate professional activity” (Lipkin et al., 1995). Previous research on surveillance programs in the elite sport setting found that interviews captured 94% of all injuries reported by other methods, whereas medical records (61%) and federation technical reports (28%) captured fewer injuries (Flørenes et al., 2011).

There are qualities inherent to the interview that may explain these findings. Athletes have shown a preference towards personal communication when participating in sport surveillance systems (Barboza et al., 2017). Interviews allow for live, two-way interaction between the clinician and athlete, including immediate feedback on responses. Athletes expect feedback from sport surveillance systems, which may occur naturally during clinician-athlete interviews (Barboza et al., 2017). In the primary care setting, it has been shown that patients who perceive that their problems are discussed have better outcomes (Rosner et al., 2018). These aspects of the human interaction between a patient and clinician cannot be readily replaced by electronic or written communication.

Challenges in collecting health history information

Collecting accurate historical medical information from patients is difficult regardless of method. There are biases that impact the accuracy and completeness of self-reported health conditions. These include recall bias, reporting bias, and information bias.

When we rely on patients to recall their own health history, we encounter recall bias. Patients can be inept at remembering their own health information (Barsky, 2002). In a study designed to determine the accuracy of athlete self-report in the previous 12 months, 80% of athletes were able to recall how many injuries they had sustained, but only 61% were able to record the exact number, body region, and diagnosis of each injury sustained (Gabbe et al., 2003). In a cohort of 104 patients tracked over a 3-month period, using free recall only 47% of health events were remembered by patients (Cohen & Java, 1995). This is compounded by the fact that when patients are provided a diagnosis during clinical care, many cannot accurately remember what they are told. It has been reported that patients only remember 17-60% of information they are told by a physician, 48% of what they recall is imagined, and after a month they only remember 11-13% (McGuire, 1996). These issues suggest that prospective surveillance systems, including frequent periodic self-reports and reports directly from health care providers may be necessary to accurately document a patient history (Hägglund, 2005; Gallagher et al., 2017).

Self-reporting bias by athletes can occur if the athlete perceives reporting their health history as a threat to their ability or right to compete (Steenstrup et al., 2014). This issue may be more pressing if the history is taken when the athlete is in the middle of a competitive season, as athletes prefer not to discuss health problems prior to a major competition (Karlsson et al., 2018). In some sport settings, athletes may have acute concerns with injury reporting due to rules that require mandatory time out of competition, such as concussion. It has been documented that athletes may intentionally under-report concussion to continue playing while injured (Hammond et al., 2009). In our setting, health information collected during the PPE was not used for team selection purposes, as the PPE occured after athletes were selected. Therefore, we do not believe self-reporting bias was an important factor during patient self-reporting in this study.

Information bias, or misclassification bias, occurs when information is not classified correctly. Information bias occurs during health history data collection when 1) information is collected but not documented, 2) information is collected but documented in format that is not useful for further analysis or 3) information is documented incorrectly. Incomplete documentation by medical staff is a valid concern in the sports medicine setting, where it has been reported that medical staff often fail to document injuries appropriately (Flørenes et al., 2011). In one report of injury surveillance, only 36% of injury forms were filled out by the physicians and 40% of injury forms were filled out incorrectly (Emery et al., 2005). An advantage of written and electronic health histories is the ability to develop the data collection form in a manner that ensures that any data is clean and formatted for future analysis. Clinicians collecting histories via interview often document the interaction with narrative descriptions of the conversation, and rely on translation into a coding system, such as ICD-10 or Orchard Sport Injury Classification System for research level analysis (Hammond et al., 2009). The process of translating form conversation to code is vulnerable to error, and many coding systems do not provide the level of detail needed for sports medicine research (Hammond et al., 2009).

Strategies to improve the patient interview

The patient interview is an art that has been refined by clinicians over centuries. The skilled clinician uses contextual clues to guide the narrative towards a more accurate history. In a narrative review by Barsky, he lists strategies to improve the accuracy of history (Barsky, 2002). These include: 1) noting and considering the patient's physical and emotional state at the time of the interview (anxiety or severe pain at the time of the injury or time of interview can affect accuracy) 2) establishing anchor points in the history (What injuries did you have prior to high school graduation?) 3) decomposing generic memories by finding things that separate events from each other (What event made you seek medical attention for this injury?) 4) work on history in retrograde fashion (Please list all of the injuries that have affected your training starting from today and working backwards).

Electronic health history questionnaires

The low reporting of injuries through an electronic health history form in this cohort is concerning, as this type of tool is frequently utilized in both clinical and research settings. When a data collection tool fails to perform as designed, it should be evaluated for its performance and improved. The tool used in this study used a command "Please list every injury that has kept you from participating in sport for two weeks or more," followed by free text box to collect responses.

The use of free text field in athlete questionnaires may not provide a user experience conducive to high compliance. Our question asked athletes to list "injuries", which infer the patient should understand and be able to free type their previous diagnosis. Patient recall symptoms better than diagnoses, and have difficulty using clinical terminology in survey tools (Rosner et al., 2018). Free text has been shown to increase error rates (Walther et al., 2011). We did not provide training or troubleshooting when administering the questionnaire. This may have led to reduced compliance, as person guidance can improve the accuracy of patient self-report surveys (Taylor et al., 2011). Providing a description of why the information is collected and how it will be used can help compliance and reduce self-reporting bias (Barsky, 2002; Taylor et al., 2011). Our patients consented to the questionnaire and its use for health and high-performance services but were not given clear guidance on how they benefitted from sharing their health history. Education and assurance that survey instruments are designed to optimize efforts to improve athlete heath may be necessary as athletes may not be motivated to share their health information willingly (Karlsson et al., 2018).

The electronic questionnaire method was effective in collecting information on concussions and surgeries. Patients have an easier time remembering medical issues that they perceive as more severe, such as surgeries (Rosner et al., 2018). The findings from this study suggest that patients may be more likely to remember and/or take the time to report these severe injury types via electronic questionnaire and may not do the same for more minor injuries. This willingness to report may indicate motivation to share information that patients deem important to their health care providers.

Strategies to improve electronic survey instruments

The findings of this study suggest that electronic questionnaires must be improved to be effective. Providing front-end education on the intent and scope of the questionnaire, the way the information will be shared and used, and interventions that will directly benefit the athlete as a result of participation may improve compliance (Barboza et al., 2017). Providing a dedicated help desk for help with access to dual authenticated websites, technical troubleshooting, and translation of clinical terminology for the patient may enhance the user experience (Taylor et al., 2011). Development of user interfaces that rely on single select questions have lower error rates as compared to free text and date fields, especially if the data entry requires no typing and can be completed with only a mouse or touchscreen (Walther et al., 2011). Integrating diagnostic coding into these systems can enhance the quality of data collected and reduce the administrative burden of data management.

Increasing the frequency of electronic surveillance has been shown to limit the effect of recall bias. Validated athlete health monitoring tools, such as the Oslo Sports Trauma Research Questionnaire on Health Problems, allows for serial inquiry into existing and newly emerging health conditions (Clarsen et al., 2020). This approach has proven to be useful in the Olympic, Paralympic, youth recreational and high school populations in many different languages and forms of electronic communication (Clarsen et al., 2015; Hirschmüller et al., 2017; Møller et al., 2018; Clarsen et al., 2020).

Validated screening tools for allergies, anxiety, depression, sleep apnoea and sleep quality have a high yield in elite athletes (Paper III)

The addition of validated health screening tools to a PHE questionnaire resulted in the identification of sleep, mental health, or allergy risk in 48% of the 257 athletes training for the Paralympics and 37% of the 683 athletes training for the Olympics. More than one fifth of athletes screened positive for allergies or poor sleep quality. Athletes training for the Paralympics had a significantly higher percentage of positive screens for anxiety, depression, poor sleep quality and sleep apnoea. There were sex differences in screening tool responses, with a greater percentage of females with positive screens for allergy and poor sleep quality. **Table 5** includes prevalence comparisons by sex and sport types.

Table 5 Prevalence of positive screens in athletes training for Olympic and Paralympic Games.

	Olympic / Paralympic				Male / Female			
Screening Tool	Olympic (n = 683) %	Paralympic (n = 257) %	χ^2	p	Male (n = 477) %	Female (n = 463) %	χ^2	p
Allergy (AQUA)	20.6	25.3	2.09	0.15	16.4	27.7	16.86	< 0.01
Anxiety (GAD-7)	3.1	7.4	7.52	< 0.01	4.0	4.5	0.07	0.80
Depression (PHQ-9)	1.9	4.7	4.50	0.03	2.7	2.6	0.00	1.00
Sleep Apnoea (Berlin)	3.5	8.6	9.94	< 0.01	5.7	3.9	1.25	0.26
Sleep Quality (PSQI)	23.1	30.7	5.33	0.02	22.2	28.3	4.28	0.04

Associations between screening tools

Sixty percent of all athletes did not have a positive finding, 27% had one positive, 9% had two, 2% had three, 1% had four and 0.4% five. There was frequent overlap of positive screening tools (**Figure 11).** Prevalence ratios for associations between tools showed that a positive screen for any individual tool increased the prevalence ratio for all other tools (**Table 6**). The magnitudes of prevalence ratios were the highest for associations between depression when positive for anxiety, depression when positive for sleep apnoea, anxiety when positive for depression, and anxiety when positive for poor sleep quality (**Table 6**). The cross sectional, observational study design does not allow for causal inferences from this data. However, clinicians should be aware that there were positive associations between all the conditions we screened for and consider this when interpreting screening data.

Figure 11 Relationship between positive screening tools. Grey indicates athletes with negative screening for all tools.

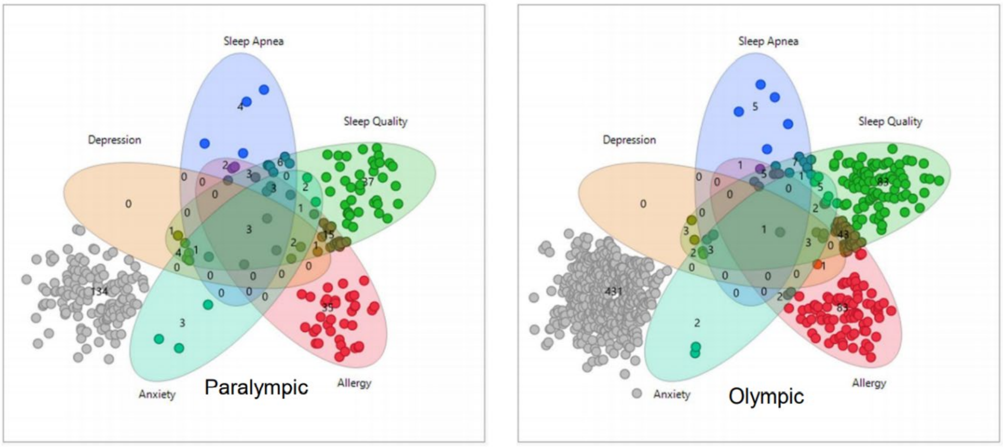


Table 6 Prevalence ratios with 95% CI for associations between positive screening tools

	Anxiety	Allergy	Depression	Sleep Apnoea	Sleep Quality
Anxiety	-	2.0 (1.4 to 3.0)	71.3 (30.1 to 168.6)	8.2 (4.3 to 15.5)	3.6 (3.0 to 4.4)
Allergy	2.6 (1.4 to 4.8)	-	2.8 (1.3 to 6.1)	2.4 (1.3 to 4.2)	1.9 (1.5 to 2.3)
Depression	33.1 (20.6 to 53.3)	2.1 (1.3 to 3.3)	-	7.9 (4.1 to 15.2)	4.1 (3.6 to 4.8)
Sleep Apnoea	8.5 (4.6 to 15.6)	1.9 (1.3 to 2.8)	9.4 (4.3 to 20.5)	-	3.2 (2.6 to 4.0)
Sleep Quality	14.0 (6.3 to 31.2)	2.0 (1.5 to 2.5)	71.2 (9.7 to 523.4)	8.2 (4.3 to 15.5)	-

**Column headings are the dependent variable for prevalence ratios, row headings the independent variable. Prevalence ratio = (Prevalence positive when row is positive)/(Prevalence positive when row negative).*

Were the associations observed due to similarity in the screening tools?

The associations between positive screens must be interpreted with caution due to the potential overlap in the items of the tools used in this study. We used Cohen's kappa to assess the level of agreement between tools; agreement was low for all combinations of tools except for the PHQ-2 and GAD-2 (kappa of 0.57) (see Table 3 of Paper II). However, there are limitations to the use of Cohen's kappa in this study, as some conditions were common (up to 30% of Paralympians for allergies) and others rare (2% of Olympians for depression). Kappa values are affected by differences in prevalence, with high prevalence differences diluting kappa values (Byrte et al., 1993). Therefore, it is possible that the agreement between the screening tools used in this study is higher than we reported.

Mental health

Our findings reveal that 2.7% of athletes screened had positive flags for depression, and 4.3% of athletes had positive flags for anxiety. In comparison, screening in the general population for these disorders results in prevalence of ~8-25% for depression and ~5% for anxiety (Davidson et al., 2010; Wittayanukorn et al., 2014; Brody et al., 2016). We found 2.5 times greater prevalence of positive mental health screens in Paralympic athletes as compared to Olympic athletes. Athletes with disability may represent a greater risk for mental health issues, a suggestion that has been previously proposed as a stereotype, but without the backing of evidence (Swartz et al., 2019). Without diagnostic confirmation, we cannot confirm that the true incidence of mental health problems is higher in the Paralympic population; however, our findings should be considered by adaptive sport organizations when developing mental health resources for their athletes.

We chose mental health screening tools for anxiety and depression that are recommended for use in the general population (Plummer at al., 2016; Siu et al., 2016). These tools, the GAD-2 and PHQ-2, are short questionnaires that can be expanded by survey logic to provide more comprehensive screening for athletes who appear to be at risk based on entry questions. This computer adaptive testing approach has been shown to be effective in primary care settings for depression and anxiety screening (Graham et al., 2019).

Sleep

One-fifth to one-third of athletes in this cohort screened positive for sleep problems. Sleep is essential, and sleep problems are difficult to identify in the primary care setting (Edinger et al., 2016). Sleep deprivation negatively impacts mood, cognition, metabolism, and the immune system (Halson et al., 2019). Athletes who sleep less have higher rates of injury, and there may be a relationship between injury risk and sleep deprivation; injury incidence is believed to increase during periods of high training load and less sleep (Milewski et al., 2014; von Rosen et al., 2017).

Paralympians were significantly more likely to be flagged for sleep problems than their Olympic counterparts; 8.6% of Paralympians were identified as at risk for sleep apnoea. There is a paucity of literature on sleep health in the adaptive sport population, so the causes for sleep disturbance in this population are not yet fully understood (Silva et al., 2012). Given the importance of sleep, the strong associations we found with sleep and other clinical screening tools, and the severe potential consequences of untreated sleep apnoea, this is an area that should be addressed with further research.

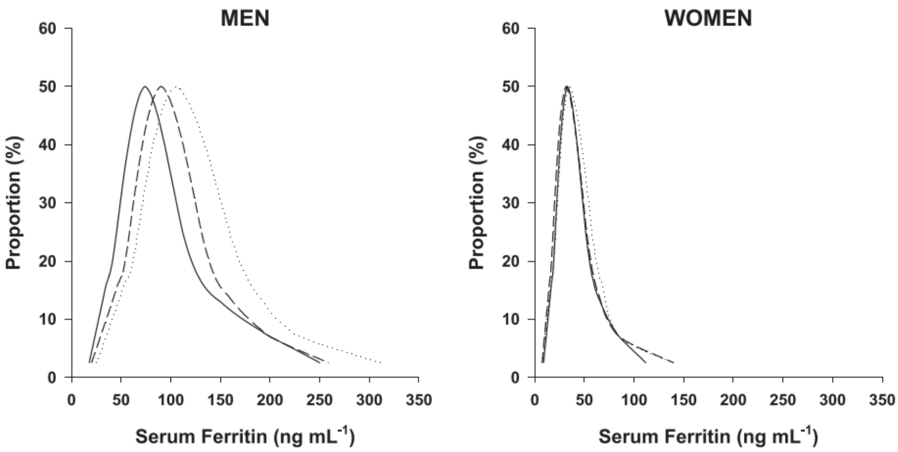
Allergy

Asthma is the most common medical condition in athletes, with an estimated prevalence of 20% (Price et al., 2021). Allergies have been associated with other conditions, such as sleep disturbance and asthma (Molzon et al., 2013). Athletes with allergies do not always seek appropriate treatment, for example, one study of endurance athletes reported only half of symptomatic athletes used allergy medication (Alaranta et al., 2005). Untreated allergies can have long-term consequences, such as development of chronic inflammatory adaptations in the respiratory or GI tract (Galli et al., 2008). Secondary manifestations of unidentified or untreated food allergies can lead to malnutrition due to food avoidance and increased risk of other atopic conditions such as rhinitis (Abrams et al., 2016). Some sport organizations already include more advanced allergy screening programs in their PHE, including skin reactivity tests to common allergens (Adami et al., 2019). More research is needed to assess the impact of robust laboratory screening as compared to screening questionnaires; however, screening questionnaires may help identify athletes who can benefit from laboratory screening (Bonini et al., 2009).

High prevalence of iron deficiency in elite athletes (Paper IV)

In a population of over 1000 elite athletes, our data indicate the distribution of SF in elite male athletes was different than the SF distribution within an otherwise normal age-matched US male population, with between 3% and 15% of athletes below the common thresholds of SF <20 ng/ml and <35 ng/ml, respectively. SF distribution in elite women athletes was not statistically different from otherwise normal age-matched women; however, a substantial proportion of female athletes are iron deficient (e.g., ~23% to 52% of the elite athletes displayed SF <20 ng/ml and <35 ng/ml, respectively). **Figure 12** displays serum ferritin distribution by sex in our cohort.

Figure 12 Distribution of serum ferritin by sex. The athlete population is represented by the solid line, with general population 20 to <24 in dashed line and general population 24 to <28 represented by a dotted line.



Iron is critical for athletic performance

Iron has an important role in exercise performance. Iron is a core element within hemoglobin, myoglobin, cytochromes, and other mitochondrial electron chain proteins important for oxygen utilization (Chatard et al., 1999; Dubnov & Constantini, 2004). Insufficient iron stores reduce oxygen carrying capacity to working skeletal muscles (Lukasiki et al, 1991), and there are established links between iron levels, total hemoglobin mass, maximal oxygen uptake, and aerobic exercise performance (Chatard et al., 1999.) Iron deficiency prevents erythropoiesis in response to erythropoietic stimulating agents, both in clinical populations (e.g., dialysis patients) (Kanbay et al., 2010) and athletes training at altitude (Govus et al., 2015). Interestingly, iron depletion even without anemia worsens exercise performance (DellaValle & Haas, 2011). These findings provide a strong rationale for the use of iron screening in athletes.

Iron meets the criteria for screening

Previous studies have examined iron deficiency in youth, collegiate, and elite athletes with outcomes and author opinions both in support of (Chatard et al., 1999; Dubnov & Constantini., 2004; Clenin et al., 2015), and against (Shaskey & Green, 2000; Parks et al., 2017) routine iron screening. Iron screening meets many of Wilson & Junger's criteria: the condition is a significant health problem, the condition can be identified at a latent stage before symptoms present, and there is a suitable test with a corresponding acceptable treatment. Given the high prevalence of iron deficiency in both male and female elite athlete populations, and the satisfaction of Wilson & Junger's criteria, we believe that the results of our study support for screening iron status in all athletes.

Choosing a SF threshold

A universal criterion level for SF to denote iron deficiency and justify iron supplementation in athletes remains a point of debate among researchers and clinicians (Chatard et al., 1999; Peeeling et al., 2007; Clenin et al., 2015). We used four different SF criterion levels suggested in the literature as thresholds for iron supplementation treatment, from 12 ng/mL to 50 ng/mL. For example, at <35 ng/mL, 82 out of 515 men athletes (15%) were identified as meeting the criteria for stage one iron deficiency. By comparison, at roughly the same percentile (15.9%) in the normal men population of Custer et al., SF values were significantly different than the athlete cohort (46.7 and 53.5 ng/mL for ages 20 to <24 and 24 to <28 yrs. respectively). We believe the data from our athlete population can be used as normative data for clinicians developing screening programs, regardless of the threshold they prefer. This is useful for the practicing clinician, as in the absence of guidelines from established clinical societies or universally accepted position papers, it remains up to the clinician to determine what SF level should trigger treatment interventions for their athlete patients.

Limitations

This dissertation consists of observational studies. The interpretation of the results is therefore limited and can only inform the reader on trends and associations. The PHE methods described cannot be assessed for their value in long-term athlete health protection. Limitations specific to each paper are listed below.

In Paper I, the survey was long, and survey fatigue may have affected the accuracy of responses. The survey was completed by a single representative from each NOC; however, the medical screening process involves many individuals. Some NOCs did not have standardized screening programs for all sports and instead preferred to allow individual sports to implement medical screening programs, making it difficult for one respondent to describe all practices in the survey form. Thus, results of this survey may not be as applicable to individual sport governing bodies. The survey also was only available in English, which may have led to misinterpretation of instructions, questions, and responses by non-English speakers. As a result of these limitations the survey responses may not be completely representative of the current beliefs and practices of the NOCs studied.

The results of Paper II are limited by the lack of a gold-standard assessment to use as a comparator of the interview and written questionnaire methods. Both techniques are known to have bias, and without a standard it is difficult to assess the accuracy of either. As a result, conclusions on the effectiveness of these methods could only be made by comparing them to each other. Access to robust medical records, or health monitoring tools such as the Oslo Sports Trauma Research Centre Questionnaire could have served as an appropriate reference standard for this study.

Paper III was a cross sectional study that compared the point prevalence of positive findings for screening tools that represent a documented risk for health conditions. The reporting method is athlete self-report via questionnaire, which may be vulnerable to selective reporting and recall bias. The questionnaires used describe point prevalence only. In studies using patient self-report through written surveys, there may be a percentage of participants who choose to not respond accurately (Meade et al., 2012). Some screening tools are designed to identify recent or current symptoms/behaviors; for example, GAD asks about anxiety symptoms present in the last two weeks. No outcomes were assessed in the study, there is an assumption that the identification of a positive screening tool in an individual is correlated to true diagnostic outcomes. Future study designs should include prospective reporting of health conditions diagnosed through full clinical evaluations and compare these to the screening tool results.

In Paper IV, the reason for the blood draw was not recorded in the USOPC EHR database. At USOPC clinics, it is common for athlete labs to be ordered as part of training camps or on a routine basis for wellness screening. It is possible that some of the athletes in the population tested may have been unhealthy at the time of the blood draw. Athletes may have had previous blood draws as part of their overall health care or wellness screening and may have been supplementing with iron at the time of the blood draw. Similarly, dietary intake of iron from food or any iron supplementation routine at the time of blood sampling was not recorded. We did not measure transferrin saturation values, which is one of three criteria (along with SF and hemoglobin concentration) used to categorize the three stages of iron deficiency (Bothwell, 1980; Peeling et al., 2007) and may provide the clinician with complementary information on when making treatment decisions.

Conclusions

In this dissertation, new information on the practice of the PHE in elite sport was identified:

1. The PHE at top performing NOCs is a comprehensive process that involves collaboration of multiple experts across sports medicine and science. The practices of NOCs are heterogenous. Programs are often customized for specific athlete populations and emphasize the importance of identifying existing conditions so they can be managed with athlete-specific action plans. Current practices suggest that the PHE has evolved beyond health evaluations and medical risk screenings, and include tests used to guide individual injury prevention programs and profile the performance of athletes in the event of future injury.
2. Patient interviews capture four times as many past or current injuries than electronic questionnaires in athletes training for the Olympic and Paralympic Games. Biases associated with patient self-reporting of health information make health history data collection difficult in this patient population.
3. The inclusion of standardized screening tools in an electronic health history resulted in the identification of potential mental health, sleep, and allergy problems in both Olympic and Paralympic athletes. Strong associations between anxiety, depression and sleep disorders highlight the importance of comprehensive screening programs to identify risk factors for these conditions.
4. SF data from the largest elite athlete cohort to appear in the literature indicates that the SF distribution is different between elite athletes and normal men. While there was no difference in the SF distribution between elite athlete and normal women, a substantial portion of both groups can be considered iron deficient. Routine iron screening is strongly recommended in both the male and female athlete populations.

Practical application

The preventive medicine model is believed to reduce the burden of disease through prevention, optimal treatment, and reduction of secondary health problems. PHEs in elite sport contribute to preventive medicine by facilitating structured, multidisciplinary interactions between athletes, medical and science staff that are focused on health promotion. The PHE is a system designed to identify and facilitate treatment of existing health problems, collect data for injury and illness surveillance and risk factor identification, and create profiles of individuals and cohorts for use in future prevention efforts.

The benefits of the PHE have not been measured in terms of short- or long-term health outcomes. Until this is accomplished, we must focus on the other benefits of the PHE. These programs are effective in identifying health problems and risk factors. The clinician-patient interactions that occur during the PHE are used to develop relationships, provide education, and help athletes comply with medico-legal requirements and anti-doping regulations.

PHEs do not come without risk—they can result in unnecessary disqualification from sport and overdiagnosis, which have the potential for downstream physical, emotional, and financial harm. Sport organizations must evaluate these risks against the perceived benefits and rely on available evidence when determining how to design and implement the PHE so that it does not negatively impact health or result in unnecessary barriers to sport participation (LaBotz & Bernhardt, 2016).

To further define the appropriate role of the PHE, a scientific approach is necessary. The IOC Consensus Statement authors recommended the PHE be used as a research opportunity to further develop best practices (Ljungqvist et al., 2009). They called for large scale, collaborative research to assess the value of PHEs. To date, evidence on this topic is lacking and is ripe for further investigation. Improved understanding of the PHE has the potential to protect athlete health, optimize resource allocation in sport organizations, and guide other areas of athlete health promotion.

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Papers I-IV

Protecting the world's finest athletes: periodic health evaluation practices of the top performing National Olympic Committees from the 2016 Rio or 2018 PyeongChang Olympic Games

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ABSTRACT

Aim To describe the periodic health evaluation (PHE) practices of the top performing National Olympic Committees (NOCs).

Methods We sent a survey to NOCs finishing in the top 8 for medal count at the 2016 Rio Olympic Games or 2018 PyeongChang Olympic Games. The survey included four sections: (1) PHE staff composition and roles, (2) beliefs regarding the PHE, (3) a ranking of risk factors for future injury and (4) details on the elements of the PHE.

Results All 14 NOCs with top 8 finishes at the 2016 Rio Olympic Games or 2018 PyeongChang Olympic Games completed the survey. NOCs included a median of seven staff specialties in the PHE, with physicians and physiotherapists having the highest level of involvement. There was agreement that PHEs are effective in identifying current health conditions (13/14) and that athletes should receive individualised action plans after their PHE (14/14), but less agreement (6/14) that PHEs can predict future injury. The practices of NOCs were diverse and often specific to the athlete population being tested, but always included the patient's health history, laboratory studies, cardiovascular screening and assessments of movement capacity. The top three risk factors for future injury were thought to be previous injury, age and training experience.

Conclusions Among the top performing NOCs, the PHE is a comprehensive, multidisciplinary process aimed to identify existing conditions and provide baseline health and performance profiles in the event of future injury. Research linking PHEs to injury prevention is needed.

INTRODUCTION

The periodic health evaluation (PHE) has the potential to reduce the burden of health problems in elite athletes; however, scientific support for this hypothesis is lacking.[1] The IOC published guidelines for the PHE in a 2009 consensus statement which described the scientific rationale and clinical recommendations for the PHE. The IOC further recommended the PHE be leveraged for research by National Olympic Committees (NOCs) to develop and improve best practices.

In practice, sport organisations have adopted diverse PHE policies designed to promote medical best practices, while addressing regional regulations and medicolegal risk.[2 3] NOCs, International Sport Federations and National Sport Governing Bodies implement their own guidelines for the PHE.[1 4] In elite sport, where success hinges on staying healthy, organisations are implementing medical testing practices that have not necessarily been validated by research.[5–7] The broad spectrum of federation guidelines and recommendations, coupled with the drive to optimise performance and health, and mitigate medicolegal risk, has culminated in the rapid evolution of PHE programmes in elite sport. To date, contemporary practices of NOCs have not been described.

The purpose of this study was to examine the PHE practices and beliefs of the highest performing NOCs. We created a survey to investigate: (1) the composition and roles of staff involved in the PHE, (2) their beliefs regarding the PHE, (3) what NOCs perceive as the most important risk factors for injury, and how this risk is communicated and managed with the athlete, and (4) which elements are included in the PHE and how these lead to interventions. We hypothesised that NOC beliefs and practices would be heterogeneous and lack evidence.

METHODS

Participants

We invited NOCs who finished in the top 8 of the total medal count at either the 2016 Rio Olympic Games or 2018 PyeongChang Olympic Games to participate. Two NOCs placed in the top 8 of both games, resulting in 14 invitations.

We emailed requests for participation to each NOC's chief medical officer, medical director or other parties identified as responsible for the PHE. Email addresses were collected through professional contacts of the investigators. The invitation included the purpose of the study, outlined the survey questions, described anticipated outcomes, how data would be used and a link to the survey website. The survey landing page allowed the participant to opt out of the survey or proceed with consent to use their anonymous data for research purposes.

Participants were asked to respond on behalf of their NOC and collect contributions from others within their organisation as necessary, as the survey included questions pertaining to many disciplines of sports medicine and science. Each NOC was allowed one survey response. Periodic reminder emails were sent to NOCs that did not complete the survey 2 weeks after the initial invitation. The dates of survey collection were from 24 August 2019 to 20 August 2020.

Survey

The survey instrument has been included as an appendix (online supplemental appendix A).

The survey included four sections: (1) questions on PHE staff composition and roles, (2) beliefs regarding the PHE, (3) a ranking of risk factors for future injury and (4) details on the elements of the PHE. For the section on beliefs, participants were asked to rate their agreement with statements on a 5-point Likert scale. The statements addressed the following topics: screening programme effectiveness in identifying current health conditions, risk factors for injury, predicting who will get injured in the future, improving training availability, team action plans, individual action plans and preference to aggregate scores from multiple tests versus single test results.

Sections of the PHE were stratified into 11 categories (history/demographics, strength, movement competency, movement capacity, cardiopulmonary, laboratory studies, fitness, mental health, body composition/nutrition, musculoskeletal health and neurocognitive health/concussion). If a respondent indicated use of an element in a category, their selection was followed with second-level questions.

Because the focus of our project was to learn how organisations evaluate athletes on their current roster, we asked respondents not to report on medical evaluations of prospective athletes, such as 'contract medical evaluations' or 'combine/pre-selection evaluations'. Additionally, we asked respondents to only describe periodic (pre-season/post-season) examination practices and exclude medical/sports performance monitoring such as daily or weekly wellness, training load or strength/range of motion evaluations.

Prior to distribution, we shared a draft of the survey with six external international experts in the PHE, and we adopted several changes to the survey based on their feedback.

Data were stored on an encrypted folder and server, and de-identified for analysis. Data were processed in the freeware statistical computing platform R and analysed in R and Excel with simple descriptive statistics. Tableau was used for data visualisation of aggregate data.

Data analysis

Counts and proportions were used to describe responses. We scored the section of beliefs regarding medical screening on a 5-point Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree), with a score of 1 for 'strongly disagree' and 5 for 'strongly agree'. The sum of Likert scale points was used to represent the strength of belief in each statement, and percentage of responses in Likert scale categories described categorical trends in response. Respondents were asked to rank the top five risk factors for injury from a list. We assigned a numerical value of 5 points to the highest ranked factor, 4 for the second, 3 for the third, 2 for fourth and 1 for the fifth, and 0 for any factor that was not ranked. We added the point totals for each risk factor and ranked them accordingly.

RESULTS

All 14 NOCs completed the survey. The median time that participants interacted with the survey was 46 min (IQR 33–331).

Staff roles in PHE

The median number of specialties involved in the PHE was 7 (range of 2–9). Figure 1 displays the roles of medical staff in four phases of the PHE (protocol design, participation in testing, data analysis/reporting, implementation of interventions). Online supplemental figure 1A, an interactive link to figure 1, converts this data to a Sankey chart that visualises the relationships between staff type and their roles in the PHE.

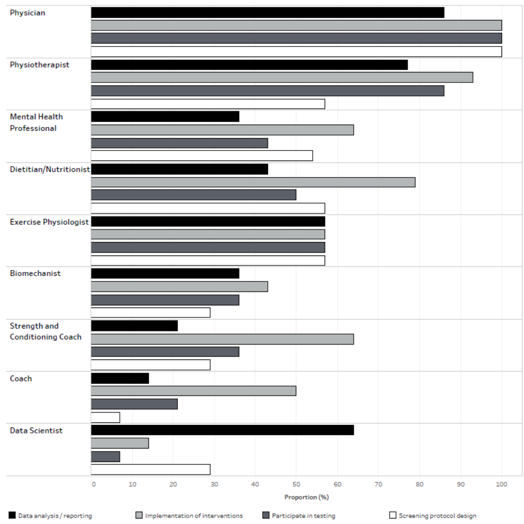

Figure 1 Roles of medical, science and coaching staff in the periodic health evaluation.

Figure 2 presents the percentage of responses to each Likert scale category for the seven belief statements.

Risk factor ranking

Table 1 lists the top 14 risk factors for future injury as ranked by NOCs.

Elements of the PHE

Figure 3 illustrates the percentage of NOCs that reported using each of the 55 PHE elements identified, organised into 11 categories. The mean number of elements included by NOCs was 25 (range 17–34); however, many NOCs noted that element selection for an individual athlete depended on factors such as timing of testing, sport and historical/demographic factors. Table 2 details the frequency, purpose, population tested, description of how risk was defined and how actions were taken after testing in each category.

DISCUSSION

This survey illustrates that among the top performing NOCs, the PHE is a multidisciplinary process that includes dozens of elements, is adapted for the team or individual being evaluated, and results in prescription of individualised health plans. Despite variation in clinical practice reported by our respondents, the described intent of the PHE aligns with the IOC recommendations. Contemporary PHE design and implementation occasionally strays from recommendations in the literature, and there is room for research to determine if elite sport organisations are ahead of the curve or wasting resources on expansive and expensive PHE programmes.

Which staff contribute to the PHE?

The multidisciplinary nature of the PHE at the NOC level has not previously been described. Although many specialists

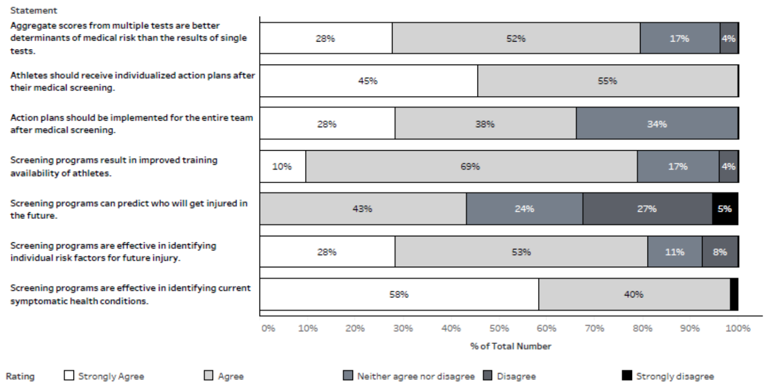

Figure 2 Beliefs regarding the periodic health evaluation.

participate in the PHE (a median of seven specialties per NOC), few are involved in the planning process. Physicians and physiotherapists form the backbone of the planning process, while other specialties including dietitians, biomechanists, strength and conditioning staff, and coaches are often asked to implement interventions based on findings. We see potential to improve the PHE through the integration of the entire medicine and science team into PHE planning which may facilitate athlete-specific interventions that emerge from the evaluation.

Why do NOCs perform the PHE?

The IOC states the purposes of the PHE are to (1) serve as a comprehensive assessment of the athlete's current health status and risk of future health problems, (2) introduce the athlete to the team's medical system and (3) serve as a tool for continuous health monitoring in athletes.[1] Our results demonstrate that NOCs believe the PHE prioritises identification and management of current health conditions, with secondary objectives of creating profiles of baseline characteristics and predicting future health problems. However, while there is good agreement that the PHE identifies current health conditions, there is a lack of agreement for the use of the PHE as a profiling or injury prediction tool. Future research is needed to investigate if the PHE is an effective tool leading to injury prevention.

Table 1

Ranking	Risk factor	Ranking points
1	Previous injury	58
2	Age	37
3	Training experience/training age	24
4	Psychological factors	17
5	Strength imbalance	14
6	Nutrition	10
7	Anatomy and morphology	9
8	Strength symmetry	8
9	Sleep	8
10	Movement competency	6
11	Genetics	6
12	Joint mobility	5
13	Flexibility	5
14	Aerobic fitness	3

Analysis of the elements of the PHE

History/demographic

Previous injury is considered the greatest risk factor for injury and every NOC surveyed used multiple methods to understand the athlete's health history.[7–9] A patient interview, which has been shown to capture more health information than questionnaires alone, was used by every NOC.[10] Some NOCs described use of continuous health monitoring, using tools such as the Oslo Sports Trauma Research Centre questionnaire, to capture all health problems and facilitate communication between athletes and medical staff.[11] The high rank of previous injury as a risk factor suggests that optimising methods for accurate and detailed injury surveillance may improve the effectiveness of health promotion programmes, while identifying the most common health conditions associated with the sport.

Cardiopulmonary

The value of cardiac screening is controversial.[12–14] Most NOCs included a history, physical examination and ECG in the PHE; some also included additional studies such as echocardiograms or stress tests. This finding is consistent with previous surveys of NOCs at the Summer Olympic Games.[15] Current guidelines recommend periodic cardiac screening that includes a history, physical examination and ECG to identify pathological cardiac conditions in elite athletes; however, there are no evidence-based guidelines supporting imaging or stress tests for screening of asymptomatic athletes.[16 17]

There is a higher prevalence of airway dysfunction in elite athletes than the general population, and as a result there are recommendations for respiratory monitoring of high-risk athletic populations.[18] Half of NOCs included pulmonary function assessments in the PHE, and these were often specifically designed for endurance athletes. The wide variety of pulmonary functions tests used suggests these assessments are often sport specific.

Mental health

Mental health problems are common in elite athletes.[19] Despite this, just over half of NOCs had mental health professionals involved in PHE design and one in three did not screen for mental health conditions. Due to the relationship between mental health, general health and performance, sport organisations

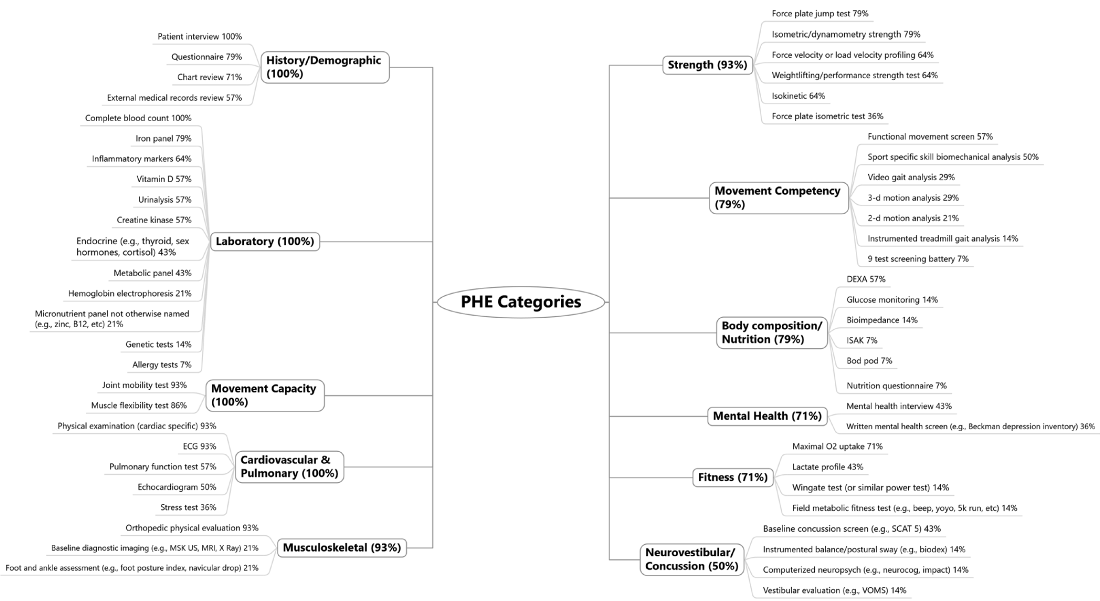

Figure 3 Elements used in each category of the periodic health evaluation (PHE), reported as the % of total responses in each category. DEXA, dual energy X-ray absorptiometry; ISAK, International Society for the Advancement of Kinanthropometry; MSK US, musculoskeletal ultrasound; SCAT, Sport Concussion Assessment Tool; VOMS, Vestibular/Ocular-Motor Screening.

should consider inclusion of collaborative mental health teams and standardised screening tools into PHE programmes.[20]

Body composition/nutrition

Athletes may encounter health problems associated with suboptimal nutrition and disordered eating.[21–23] Most NOCs addressed this by including a nutrition element in the PHE. However, only just over half of teams included a nutrition professional in the design process. The most commonly used tool in the nutrition category was dual energy X-ray absorptiometry to assess body composition.[24 25] Although many screening methods have been developed for disordered eating, NOCs do not report consistent use of any single validated instrument.

Laboratory studies

Routine laboratory screening has been described as low yield in athletic populations.[26] However, evidence shows screening for iron and vitamin D identifies many 'healthy' athletes with insufficient micronutrient status.[27 28] The practices of NOCs are consistent with these recommendations. There was wide variation in the use of other laboratory tests, with some NOCs reporting the use of endocrine studies, haemoglobin electrophoresis, metabolic panels, micronutrient panels, genetic and allergy tests. With the exception of haemoglobin-type screening, which has been proposed as a standard for the screening of sickle cell trait, there is no evidence supporting the use of these tests in the PHE for asymptomatic athletes.[29 30]

Musculoskeletal health

Musculoskeletal injury is the most common cause for time loss in Olympic sport.[31 32] The use of a standard physical examination to screen for current orthopaedic problems, inadequate rehabilitation of prior injuries or risk factors for future injury is a cornerstone of the PHE.[1 27 33] This practice was reported by 93% of NOCs.

The physical examination was supplemented by baseline imaging (eg, musculoskeletal ultrasound, MRI or plain radiographs) by some NOCs, primarily during shoulder evaluations for overhead throwing sports. One NOC noted that baseline radiographic imaging is not legal in their country, eliminating this as an option in the PHE. The high rate of incidental findings found on diagnostic imaging in asymptomatic athletes suggests that baseline imaging is difficult to interpret in athlete populations, and careful consideration must be made for how to use baseline imaging for patient management.[34]

Neurocognitive health/concussion

Baseline concussion screening has been proposed as a tool to help identify abnormal subtests in healthy athletes and develop population reference values.[35] The least used test category in our survey was neurocognitive and concussions tests (50%), with only 43% of NOCs performing baseline concussion tests. Notably, baseline screening for concussion was not recommended in the most recent International Concussion Consensus.[36]

Strength

Absolute strength deficiencies and kinetic asymmetries have been suggested to represent risk factors for injury in some sport populations.[37–40] Strength and muscle power tests were used by nearly every NOC, with most using a combination of isometric dynamometry, isokinetic testing, force plate jump testing and weightlifting performance evaluations. Our results suggest strength tests are chosen for specific populations, to create athlete-specific baseline data in the event of future injury and to evaluate current health status. Prospective collection of strength data in the PHE may help determine its role as an injury risk factor.

Table 2 Survey responses for each periodic health evaluation category

	History and demographics	Strength	Movement competency	Movement capacity	Cardiopulmonary	Laboratory	Fitness	Mental health	Nutrition and body composition	Musculoskeletal	Neurocognitive
Elements performed in category (N)	43	54	30	25	46	81	20	11	15	19	11
Frequency (%)											
Annual	53	28	33	48	63	43	50	45	53	74	50
Semiannual	37	26	43	48	26	49	50	36	27	21	—
Quarterly	—	20	3	8	2	8	—	—	7	—	—
Monthly	—	—	—	—	—	—	—	—	7	—	—
Intake	47	52	47	44	59	37	40	36	40	63	83
Discharge	23	—	—	8	7	9	—	—	—	—	—
Other	2	4	—	16	2	—	—	—	7	—	—
Population (%)											
All athletes	60	33	33	64	65	54	30	73	60	53	25
Specific populations	40	67	67	36	35	46	70	27	40	47	75
Purpose of test (%)											
Determine the athlete's current health status	98	85	87	96	100	100	100	100	93	89	92
Baseline in the event of future injury	63	85	77	80	70	68	55	45	67	84	100
Risk of future injury	58	39	80	56	76	57	70	45	53	42	33
How is health status/risk determined? (%)											
Known literature	N/A	52	67	56	91	91	90	100	93	68	67
Team experience/data	N/A	61	73	56	65	58	95	82	80	79	67
Athlete-specific change	N/A	65	83	64	72	63	90	64	73	63	25
Athlete score as compared with normative data	N/A	44	57	52	65	57	70	55	53	53	25
Clinician experience	N/A	54	73	56	83	75	65	73	67	79	58
How findings are acted on (%)											
Individual athletes are given personalised interventions	N/A	94	93	92	100	96	100	100	100	89	58
Athletes are provided a report of findings (but no intervention)	N/A	17	17	24	30	31	50	18	47	26	25
Aggregate findings are used to develop team interventions	N/A	33	53	44	26	16	50	18	27	37	25
Clusters of athletes with similar findings are given small group interventions	N/A	39	27	32	13	4	35	18	20	11	—

N/A, not available.

Movement competency

Movement screening tests cannot predict injury in athletic populations.[41–43] Movement-competency evaluations, which we categorised as subjective or objective assessments of functional or sport-specific movements, were used by the majority of NOCs. This category had the highest reported percentage of elements used for injury prediction. Paradoxically, the Functional Movement Screen, which does not predict injury, was the most commonly reported movement competency test.[42–44] This mismatch of current practices with supportive evidence has been observed in professional football, and raises the question as to whether elite sport organisations understand the predictive value of these tests and limits of injury prediction.[7] Other explanations for the widespread use of movement screens include a rationale that they help guide coaches on decisions for individual exercise prescription.

The other most commonly used elements were biomechanical analyses, such as sport-specific movement analysis, 2D and 3D motion analysis, and gait analysis. Personalisation was a common theme in this category: elements were usually prescribed for special populations, athlete-specific change was commonly reported as a risk factor definition for these tests, and results were always acted on with personal interventions. Personalisation of the PHE to adjust screening protocols, analysis and interventions to the individual athlete may be a luxury available to elite athletes that is not feasible at lower levels of sport.

Movement capacity

Deficits in flexibility and joint mobility are perceived to be risk factors for injury, although evidence is lacking.[7 45] Every NOC reported using movement capacity tests, even though this was not a highly ranked risk factor. Mobility deficits were almost always treated with athlete-specific interventions; however, there was not a consistent approach to defining risk. Conflicting literature on movement capacity as a risk factor for injury makes the predictive value of this type of screening unclear.[45 46] Although reduced range of motion (ROM) may be a risk factor for injury in some populations, screening is unlikely to identify athletes at risk due to small differences in at-risk populations and poor properties of ROM measures.[47 48] In sports where ROM is known to change with activity, regular monitoring to evaluate changes that occur during a competitive season may be preferable to pre-season screens.[49 50] This practice appears to be adopted by some NOCs, as this category had the highest frequency of use.

Cardiorespiratory fitness

Fitness is an indicator of health, and lower fitness may be a risk factor for injury in specific populations.[51–53] Despite this, we questioned whether fitness assessments are performed as part of the PHE. We learnt that some NOCs include fitness assessments in the PHE, mostly maximal oxygen uptake tests and lactate profiles for select athlete populations. More information is necessary to see how fitness assessments fit into the health promotion data ecosystem as an outcome measure or independent measure of risk.

Limitations

The survey was long, and survey fatigue may have affected the accuracy of responses. The survey was completed by a single representative from each NOC; however, the medical screening process involves many individuals. Some NOCs did not have standardised screening programmes for all sports and instead preferred to allow individual sports to implement medical screening programmes, making it difficult for one respondent to describe all practices in the survey form. Thus, results of this survey may not be as applicable to individual sport-governing bodies. The survey also was only available in English, which may have led to misinterpretation of instructions, questions and responses by non-English speakers. As a result of these limitations, the survey responses may not be completely representative of the current beliefs and practices of the NOCs studied.

Practical application of survey findings

When developing PHE programmes, organisations should define their objectives and then create multidisciplinary teams with appropriate medicine and science expertise to design the programme. The practices of NOCs suggest that the evaluations included in PHE programmes are most commonly used for three distinct purposes: health evaluations used to identify existing and symptomatic conditions; screening tests for identification of silent conditions or risk factors for injury; and assessments to profile performance as an individual baseline or population norm in the event of injury. Prioritising the objectives of the PHE will help sport organisations choose which parts of the PHE to focus on and eliminate unnecessary or costly tests from the PHE process.

The comprehensive screening practices of these NOCs should not be applied to broader sport populations due to the significant time, resources and expertise available at the NOC level, as well as the weak evidence underpinning many of the PHE elements. Prospective studies that evaluate the impact of each element of the PHE on subsequent health and performance will help sport organisations prioritise resource allocation for PHE programmes.

CONCLUSION

The PHE at top performing NOCs is a comprehensive process that includes many elements and input from multiple experts across medicine and science disciplines. The practices of NOCs are heterogeneous and generally lack evidence. Programmes are often customised for specific athlete populations and emphasise the importance of identifying existing conditions so they can be

What are the findings?

- The periodic health evaluation (PHE) is a multidisciplinary endeavour among top performing National Olympic Committees (NOCs); however, few specialties are involved in programme design.
- PHE programmes of top performing Olympic teams include multiple tests, many of which have aims that extend beyond the traditional objective of the PHE.
- Top NOCs often tailor the PHE to specific athlete populations, rather than use a single standard PHE for all athletes.

How might it impact on clinical practice in the future?

- NOCs should consider multidisciplinary planning and participation to provide a comprehensive PHE.
- The PHE provides an opportunity for baseline testing relevant to sports performance or research purposes.
- Each PHE should be modified based on individual and sport-specific needs.

managed with athlete-specific action plans. Current practices suggest that the PHE has evolved beyond health evaluations and medical risk screenings, and include tests used to guide individual injury prevention programmes and profile the performance of athletes in the event of future injury.

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If you agree to complete the survey, indicate your agreement by ticking the below box and you will be taken to the survey tool. Only one representative should complete the survey on behalf of each sport organization. Please collaborate with your Medicine & Science team to provide one answer that represents your organizations practices and beliefs. We anticipate this survey will take 20-45 minutes to complete, depending on how you respond. Please note, the questionnaire includes logic that asks follow up questions to positive responses in each section. It may be helpful to plan for 45 minutes to complete the survey in its entirety.

☐ Agree ☐ Choose not to participate

Thank you for participating, please enter your contact information.

Name: ☐

Email address: ☐

Organization: ☐

Title: ☐

We thank you for your time spent taking this survey.
Your response has been recorded.

End.

1. Staff
Check the box for each type of staff included in the screening process. For each professional, select the roles they play in the screening process. Mark N/A if "Other" is not relevant.

	Screening protocol design	Participate in testing	Data analysis / reporting	Implementation of interventions	NA / Not involved
Physician	☐	☐	☐	☐	☐
Physiotherapist / physical therapist / athletic trainer	☐	☐	☐	☐	☐
Psychologist / mental health professional	☐	☐	☐	☐	☐
Dietitian / nutritionist	☐	☐	☐	☐	☐

Exercise physiologist	☐	☐	☐	☐	☐
Biomechanist	☐	☐	☐	☐	☐
Strength and conditioning / fitness / movement coach	☐	☐	☐	☐	☐
Sport coach	☐	☐	☐	☐	☐
Data scientist	☐	☐	☐	☐	☐
Other (please enter title)	☐	☐	☐	☐	☐

If other, please provide any additional information or details: [ ]

2. Beliefs

Please rate your organization's belief in the following statements:

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Screening programs are effective in identifying current symptomatic health conditions.	○	○	○	○	○
Screening programs are effective in identifying individual risk factors for future injury	○	○	○	○	○
Screening programs can predict who will get injured in the future.	○	○	○	○	○
Screening programs result in improved training availability of athletes.	○	○	○	○	○
Action plans should be implemented for the entire team after medical screening.	○	○	○	○	○
Athletes should receive individualized action plans after their medical screening.	○	○	○	○	○
Aggregate scores from multiple tests are better determinants of medical risk than the results of single tests.	○	○	○	○	○

Screening test categories
This section stratifies medical screening tests into 11 categories (history/demographic, strength, movement competency movement capacity, cardiopulmonary, laboratory studies, fitness, mental health, body composition/nutrition, musculoskeletal health and neurocognitive/concussion).
For each test selected, you will be asked to select the frequency, type of risk score used for the test, and how the test is used to implement interventions. You will have an opportunity to include categories and tests that are not listed at the end of the survey.

---

3. History/demographic tests
Please select each history/demographic test your organization uses. Select all that apply.

- ☐ Injury history questionnaire
- ☐ Medical chart review (your organization's medical records)
- ☐ Patient interview
- ☐ Review of athlete's external medical records
- ☐ None of the above

For each test selected:

4. How frequently is _________ conducted? Select all that apply.

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Quarterly
- ☐ Semiannually
- ☐ Annually
- ☐ On intake to program
- ☐ On discharge from program

5. Which athletes do you screen with this test?

- ○ All athletes
- ○ Specific populations (please describe) [ ]

6. What is the role of _________ in medical screening?

- ☐ This test is used to determine the athlete's current health status
- ☐ This test is used to determine the athlete's future risk of injury
- ☐ This test is used as a baseline in the event of future injury

---

7-9 are excluded for historical/demographic tests

7. How is the health status/risk determined from these test results (please check all that apply):

- ☐ Known literature
- ☐ Athlete score compared to normative data.
- ☐ Team experience/data
- ☐ Clinician experience
- ☐ Athlete specific change

8. Can you please describe the score or guideline used to interpret this test (optional).

[ ]

9. How are positive findings acted upon? (check all that apply)

- ☐ Individual athletes are provided with personalized interventions
- ☐ Clusters of athletes with similar findings are provided small group interventions
- ☐ Athletes are provided a report of findings (but no specific intervention)
- ☐ Aggregate findings used to develop team interventions

For each category:

10. Do you use any tests that were not listed? If yes, how many?

- ○ No / none
- ○ One
- ○ Two
- ○ Three

For each additional test:

11. What is the name of the test? [ ]

Repeat questions 4 – 9.

---

12. Strength tests

Please select each strength test your organization uses. Select all that apply.

- ☐ Isometric/dynamometry strength (e.g., HHD, groin squeeze or fixed dynamometry)
- ☐ Weightlifting/performance strength test (e.g., squat, deadlift, clean, etc.)
- ☐ Force velocity or load velocity profiling (e.g., tendo/gymaware/myjump/loaded jumps/loaded sprints)

☐ Force plate isometric (e.g., mid thigh high pull, isometric squat)

☐ Force plate jump test (e.g., CMJ/squat jump/single leg hops/depth jump)

☐ Isokinetic testing

☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for strength tests

13. Movement competency tests
Please select each movement competency test your organization uses. Select all that apply.

☐ Functional movement screen

☐ 9 Tests screening battery

☐ 2-d motion analysis

☐ 3-d motion analysis

☐ Video gait analysis

☐ Instrumented treadmill gait analysis

☐ Sport specific skill biomechanical analysis

☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for movement competency tests

14. Movement capacity tests
Please select each movement capacity test your organization uses. Select all that apply.

☐ Joint mobility test (e.g., goniometric AROM)

☐ Muscle flexibility test (e.g., hamstring length)

☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for movement capacity tests

15. Cardiovascular and pulmonary health tests
Please select each cardiovascular and pulmonary health test your organization uses. Select all that apply.

☐ Physical examination (cardiac specific)

☐ ECG

☐ Echocardiogram

- ☐ Stress test (ECG)
- ☐ Pulmonary function test
- ☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for cardiovascular and pulmonary health tests

16. Laboratory tests
Please select each laboratory test your organization uses. Select all that apply.

- ☐ Complete blood count
- ☐ Metabolic panel (CMP/BMP)
- ☐ Hemoglobin electrophoresis
- ☐ Iron panel
- ☐ Vitamin D
- ☐ Urinalysis
- ☐ Endocrine (e.g., thyroid, sex hormones, cortisol)
- ☐ Creatine kinase
- ☐ Specific micronutrient panel not otherwise named
- ☐ Inflammatory markers (e.g., CRP, ESR, etc)
- ☐ Genetic tests
- ☐ Allergy tests
- ☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for laboratory tests

17. Fitness tests
Please select each fitness test your organization uses. Select all that apply.

- ☐ Maximal O2 uptake
- ☐ Lactate profile
- ☐ Field metabolic fitness test (e.g., beep, yoyo, 5k run, etc)
- ☐ Wingate test (or similar power test)
- ☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for fitness tests

18. Mental health tests
Please select each mental health test your organization uses. Select all that apply.

☐ Written mental health screen (e.g., Beckman depression inventory)
☐ Mental health interview
☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for mental health tests.

19. Body composition/nutrition tests
Please select each body composition/nutrition test your organization uses. Select all that apply.

☐ DEXA
☐ Bod pod
☐ ISAK
☐ Bioimpedance
☐ Glucose monitoring
☐ Glyocogen monitoring
☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for body composition/nutrition tests

20. Musculoskeletal health tests
Please select each musculoskeletal health test your organization uses. Select all that apply.

☐ Orthopedic physical evaluation
☐ Baseline diagnostic imaging (e.g., MSK US, MRI, X Ray)
☐ Foot and ankle assessment (e.g., foot posture index, navicular drop)
☐ Thermography
☐ Tissue quality measurement (e.g., tensiomyography, myoton)
☐ None of the above

For each test selected repeat questions 4 – 9
Repeat question 10 for musculoskeletal health tests

21. Neurovestibular/concussion tests

Please select each neurovestibular/concussion test your organization uses. Select all that apply.

- ☐ Baseline concussion screen (e.g., SCAT 5)
- ☐ Computerized neuropsych (e.g., neurocog, impact)
- ☐ Instrumented balance/postural sway (e.g., biodex)
- ☐ Vestibular evaluation (e.g., VOMS)
- ☐ None of the above

For each test selected repeat questions 4 – 9

Repeat question 10 for neurovestibular/concussion tests

---

22. Top 5 Risk Factors Ranked

Please drag and drop the top 5 risk factors into the box on the right in order of how your organization perceives their relative importance as risk factors for future injury (1 - most important; 5 - least important)

Age
Anatomy/morphology
Growth period
Genetics
Strength imbalance (agonist to antagonist)
Strength endurance
Maximal strength
Strength asymmetry (side to side)
Sleep
Flexibility
Joint mobility
Movement competency (movement skill)
Psychological factors (stress, anxiety, mental illness)
Aerobic fitness
Anaerobic fitness
Diet/nutrition status
Training experience/training age

1.
2.
3.
4.
5.

Previous injury
Other (please enter)

43. Feel free to provide any final comments on this survey.

End.

[RESEARCH REPORT]

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The Value of the Patient History in the Periodic Health Evaluation: Patient Interviews Capture 4 Times More Injuries Than Electronic Questionnaires

Accurate understanding of a patient's previous health history is critical for health care providers and clinical researchers. Sports medicine researchers depend on previously reported health conditions as a foundation for injury surveillance, risk factor identification, and secondary prevention.[2,14] However, the methods for health history data collection in the sports medicine setting have not been investigated for their validity or reliability.

Several techniques and methods are used to identify the prior health conditions in individuals and populations. In sport, these include patient interviews, written or electronic survey tools, medical record reviews, and sport federation injury reports. Each method has strengths and limitations, including the accuracy and completeness of data collected, the likelihood of compliance from athletes and medical staff, and the resources required to incorporate them.

Clinicians have historically used guided patient interviews as a primary means of understanding the patient's current and past health status, and to create a professional relationship with a new patient. In sport, this occurs during the preparticipation physical evaluation (PPE) or periodic health evaluation (PHE).[1,19] Despite the frequency of these interactions, there has been little research on best practices for completing the interview portion of the PHE, or for using the patient interview as a formal injury surveillance method. The absence of best practices may result in heterogeneity of interview style, goals, and data collected from the interview. Additionally, the information captured from these encounters may not always be reconciled with other health records, such as questionnaires or medical surveillance reports, for use in larger data sets.

Written or electronic questionnaires are frequently used as a clinical and research tool for collecting health history information. The International Olympic Committee's PHE position statement[19] and the American Academy of Family Physicians et al's PPE monograph[1] both include written health history survey forms. Clinicians and researchers have leveraged technology to develop electronic means of collecting health information,

OBJECTIVE: To assess the value of the patient interview and electronic questionnaire methods of health history data collection in elite athletes.

DESIGN: Cohort study.

METHODS: A retrospective chart review compared health history data collected by questionnaire and by interview in a cohort of 142 athletes who participated in a periodic health evaluation at the US Olympic & Paralympic Training Center sports medicine clinic. The main outcome measure was number of injuries reported by either interview or written questionnaire.

RESULTS: Six hundred twenty-six injuries were reported by interview and 157 by questionnaire. The mean ± SD number of injuries reported per participant was 4.4 ± 4.2 by interview and 1.1 ± 1.3 by questionnaire (difference, 3.3; $P<.001$). Capture rate by method was similar across sexes and for both Olympic and Paralympic athletes. More injuries were reported by interview than by questionnaire for all injury categories, except for concussions and surgeries.

CONCLUSION: Patient interviews capture 4 times as many past or current injuries than electronic questionnaires in athletes training for the Olympic and Paralympic Games. Questionnaires provide incomplete health history information in this patient population. *J Orthop Sports Phys Ther 2021;51(1):46-51. Epub 11 Dec 2020. doi:10.2519/jospt.2021.9821*

KEY WORDS: *electronic medical records, epidemiology, informatics, injury prevention*

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which can result in ease of distribution and data collection.[17,29] Use of electronic health history collection tools has been associated with more active patient participation in the health history process, more complete patient records, identification of conditions not identified by clinical care, and time savings.[5,21,22] However, other studies have identified problems when using electronic methods to capture health history information compared to traditional methods.[21,22,25]

The multiple tools available for health history collection create important questions for the clinician and researcher who aim to collect an accurate health history. First, are there differences in the completeness of information collected from these methods? If there are differences, are there specific components of the health history that are more frequently captured by each method? This study compares the use of oral patient interviews and electronic questionnaires to identify history of significant injury in a cohort of elite athletes at the US Olympic & Paralympic Training Center.

METHODS

Study Design and Participants

We performed a retrospective chart review of electronic medical records of the US Olympic & Paralympic Committee. The Committee's Sports Medicine Division provides medical services to athletes determined to be elite, as defined by their national governing body. The criteria for elite status most commonly require making a senior-level national team or world team. A data set including age, sport, and health history information was extracted from the medical record for Olympic and Paralympic athletes who had completed both a clinician-guided oral interview of their medical history and an electronic health history questionnaire within 4 weeks of each other. This produced a data set of 142 athletes, which was de-identified and used for final analysis. Ethics approval for the use of this de-identified data set for the purpose of this project was provided by Southern California University of Health Sciences.

Patient Interview and Electronic Health History Process

The PHE at the US Olympic & Paralympic Committee facilities included 2 methods of health history collection, a structured patient interview and an electronic health history. These health histories were used to screen the athlete for any current or prior medical conditions that require treatment, preventative measures, or monitoring as part of ongoing efforts to maintain optimal health. The patient interview was performed by sports medicine clinicians (physician/chiropractor/physical therapist/athletic trainer) in a private clinic setting. The interview was structured and included questions regarding the patient's ongoing medical conditions, cardiac history, past health history, family history, medications, and allergies. The clinician recorded the interview in a free-text narrative in the patient chart within the electronic medical record. Diagnoses identified during the interview were then coded and entered in the patient medical record.

The electronic health history was a web-based questionnaire. Patients were provided access to their electronic health record patient portal via an encrypted website (DocuSign Inc, San Francisco, CA). The questionnaire included many items from widely distributed health history forms, including one from the PPE monograph[1] and the International Olympic Committee PHE health history form.[19] The format of the questionnaire included yes/no, multiple-choice, and free-text items. The questionnaire took approximately 20 minutes to complete.

A standard question in both the patient interview and electronic health history was, "Please list every injury that has kept you from participating in sport for 2 weeks or more." There was no time frame tied to this question in either the interview or health history questionnaire, and all injuries that affected sport participation were included in the final data set. Injuries or illnesses that did not affect sport participation were excluded. This question was chosen to designate "serious sports injuries," as per usual practice of the US Olympic & Paralympic Committee. Within the electronic health history patient portal, there were free-text spaces that allowed athletes to enter information regarding each injury. Clinicians recorded these injuries in a bullet-pointed, narrative review format. If athletes disclosed injuries that did not affect sport participation or did not result in a time loss of 2 weeks or greater from sport participation, the injuries were not included in the final data set.

Data Analysis

A data analyst (A.H.) counted the number of serious sport injuries reported by each athlete in both interview and questionnaire formats and recorded them in a spreadsheet. Injuries were stratified into several categories for secondary analysis (concussion, upper extremity injury, lower extremity injury, spine and trunk injury, muscle strain, ligament sprain, tendinopathy, surgery). Any health condition not associated with sport participation was excluded. Data were analyzed in JASP (Version 0.8.2; The JASP Team, Amsterdam, the Netherlands) and JMP (Version 14.0; SAS Institute Inc, Cary, NC), using paired t tests to compare data-collection methods.

RESULTS

Complete data were available for 142 athletes (78 female and 64 male), 117 from Olympic programs and 25 Paralympic athletes. The athletes represented 12 sport federations. Athlete characteristics, including age, sex, and sport type, are summarized in **TABLE 1**.

A total of 626 injuries were reported by the interview method and 157 by questionnaire. The mean ± SD number of injuries reported was 4.4 ± 4.2 by interview and 1.1 ± 1.3 by questionnaire (difference, 3.3; $P<.001$). In athletes training for the

Olympics, 4.8 ± 3.1 injuries were reported by interview and 1.1 ± 1.3 by questionnaire (difference, 3.7; *P*<.001). For athletes training for the Paralympics, 2.8 ± 3.4 injuries were reported by interview and 1.3 ± 1.4 by questionnaire (difference, 1.5; *P*<.001). Female athletes reported 4.3 injuries by interview and 1.1 injuries by questionnaire (*P*<.001). Male athletes reported 4.6 injuries by interview and 1.1 injuries by questionnaire (*P*<.001). The **FIGURE** reports the number of injuries recorded by each method in both Olympic and Paralympic athletes.

Significantly more injuries were reported by interview than by questionnaire for all injury categories, except for concussions and surgeries (**TABLE 2**).

TABLE 1 ATHLETE CHARACTERISTICS

	Olympic (n = 117)	Paralympic (n = 25)
Mean ± SD age, y	22.7 ± 3.1	26.2 ± 7.4
Sex (female), n (%)	62 (53)	16 (64)
Sport, n		
Athletics	65	4
Boxing	28	...
Cycling	...	5
Diving	6	...
Fencing	4	...
Figure skating	4	...
Gymnastics	4	...
Luge	1	...
Speed skating	1	...
Swimming	4	5
Triathlon	...	2
Volleyball	...	9

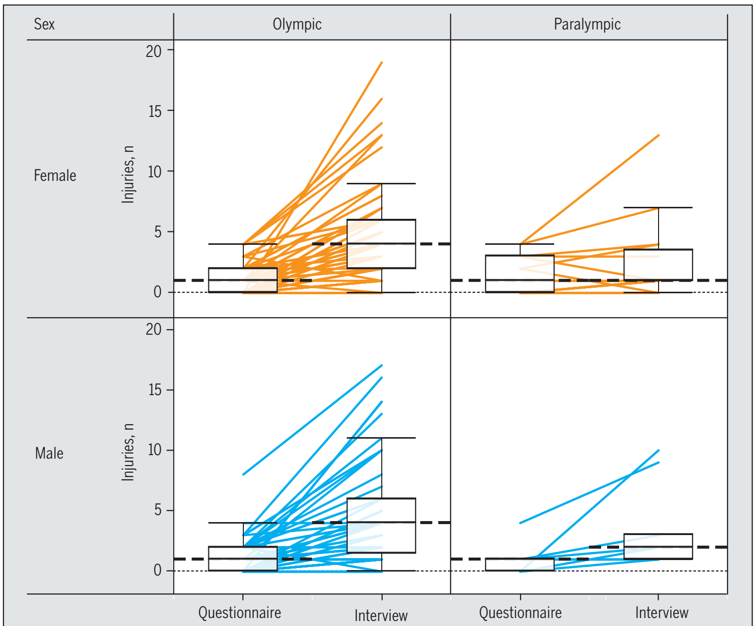

FIGURE. Number of injuries reported by survey method in Olympic and Paralympic athletes.

DISCUSSION

We observed that a guided patient interview records 4 times more past or present injuries than an electronic health history questionnaire in a cohort of elite Olympic and Paralympic athletes. The only injury types that did not differ between reporting methods were concussions and surgeries. The magnitude of reporting difference was consistent across both sexes and was similar for athletes training for the Olympics and for the Paralympics. These findings have important implications for clinicians and researchers who rely on an accurate health history as a component of medical care or injury prevention research in elite athlete populations. Further investigation in other populations is necessary to understand whether these findings generalize across different levels of sport participation.

The Patient Interview

Our findings suggest that there may be advantages to the interview that result in more complete health history data collection. Patient interviews have been deemed "the core of clinical interaction and the clinician's most important and intimate professional activity."[18] Previous research on surveillance programs in the elite sport setting found that interviews captured 94% of all injuries reported by other methods, whereas medical records (61%) and federation technical reports (28%) captured fewer injuries.[10]

There are qualities inherent to the interview that may explain these findings. Athletes have shown a preference toward personal communication when participating in sport surveillance systems.[3] Interviews allow for live, 2-way interaction between the clinician and athlete, including immediate feedback on responses. Athletes expect feedback from sport surveillance systems, which may occur naturally during interviews.[3] In the primary care setting, patients who perceive that their problems are discussed have better outcomes.[27] These aspects of the human interaction between a patient and clinician cannot be readily replaced by electronic or written communication.

Challenges to Collecting Health History Information

Collecting accurate historical medical information from patients can be difficult, regardless of method. There are biases that impact the accuracy and completeness of self-reported health conditions. These include recall bias, reporting bias, and information bias.

When clinicians rely on patients to recall their own health history, clinicians encounter recall bias. Patients can be inaccurate when remembering their own health information.[4] In a study designed to determine the accuracy of athlete self-report in the previous 12 months, 80% of athletes were able to recall how many injuries they had sustained, but only 61% were able to record the exact number, body region, and diagnosis of each injury sustained.[11] In a cohort of 104 patients tracked over a 3-month period, using free recall, patients only remembered 47% of health events.[8] This is compounded by the fact that when patients are provided a diagnosis during clinical care, many cannot accurately remember what they were told. Patients only remember 17% to 60% of information they are told by a physician, 48% of what they recall is imagined, and after a month they only remember 11% to 13%.[20] These issues suggest that prospective surveillance systems, including frequent periodic self-reports and reports directly from health care providers, may be necessary to accurately document a patient history.[12,13]

Self-reporting bias by athletes can occur when athletes perceive reporting their health history to be a threat to their ability or right to compete.[26] This issue may be more pressing when health history is taken in the middle of a competitive season, as athletes prefer not to discuss health problems prior to a major competition.[17] In some sport settings, athletes may have acute concerns with injury reporting due to rules that require mandatory time out of competition, such as concussion. Athletes may intentionally underreport concussion to continue playing while injured.[15] In our setting, health information collected during the PPE is not used for team selection purposes, as the PPE occurs after athletes are selected. Therefore, we do not believe that self-reporting bias was an important factor during patient self-reporting in this study.

Information bias, or misclassification bias, occurs when information is not classified correctly. Information bias occurs during health history data collection when (1) information is collected but not documented, (2) information is collected but documented in a format that is not useful for further analysis, or (3) information is documented incorrectly. Incomplete documentation by medical staff is a valid concern in the sports medicine setting, as medical staff often fail to document injuries appropriately.[10] In one report of injury surveillance, only 36% of injury forms were completed by the physicians, and 40% of injury forms were completed incorrectly.[9] An advantage of written and electronic health histories is the ability to develop the data-collection form in a manner that ensures that all data are clean and formatted for future analysis. Clinicians collecting histories via interview often document the interaction with narrative descriptions of the conversation, and rely on translation into a coding system, such as the International Classification of Diseases, 10th Revision or the Orchard Sports Injury Classification System,[15] for research-level analysis. The process of translating from conversation to code is vulnerable to error, and many coding systems do not provide the level of detail needed for sports medicine research.[15]

TABLE 2 Number of Injuries Reported by Survey Method, Stratified by Injury Type[a]

Injury Type	Interview	Questionnaire	*P* Value	Difference, %
Concussion	0.3 ± 1.1	0.2 ± 0.7	.190	26
Upper extremity injury	0.7 ± 1.0	0.2 ± 0.5	<.001	70
Lower extremity injury	2.5 ± 2.8	0.5 ± 0.8	<.001	82
Spine and trunk injury	0.6 ± 1.2	0.6 ± 1.1	.014	7
Muscle strain	0.9 ± 1.5	0.2 ± 0.5	<.001	77
Ligament sprain	1.2 ± 2.0	0.3 ± 0.6	<.001	78
Tendinopathy	0.4 ± 0.8	0.0 ± 0.2	<.001	92
Surgery	0.1 ± 0.3	0.1 ± 0.3	.570	10

[a]*Values are mean ± SD unless otherwise indicated.*

Strategies to Improve the Patient Interview

The patient interview is an art that has been refined by clinicians over centuries. The skilled clinician uses contextual clues to guide the narrative toward a more accurate history. In a narrative review by Barsky,[4] the author lists strategies to improve the accuracy of history. These include (1) noting and considering the patient's physical and emotional states at the time of the interview (anxiety or severe pain at the time of injury or time of the interview can affect accuracy), (2) establishing anchor points in the history ("What injuries did you have prior to high school graduation?"), (3) decomposing generic memories by finding things that separate events from each other ("What event made you seek medical attention for this injury?"), and (4) working on history in retrograde fashion ("Please list all of the injuries that have affected your training, starting from today and working backward").[10]

Electronic Health History Questionnaires

The low reporting of injuries through an electronic health history form in this cohort is concerning, as this type of tool is frequently used in clinical and research settings. When a data-collection tool fails to perform as designed, it should be evaluated for its performance and improved. The tool used in this study used a command, "Please list every injury that has kept you from participating in sport for 2 weeks or more," followed by a free-text box to collect responses.

The use of a free-text field in athlete questionnaires may not provide a user experience conducive to high compliance. Our question asked athletes to list "injuries," which implies that the patient should understand and be able to free type their previous diagnosis. Patients recall symptoms better than diagnoses, and have difficulty using clinical terminology in survey tools.[25] The use of free text may increase error rates.[30] We did not provide training or troubleshooting when administering the questionnaire. This may have led to reduced compliance, as guidance can improve the accuracy of patient self-report surveys.[28] Providing a description of why the information is collected and how it will be used can help compliance and reduce self-reporting bias.[4,28] Our athletes consented to the questionnaire and its use for health and high-performance services but were not given clear guidance on how they benefited from sharing their health history. Education and assurance that survey instruments are designed to optimize efforts to improve athlete health may be necessary, as athletes may not be motivated to share their health information willingly.[17]

The electronic questionnaire method was effective in collecting information on concussions and surgeries. Patients have an easier time remembering medical issues that they perceive as more severe, such as surgeries.[25] The findings from this study suggest that patients may be more likely to remember and/or take the time to report these severe injury types via electronic questionnaire and may not do the same for more minor injuries. This willingness to report may indicate motivation to share information that patients deem highly important with their health care providers.

Strategies to Improve the Electronic Survey Instrument

There is room for improvement in the electronic questionnaire. Providing front-end education on the intent and scope of the survey, the way the information will be shared and used, and interventions that will directly benefit the athlete as a result of participation may improve compliance.[3] Providing a dedicated helpdesk for help with access to dual-authenticated websites, technical troubleshooting, and translation of clinical terminology for the patient may enhance the user experience.[28] User interfaces that rely on single-select questions have a lower error rate than those that rely on free-text and date fields, especially when data entry requires no typing and can be completed with only a mouse or touchscreen.[30] Integration of diagnostic coding into these systems can enhance the quality of data collected and reduce the administrative burden of data management.

Increasing the frequency of electronic surveillance can limit the effect of recall bias. Validated athlete health monitoring tools, such as the Oslo Sports Trauma Research Center questionnaire on health problems,[6] allow for serial inquiry into existing and newly emerging health conditions. This approach has been useful in Olympic, Paralympic, youth recreational, and high school populations in many different languages and forms of electronic communication.[6,7,16,23,24]

Future Directions

Clinicians and researchers collecting health history information are encouraged to consider health history data collection as a measurement tool that comes with some inaccuracy. Clinical audits and research on data-collection techniques can help guide the development of new and more robust tools. Until these tools are validated, the guided patient interview and prospective reporting tools should be the preferred method in clinical and research settings. Combined data sets that include prospective patient reports, patient interviews, questionnaires, and data from past medical records provide the best chance of complete and accurate data collection.

CONCLUSION

Patient interviews capture 4 times more past or current injuries than do electronic questionnaires in athletes training for the Olympic and Paralympic Games. Biases associated with patient self-reporting of health information make health history data collection difficult in this patient population. ◉

KEY POINTS

FINDINGS: Patient interviews result in the collection of 4 times more injuries than electronic questionnaires. Patients report severe injuries by questionnaire and may not report less severe injuries. Patients may neglect to report minor injuries such as sprains, strains, and tendinopathy by questionnaire.

IMPLICATIONS: Structured interviews should be preferred over electronic questionnaires. Integrated systems that include interview, questionnaire, medical record, and surveillance data should be developed for health history data collection. Prospective self-reports may be effective in removing recall bias.

CAUTION: The findings in this manuscript come from one set of methods in a very defined patient population. More research is needed on health history data-collection methods in diverse populations for better understanding of this topic.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Dr Nabhan contributed to the research design, data

acquisition and analysis, writing the manuscript, participant recruitment, and final approval. Mr Taylor and Mr Hedges contributed to data acquisition and analysis. Dr Bahr contributed to the research design, writing the manuscript, and final approval.

DATA SHARING: All data relevant to the study are included in the article.

PATIENT AND PUBLIC INVOLVEMENT: No patients/athletes/public partners were involved in the design, conduct, interpretation, and/or translation of the research.

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Expanding the screening toolbox to promote athlete health: how the US Olympic & Paralympic Committee screened for health problems in 940 elite athletes

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ABSTRACT

Aim To assess the value of including validated screening tools for allergies, anxiety, depression, sleep apnoea and sleep quality into an electronic patient health history questionnaire.

Methods In this descriptive study, we reviewed electronic medical records of Olympic and Paralympic athletes who completed health screenings, which included validated screens for allergies (Allergy Questionnaire for Athletes), anxiety (General Anxiety Disorder-2), depression (Patient Health Questionaire-2), sleep apnoea (Berlin Questionnaire) and sleep quality (Pittsburgh Sleep Quality Index), using established criteria for a positive screen. We report the prevalence of positive tests and the associations between positive screening tools.

Results A total of 683 Olympic and 257 Paralympic athletes (462 male, 478 female) completed the health history between May and September of 2019. At least one positive screen was reported by 37% of athletes training for the Olympics and 48% of athletes training for the Paralympics. More than 20% of all athletes screened positive for allergies and poor sleep quality. Athletes training for the Paralympics had a significantly higher percentage of positive screens for anxiety, depression, poor sleep quality and sleep apnoea risk. Females had significantly more positive screens for allergy and poor sleep quality.

Conclusions The addition of standardised screening tools to an electronic health history resulted in the identification of potential mental health, sleep and allergy problems in both Olympic and Paralympic athletes. Strong associations between mental health and sleep disorders suggest these problems should be considered together in health screening programmes.

INTRODUCTION

Health is defined as the state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.[1] Evidence-based health promotion is defined as the use of information derived from formal research and systematic investigation to identify causes and contributing factors to health needs and the most effective health promotion actions to address these in given contexts and populations.[2] Sports medicine screening programmes contribute to evidence-based health promotion by identifying athletes with current health conditions, risk factors for future conditions and serving as a portal of entry for athletes into clinical programmes dedicated to health promotion.[3–5] However, to address all aspects of athlete health, the scope of these programmes must expand beyond the prevention of injuries and take a holistic approach.

In elite sport, health promotion programmes often include some combination of screening, monitoring, injury and illness surveillance. The use of questionnaires as part of these programmes, often as a first step in a periodic health evaluation (PHE), is standard practice.[4 6 7] These questionnaires have common themes that include investigation into an athlete's medical history, current signs or symptoms and family history. The goal of questionnaires is to identify current and potential health conditions in an individual; the data are then used to guide a structured physical examination, and occasionally other special tests such as ECG or laboratory studies.[3 4] Also, aggregate data can be used for research and to guide the development of more effective health promotion programmes.[4 5]

However, the traditional structure of the PHE may not capture many conditions that are difficult to diagnose in the primary care setting. There are common and clinically significant health conditions that are missed in routine clinical practice, such as anxiety, depression, allergies and sleep disorders.[8–12] Screening tools have been validated to help identify some of these conditions.[13–17] Integration of screening questionnaires into health promotion programmes may result in greater capture and improved management of these conditions.[15 18–20] However, the value of including such screening tools in the PHE has not been assessed in an elite sport setting.

Our research group developed an electronic health history questionnaire that included screening tools for mental health, sleep and allergies. We implemented this questionnaire as part of a screening programme for Olympic and Paralympic athletes and retrospectively reported the prevalence of positive findings for each screening tool and examined the associations between tools.

METHODS

Study design and participants

We performed a retrospective analysis of data collected between May 2019 and September 2019 by a web-based health history questionnaire developed for clinical use by the United States Olympic & Paralympic Committee (USOPC). Athletes who chose to participate in medical screenings at USOPC clinics, resident athletes at USOPC training centres and athletes who registered for international games completed a preparticipation health history questionnaire. This questionnaire was used to screen athletes for current or prior medical conditions that require treatment, to identify risk factors for injury, illness or suboptimal performance, and identify the use of medications or supplements that may place the athlete at risk for an antidoping violation. Completed health histories are used to create patient-specific and team-specific dashboards to be reviewed by team clinicians as part of usual patient care, and documentation of the questionnaire are entered in the corresponding electronic health record. Deidentified data from these questionnaires were aggregated and analysed for the purpose of this study.

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted to develop patient relevant outcomes or interpret the results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

Electronic health history process

Patients were emailed a hyperlink to the health history questionnaire via an encrypted website (Qualtrics). The questionnaire included items from widely distributed health history forms, including the PPE Monograph fourth edition, the IOC Periodic Health Examination health history form, the Allergy Questionnaire for Athletes (AQUA), the Berlin Sleep Apnoea Questionnaire, the Patient Health Questionaire-2 (PHQ2), the General Anxiety Disorder-2 (GAD2) and the Pittsburgh Sleep Quality Index (PSQI).[4 7 13–17] The questionnaire used embedded logic to present items relevant to the patient. Screening tools that used entry or exit questions such as the GAD2 and PHQ2 were incorporated with their logic to minimise questionnaire burden.

Data analysis

Data sets were stratified by sex and sport. Screening tools were scored and dichotomised as positive or negative according to thresholds defined in the literature, with the following criteria for a positive score: AQUA ≥ 5, Berlin≥ 2, GAD2 ≥ 3, PHQ2 ≥ 3, PHQ 9≥ 10, PSQI≥ 5.[13–17]

A χ^2 test of independence was used in R to determine statistically significant differences in proportions of positive screening responses in sex and Olympic versus Paralympic sport populations. Cohens kappa was calculated in JMP V.15.1 (SAS) to evaluate the level of agreement between screening tools. Prevalence ratios were calculated in Microsoft Excel for the prevalence of being flagged for one screening tool (consequent) if positive for an alternate screening tool (antecedent), as compared with being screened positive for the consequent and negative to the antecedent.

RESULTS

Nine hundred and forty athletes (462 female and 478 male), 683 from Olympic programmes and 257 Paralympic completed the health history questionnaire. The athletes represented 36 federations. The electronic health history took a median of 28 min to complete. Athlete characteristics are summarised in table 1.

Table 2 presents the proportion of positive screens for the five screening tools; 37% of athletes training for the Olympics and 48% of athletes training for the Paralympics were identified to have at least one positive screen. More than 20% of all athletes screened positive for the allergies and poor sleep quality. Athletes training for the Paralympics had a significantly higher percentage of positive screens for anxiety, depression,

Table 1 Athlete distribution by federation

	Olympic (n=683)		Paralympic (n=257)	
Sport	Male	Female	Male	Female
Archery	4	4	–	–
Athletics	113	114	40	25
Badminton	4	4	2	1
Basketball	16	14	12	12
Boccia	–	–	1	–
Boxing	5	5	–	–
Canoe-Kayak	9	8	–	–
Cycling	8	8	7	6
Diving	4	3	–	–
Equestrian	4	9	–	–
Fencing	8	9	–	–
Field Hockey	15	16	–	–
Golf	2	2	–	–
Goalball	–	–	6	6
Gymnastics	7	11	–	–
Handball	13	12	–	–
Judo	3	6	7	4
Karate	4	5	–	–
Pentathlon	2	3	–	–
Powerlifting	–	–	4	–
Rowing	11	8	–	–
Rugby 7 s	8	20	12	–
Sailing	9	5	–	–
Softball	–	15	–	–
Shooting	7	11	8	4
Soccer	–	–	15	–
Swimming	19	19	15	20
Synchronised Swimming	–	6	–	–
Tennis	1	3	4	2
Taekwondo	3	4	5	2
Triathlon	3	3	–	–
Table Tennis	1	3	10	4
Volleyball	12	14	12	11
Olympic Weightlifting	1	4	–	–
Water Polo	11	11	–	–
Wrestling	11	6	–	–

poor sleep quality and sleep apnoea risk (χ^2, table 2). There were also sex differences in screening tool responses, with a greater percentage of females with positive screens for allergy and poor sleep quality (table 2).

There was significant overlap of positive screening tools (figure 1). Sixty per cent of all athletes did not have a positive finding, 27% had one positive, 9% had two, 2% had three, 1% had four and 0.4% five.

Table 3 shows the level of agreement between screening tools. There were higher levels of agreement for the anxiety and depression tools than the other pairs of tools.

Prevalence ratios for associations between tools showed that a positive screen for any individual tool increased the prevalence ratio for all other tools (table 4). The magnitudes of prevalence ratios were the highest for associations between depression when positive for anxiety, depression when positive for sleep apnoea, anxiety when positive for depression and anxiety when positive for poor sleep quality.

Table 2 Prevalence of positive screening tool findings in male and female athletes training for Olympic and Paralympic Games

	Olympic/Paralympic				Male/female			
Screening tool	Olympic (n=683), %	Paralympic (n=257), %	χ^2	P value	Male (n=477)	Female (n=463), %	χ^2	P value
Allergy (AQUA)	20.6	25.3	2.09	0.15	16.4	27.7	16.86	<0.01
Anxiety (GAD)	3.1	7.4	7.52	<0.01	4.0	4.5	0.07	0.80
Depression (PHQ-9)	1.9	4.7	4.50	0.03	2.7	2.6	0.00	1.00
Sleep apnoea (Berlin)	3.5	8.6	9.94	<0.01	5.7	3.9	1.25	0.26
Sleep quality (PSQI)	23.1	30.7	5.33	0.02	22.2	28.3	4.28	0.04

AQUA, Allergy Questionnaire for Athletes; GAD, General Anxiety Disorder; PHQ-9, Patient Health Questionaire-9; PSQI, Pittsburgh Sleep Quality Index.

DISCUSSION

The addition of validated health screening tools to a standard PHE questionnaire resulted in the identification of either sleep, mental health or allergy risk in 48% of athletes training for the Paralympics and 37% of athletes training for the Olympics. This a relevant finding for sports medicine clinicians, as these conditions are difficult to diagnose in the primary care setting.[8–12]

Associations between screening tools

The presence of any positive screen was associated with increased prevalence of other positive screens for all five tools used in this programme. The cross-sectional, observational study design introduces the antecedent-consequent paradox, in which we cannot make causal inferences from the data. However, clinicians should be aware that there were positive associations between all the conditions we screened for and consider this when interpreting screening data. Positive associations between tools can guide clinicians to identify associated health problems.

The associations between positive screens must be interpreted with caution due to the potential overlap in the items of the tools used in this study. We used Cohen's kappa to determine the level of agreement between tools; agreement was low for all combinations of tools except for the PHQ2 and GAD2 (kappa of 0.57). There are limitations to the use of Cohen's kappa in this study, as some conditions were common (up to 30% of Paralympians for allergies) and others rare (2% of Olympians for depression). Kappa values are be affected by differences in prevalence, with high prevalence differences diluting kappa values.[21] Therefore, it is possible that the agreement between the screening tools used in this study is higher than we reported.

The prevalence ratios with the strongest association were anxiety with depression and sleep apnoea with depression and anxiety. These prevalence ratios we found suggest that the identification of one risk factor increases the probability of associated conditions. Reciprocal relationships between sleep and immune function, sleep and mental health conditions, and immune function and mental health have been proposed, which suggest that there may be complex, interconnected pathophysiology between these conditions.[22–25] Providing optimal care to patients with these conditions should include addressing each system as a potential risk factor for the others.

Mental health

The prevalence of mental health problems in elite athletes is unknown, however, there are known relationships between mental health, performance, injury, reinjury and illness risk.[26] There are barriers to access of mental health services in the elite athlete population, including a stigma that reduces athlete motivation to seek treatment, a lack of mental health resources, poor understanding of mental health, and poor experience interfacing with mental health providers.[27] Valid clinical tools for screening and/or diagnosing these conditions must be identified or developed so healthcare providers can appropriately diagnose and treat symptomatic athletes.[28]

We chose mental health screening tools for anxiety and depression that are recommended for use in the general population.[29 30] These tools, the GAD2 and PHQ2, are short questionnaires that can be expanded by survey logic to provide more comprehensive screening for athletes who appear to be at risk based on entry questions. This computer adaptive testing approach has been

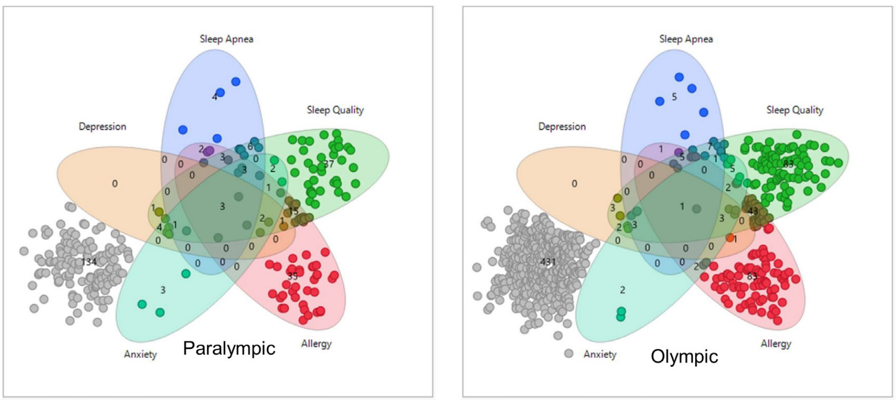

Figure 1 Relationship between positive screening tools. Grey indicates athletes with negative screening for all tools.

Table 3 Measure of agreement between screening tools

Screening tool		Kappa
Anxiety	Allergies	0.07 (0.02 to 0.13)
Anxiety	Sleep quality	0.18 (0.12 to 0.24)
Anxiety	Sleep apnoea	0.25 (0.12 to 0.38)
Anxiety	Depression	0.57 (0.43 to 0.72)
Allergies	Sleep quality	0.18 (0.11 to 0.25)
Allergies	Sleep apnoea	0.07 (0.01 to 0.13)
Allergies	Depression	0.05 (0.00 to 0.10)
Depression	Sleep quality	0.14 (0.09 to 0.19)
Depression	Sleep apnoea	0.20 (0.07 to 0.33)
Sleep apnoea	Sleep quality	0.17 (0.11 to 0.23)

shown to be effective in primary care settings for depression and anxiety screening.[31]

Our findings reveal that 2.7% of athletes screened had positive flags for depression, and 4.3% of athletes had positive flags for anxiety. In comparison, screening in the general population for these disorders results in prevalence of ~8%–25% for depression and ~5% for anxiety.[10 32 33] We identified 2.5 times greater prevalence of positive mental health screens in the Paralympic population as compared with the Olympic population. This finding suggests that athletes living with disability may represent a greater risk for mental health issues, a suggestion that has been previously proposed as a stereotype, but without the backing of evidence.[34] Without diagnostic confirmation, we cannot confirm that the true incidence of mental health problems is higher in the Paralympic population; however, our findings should be considered by adaptive sport organisations when developing mental health resources for their athletes.

Sleep

Sleep is essential. Sleep deprivation negatively impacts mood, cognition, metabolism and the immune system.[35] Athletes who sleep less have higher rates of injury, and there may be a relationship between injury risk and sleep deprivation; injury incidence is believed to increase during periods of high training load and less sleep.[36 37] Adults who sleep less have higher susceptibility to infection after exposure to pathogens.[38 39] Observational studies of elite athletes who sleep less have demonstrated higher illness incidence, however there is limited research on this topic outside of cross-sectional surveys.[40]

Sleep disorders are poorly identified by usual care in the primary care setting.[41] Recognition of sleep disorders can be improved when screening tools are implemented routinely.[16] Clinicians must consider both sleep quality and sleep apnoea screening, as they are distinct clinical entities that must be screened for separately.[42] Many athletes have anthropometric characteristics (ody mass index >28 kg/m^2 and neck circumference >40 cm) that increase their risk for sleep apnoea, which warrants special consideration for screening.[43]

A significantly higher proportion of athletes training for the Paralympic Games were flagged for sleep problems than their Olympic counterparts; 8.6% of Paralympians were identified as at risk for sleep apnoea. There is a paucity of literature on sleep health in the adaptive sport population, so the causes for sleep disturbance in this population are not yet fully understood.[44] Given the importance of sleep, the strong associations we found with sleep and other clinical screening tools, and the severe potential consequences of untreated sleep apnoea, this is an area that should be addressed with further research.

Allergy

Allergies are common in elite athlete populations, with a prevalence of allergic rhinitis reported to range from 13% to 41%.[15] Allergies negatively impact quality of life, physical performance, and may contribute to the development of other comorbidities.[45] Allergy screening can be expensive, requiring laboratory tests and specialty referrals. However, the use of a short questionnaire has been validated for use in athlete populations that has proven to have a high positive predictive value.[15]

The high prevalence of athletes with positive allergy screening suggests that it is reasonable to include this item into a standard screening battery. Allergy is closely linked with other conditions, such as sleep disturbance and asthma.[25] It has been previously reported that athletes with allergies may not be seeking appropriate treatment, with one study of endurance athletes showing only half of symptomatic athletes used allergy medication.[45] Untreated allergies may have long-term consequences, such as development of chronic inflammatory adaptations in the respiratory or gastrointestinal tract.[46] Secondary manifestations of unidentified or untreated food allergies can lead to malnutrition due to food avoidance and increased risk of other atopic conditions such as rhinitis.[47] Some sport organisations already include more advanced allergy screening programmes in their PHE, including skin reactivity tests to common allergens.[48] More research is needed to assess the impact of robust laboratory screening as compared with screening questionnaires.

Limitations

This is a cross-sectional study that compares the point prevalence of positive findings for screening tools that represent a documented risk for health conditions. The reporting method is athlete self-report via questionnaire, which may be vulnerable to selective reporting and recall bias. The questionnaires used describe point prevalence only. In studies using patient self-report through written surveys, there may be a percentage of participants who choose to not respond accurately.[49] Some screening tools are designed to identify recent or current symptoms/behaviours; for example, GAD asks about anxiety symptoms

Table 4 Prevalence ratios with 95% CI for associations between positive screening tools

	Anxiety	Allergy	Depression	Sleep apnoea	Sleep quality
Anxiety	–	2.0 (1.4 to 3.0)	71.3 (30.1 to 168.6)	8.2 (4.3 to 15.5)	3.6 (3.0 to 4.4)
Allergy	2.6 (1.4 to 4.8)	–	2.8 (1.3 to 6.1)	2.4 (1.3 to 4.2)	1.9 (1.5 to 2.3)
Depression	33.1 (20.6 to 53.3)	2.1 (1.3 to 3.3)	–	7.9 (4.1 to 15.2)	4.1 (3.6 to 4.8)
Sleep apnoea	8.5 (4.6 to 15.6)	1.9 (1.3 to 2.8)	9.4 (4.3 to 20.5)	–	3.2 (2.6 to 4.0)
Sleep quality	14.0 (6.3 to 31.2)	2.0 (1.5 to 2.5)	71.2 (9.7 to 523.4)	8.2 (4.3 to 15.5)	–

Column headings are the dependent variable for prevalence ratios, row headings the independent variable. Prevalence ratio = (prevalence positive when row is positive)/(prevalence positive when row negative).

present in the last 2 weeks. No outcomes were assessed in the study, there is an assumption that the identification of a positive screening tool in an individual is correlated to true diagnostic outcomes. Future study designs should include prospective reporting of health conditions diagnosed and compare these to the screening tool results.

CONCLUSION

The inclusion of standardised screening tools in an electronic health history resulted in the identification of potential mental health, sleep and allergy problems in both Olympic and Paralympic athletes. Strong associations between anxiety, depression and sleep disorders highlight the importance of comprehensive screening programmes to identify risk factors for these conditions.

What are the findings?

- Including validated screening tools into an electronic health history helps identify sleep, mental health and allergies in the elite athlete population.
- There are strong associations between the prevalence of sleep, mental health and allergy in elite athletes.

How might it impact on clinical practice in the future?

- Clinicians should include screening tools for conditions that are difficult to identify in the clinical setting into the periodic health evaluations.
- The identification of sleep, mental health or allergy should prompt investigation into associated conditions.
- This screening method supports the medical team by giving them a more specific picture of large groups. Identifying athletes with complex conditions allows clinicians to prioritise them and prepare more advanced clinical screening to those athletes with positive results.

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Original research

Serum ferritin distribution in elite athletes

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ABSTRACT

Objectives: It is not uncommon for athletes to be diagnosed with iron deficiency, yet there remains uncertainty whether the prevalence of suboptimal iron status in elite athletes differs from the normal population or warrants routine screening. The purpose of this study is to describe the distribution of serum ferritin (SF) in a cohort of elite athletes.
Design: Retrospective cohort study.
Methods: Electronic health records of 1085 elite adult athletes (570 women, 515 men) from 2012–2017 were examined retrospectively. SF values were compared to published normal population data. The proportion of athletes meeting criterion values for iron deficiency or initiation of treatment was examined.
Results: SF distributions in male athletes were significantly lower than normal males aged 20 to <24 yrs. (χ^2 28.8, $p < 0.001$) and aged 24 to <28 yrs. (χ^2 91.9, $p < 0.001$). SF status was similar in female athletes and normal women aged 20 to <24 yrs. (χ^2 9.5, $p > 0.05$) or aged 24 to <28 yrs. (χ^2 11.5, $p > 0.05$). Using 35 ng/ml as the criterion value for stage one iron deficiency, 15% of male athletes and 52% of female athletes displayed suboptimal iron status.
Conclusions: Male athletes have a significantly lower population distribution of SF values as compared to normative data on healthy males, with 15% of male athletes having suboptimal SF status. The distribution of SF values in elite female athletes did not differ from population values, however approximately half women athletes were iron deficient. These data suggest that iron screening should be considered in both male and female athlete populations.

Practical implications

- Male elite athletes have significantly lower serum ferritin status than healthy male non-athletes, with up to 15% of elite male athletes meeting suboptimal iron status thresholds.
- Female athletes and non-athletes have a high prevalence of suboptimal iron status.
- Routine screening for iron status should be considered in both male and female athlete populations.

1. Introduction

The most prevalent nutritional disorder, even in the developed world, is iron deficiency.[1] Athletes are not immune to this condition, and it is not uncommon for athletes to be diagnosed with iron deficiency, even with hemoglobin and hematocrit values that fall within clinically normal population ranges.[2,3] Athletes may experience both training-mediated iron loss and impaired iron absorption — in excess of the normal, untrained population — through factors including hemolysis, hematuria, sweating, gastrointestinal bleeding, altered dietary regimens, and downstream effects of pro-inflammatory cytokines resulting in hepcidin mediated changes in iron movement and metabolism.[3–6]

Many researchers and clinicians in sports medicine practice believe, based on their experience, that normative blood chemistry values, particularly for serum ferritin (SF), within trained athletes

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may be substantially different than population norms.[7] This belief is supported, in part, by studies suggesting an increased iron demand with physiological adaptations to training in athletes, and thus higher iron stores may be required in athletes to avoid an impaired training response.[8] Several threshold levels of SF for treatment interventions with athletes appear in the literature, which target higher than normal clinical ranges.[9–11] However, the basis for these recommendations is unclear, as no data exists establishing whether the population distribution of iron stores in elite adult athletes differs from the non-athlete population. In fact, in a literature search for SF values in elite adult athletes, the largest cohort included only 123 men and 174 women,[12] too few to draw conclusions about normative values in athletes.

It is important to understand normative iron levels in the elite athlete population, as there is uncertainty as to whether the prevalence of suboptimal iron status in elite athletes warrants routine screening.[13,14] Guidelines for the periodic screening of elite athletes suggest clinicians consider iron screening in women, where there is a high prevalence of low iron status.[3] However, in male athletes, there is a historical perspective of low yield and lack of perceived benefit for iron screening.[12,15,16] While many authors conclude that SF screening is reasonable for both men and women,[7,17,18] others believe routine iron screening should not be performed.[14,19] These conflicting recommendations may be better informed through improved data on the normal distribution of iron status in athlete populations.

The purpose of this descriptive study was to determine the distribution of SF measures in a large cohort of elite athletes, for comparison to the normal, non-athletic population. Utilizing data from >1000 athletes training at United States Olympic Training Centers, this data set is unique in its size and the elite athlete nature of the cohort. We hypothesized the distribution of SF measures in elite athletes would differ significantly from non-athletes for both sexes. Ultimately, this data can be used to inform the decision of whether to screen for iron status in elite athlete populations.

2. Methods

This was a retrospective cohort study reported using STROBE guidelines.[20] A retrospective analysis of de-identified medical records from the United States Olympic Committee (USOC) electronic health record (EHR) (Centricity, GE, Chicago, IL) was performed for all laboratory studies completed on adult athletes over a five-year period from 2012 to 2017. Athletes in the USOC EHR include US athletes training and competing for the Olympics or Paralympics under the USOC Sports Performance Division. Therefore, all athletes were defined as "elite" through objective or subjective criteria used by the USOC and/or the athlete's US national governing bodies for sport. All athletes gave consent for evaluation and treatment. This project was approved by the institutional review board of Southern California University of Health Sciences.

Blood collection occurred at hospitals and clinical laboratories associated with the USOC and US Olympic Training Centers in Colorado Springs, Chula Vista and Lake Placid. Blood was collected in evacuated serum separation tubes and either processed on site (typically <60 min from the time of collection) or transported to regional clinical laboratories, where the samples were typically processed within 12 h of collection. SF was determined by "sandwich" enzyme-linked immunosorbent assay, using commercially available kits (Dimension®, Flex® Reagent Cartridge, Siemens, Malvern, PA; VITROS® Immunodiagnostic Products Ferritin Reagent Pack, Ortho-Clinical Diagnostics, Rochester, NY), which have reported within-calibration coefficients of variation of 1.3–4.1%. Laboratory reliability was not assessed as part of this study, and standardization and interlaboratory comparability was assumed for the SF assessment.

The EHR database was queried for all laboratory studies performed between 2012–2017 with data analytics software (Tableau, Seattle WA). The specific reason the laboratory blood draw was ordered was not available in the database. However, usual care at USOC Clinics includes the use of laboratory screening of healthy athletes as an assessment of micronutrient status by dietitians, for monitoring of response to training or altitude stimulus by physiologists, and as a health screening or diagnostic tool by sports medicine staff.

Data were converted into comma-separated value format and analyzed using Microsoft Excel and Microsoft R Open (Redmond, WA). Clinical and demographic information included in the query included the SF value on their first study recorded in the database, the athletes' sex and sport, and a randomly generated unique patient identifier.

Distributions of SF results were calculated for each athlete and stratified by sex. For comparisons to normal population values, we utilized the data set of Custer et al.[21] The Custer et al. study represents, to date, the most thorough and largest descriptive investigation of SF to determine "the physiologic range of normalcy and consequently form a basis for a more detailed interpretation of clinical values." From an initial data set of over 900,000 test panels, a subset of >14,000 men and >21,000 women were identified in which 28 laboratory results (exclusive of the SF level) were within limits that approximated conventional reference ranges. Custer et al. stratified the SF data into four-year age bins; therefore, SF distributions from the 20 to <24 yr. old age group (720 men, 1711 women) and 24 to <28 yr. old age group (1085 men, 2175 women) were compared to the elite athlete distributions, as these age ranges best match that of the elite athlete cohort. Additionally, Custer et al. reported data in percentile bins of 2.5%, 15.9%, 25%, 50%, 75%, 84.1%, and 97.5%. Distribution graphs and tables using these percentiles were created for each sex, using the quantile function in Microsoft R, which uses linear interpolation when there is not an exact value in the dataset at the specified percentile. Counts in distribution bins were compared using Pearson's chi-square test for independence.

To facilitate discussion of an appropriate criterion value for SF for commencing treatment, we calculated the percentages of athletes and the normal population who met select thresholds. We selected four threshold values.

1 <12 ng/mL: This SF value has been correlated with depleted bone marrow iron stores[22] and is commonly used as the lower bound of the normal range by clinical testing laboratories. This also is the SF component threshold of stage three iron-deficient anemia, as defined originally by Bothwell et al.,[23] and updated by others.[2]
2 <20 ng/mL: This matches the stage two iron-deficient erythropoiesis SF threshold.[2,23]
3 <35 ng/mL: This matches the stage one iron depletion threshold[2,23] and the iron deficiency threshold recommended by several other authors for treatment in athletic populations.[24,25]
4 <50 ng/mL: This matches the threshold recommendation of Custer et al.[21] for men, as well as the SF threshold used for inclusion by many researchers in examining iron treatments for patients presenting with fatigue.[26] This threshold has also been recommended as a minimum level for adult athletes preparing to train at altitude.[18]

Suboptimal iron rates among normal men and women aged 20 to <24 yrs. and 24 to <28 yrs. at 12, 20, 35, and 50 ng/mL were estimated by fitting a second-order polynomial equation for each cohort to log-transformed percentile and SF values from Custer et al.[21] and calculating the proportion of subjects below each threshold. Chi-square tests were used to compare the proportion

Table 1
Number of male and female athletes by sport.

Sport	Males, N	Females, N
Basketball (Para)	17	15
Biathlon	10	–
Bobsled	23	20
Boxing	31	16
Curling	14	12
Cycling	18	28
Cycling (Para)	17	14
Fencing	13	19
Figure skating	22	26
Goalball (Para)	11	–
Gymnastics	19	–
Ice Hockey	–	92
Luge	11	–
Rowing	59	34
Rugby	–	11
Rugby (Para)	14	–
Skiing (Para)	20	–
Soccer	–	23
Swimming	30	34
Swimming (Para)	22	25
Track & field	42	50
Track & field (Para)	24	10
Triathlon	21	15
Water Polo	12	18
Wrestling	23	32
Other sports (<10 each)	42	72
Total	515	570

N = number of athletes. All sports listed are able-bodied, except where noted by (Para) = Paralympic. Male sports with less than 10 subjects included: shooting, speed skating, modern pentathlon, volleyball, Taekwondo, weightlifting, tennis, golf, judo, ice hockey, diving, judo (Para), skiing (Para), soccer (Para), shooting (Para). Female sports with less than 10 subjects included: biathlon, judo, shooting, skiing, weightlifting, gymnastics, speedskating, luge, modern pentathlon, volleyball, judo (Para), Taekwondo, archery, diving, shooting (Para), skiing (Para).

of each group (athletes, normals 20 to <24y, normals 24 to <28y) at each SF threshold value. The alpha for statistical significance was set at $p < 0.05$.

3. Results

We included results from 1,085 elite athletes (570 women, 53%; 515 men, 47%). A breakdown of athletes by sex and sport can be found in Table 1. Distribution of values for SF by sex, compared to the population data reported by Custer et al., can be seen in Fig. 1. In elite athletes, the median SF was 74.0 ng/mL (interquartile range 45.5–112.0 ng/mL) for men and 33.0 ng/mL (interquartile range 30.7–51.3 ng/mL) for women. In the normal population reported by Custer et al., the median for men age 20 to <24 yrs. (n = 720) is 90.2 ng/mL (interquartile range 58.6–131 ng/mL) and for ages 24 to <28 yrs. (n = 1085) 105 ng/mL (76.9–172 ng/mL). Similarly, for women aged 20 to <24 yrs. (n = 1711), the published normal population median from Custer et al. was 31.8 ng/mL (interquartile range 18.6 – 52.3 ng/mL) and for women equal to 24 to <28 yrs. (n = 2175) the median was 38.8 ng/mL (22.5–63.4 ng/mL). SF distributions differed between the elite male athletes and both normal men aged 20 to <24 yrs. (χ^2 (7) = 28.8, $p < 0.001$) and 24 to <28 (χ^2 (7) = 91.9, $p < 0.001$) but not between the elite female athletes and normal women aged 20 to <24 yrs. (χ^2 (7) = 9.49, $p = 0.219$) or aged 24 to <28 yrs. (χ^2 (7) = 11.5, $p = 0.118$).

SF status at thresholds of 12, 20, 35, and 50 ng/mL in athletes and normal men and women can be found in Table 2, with SF percentiles for each group in Table 3. Elite men athletes had a greater proportion below the 35 ng/mL and 50 ng/mL thresholds compared to normal men aged 20 to <24 yrs. (35 ng/mL: χ^2 (1) = 8.19, $p = 0.004$; 50 ng/mL: χ^2 (1) = 15.03, $p < 0.001$) and at 20 ng/ml, 35 ng/mL, and 50 ng/mL thresholds compared to normal men aged 24 to <28 yrs. (20 ng/mL: χ^2 (1) = 8.53, $p = 0.003$; 35 ng/mL: χ^2 (1) = 31.43, $p < 0.001$; 50 ng/mL: χ^2 (1) = 58.63, $p < 0.001$). In elite women athletes, there was a greater proportion of athletes below thresholds of 35 ng/mL and 50 ng/mL compared to normal women aged 20 to <24 yrs. (35 ng/mL: χ^2 (1) = 4.64, $p = 0.031$; 50 ng/mL: χ^2 (1) = 8.55, $p = 0.003$) but not compared to normal women aged 24 to <28 yrs. (35 ng/mL: χ^2 (1) = 1.28, $p = 0.258$; 50 ng/mL: χ^2 (1) = 2.18, $p = 0.140$).

4. Discussion

The purpose of this study was to describe SF status in a large cohort of elite athletes and to determine if differences exist in the distribution of SF levels between athletes and the normal, non-athlete population. In our novel population of over 1000 elite US athletes, our data indicate the distribution of SF in elite male athletes was different than the SF distribution within an otherwise normal 20 to <28-yr old US male population, with between 3 and 15% of athletes below the common thresholds of SF < 20 ng/ml and <35 ng/ml, respectively. While the SF distribution in elite women athletes was not statistically different from otherwise normal 20 to <28-year old women, the prevalence of iron deficiency (using any of the commonly utilized criterion levels) is substantial (e.g. ~23%–52% of the elite athletes displayed SF < 20 ng/ml and <35 ng/ml, respectively).

The reason iron status is screened, even in otherwise healthy athletes, is the critical role iron plays in exercise performance. Iron is a core element within hemoglobin, myoglobin, cytochromes and other mitochondrial electron chain proteins important for oxygen utilization.[7,18] Insufficient iron stores reduce O_2-carrying capacity to working skeletal muscles,[27] and there are well established links between iron levels, total hemoglobin mass, maximal oxygen uptake, and aerobic exercise performance.[7] Iron deficiency prevents erythropoiesis in response to erythropoietic stimulating agents, both in clinical populations (e.g. dialysis patients)[28] and athletes training at altitude,[24] and interestingly, iron depletion even without anemia worsens exercise performance.[29] It is for these reasons (and perhaps others not listed) that iron screening is often utilized in the diagnosis of athletic performance decline, as well as with athlete screening at routine intervals, even in the absence of athletic performance issues.

Previous studies have examined iron deficiency in youth, collegiate, and elite athletes with outcomes and author opinions both in support[7,17,18] and against[14,19] routine iron screening. By definition, screening tests are used to "determine whether an asymptomatic individual has an undetected disease or condition".[30] In the decision-making process, clinicians must weigh the cost of a diagnostic test (e.g. patient burden, health risk, monetary expense) against the probative value of the test. It has been suggested by Herman,[30] writing in the Ethics Journal of the American Medical Association, that the two major objectives of a good screening program are: (1)—detection of disease at a stage when treatment can be more effective than it would be after the patient develops signs and symptoms, and (2)—identification of risk factors that increase the likelihood of developing the disease and use of this knowledge to prevent or lessen the disease by modifying the risk factors. While iron deficiency is not a disease, for the elite athlete, it does affect an important quality of life outcome: Athletic performance. The cost to support an elite athlete can be substantial, from direct financial costs such as athlete salary, coaching and support staff salaries, travel, equipment, and university scholarships, to opportunity costs such as hours of training and time away from family.[13]

Our data demonstrate the distribution of SF levels in elite men athletes is significantly lower than the normal population of 20–28 year old men, a finding that challenges past recommenda-

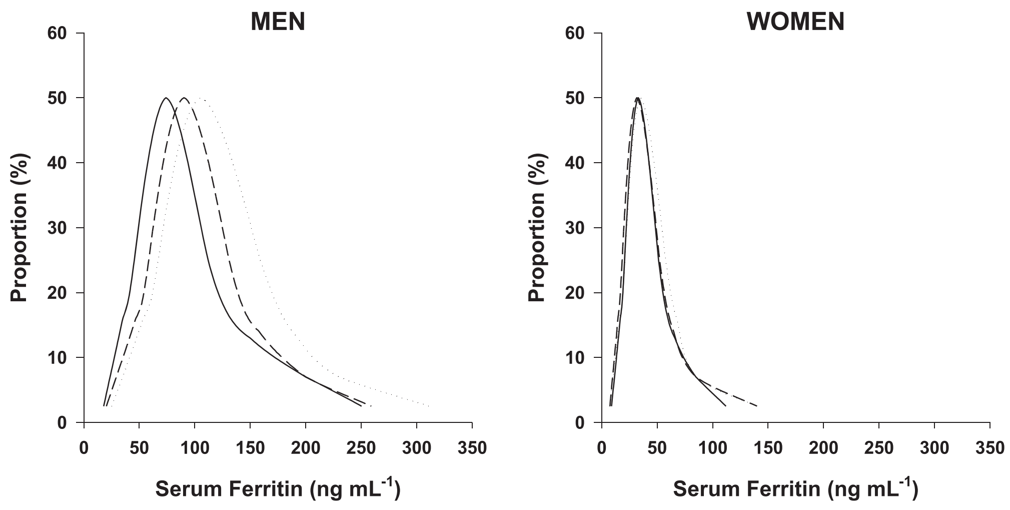

Fig. 1. (top) Distribution of serum ferritin by sex. N = number of subjects. (bottom) Cumulative probability plots of serum ferritin values in cohorts of men and women athletes and normal subjects of differing age groups. Note log scaling of the X-axis. Solid lines represent least squares regression. Values for normal subjects are taken from Von Elm et al.[21]

Table 2
Iron deficiency proportions within selected groups, utilizing various serum ferritin thresholds from the literature.

	<12 ng/mL	<20 ng/mL	<35 ng/mL	<50 ng/mL
Female				
Female athletes (N = 570)	6.8%	23.3%	52.1%[a]	72.8%[b]
Normals age 20 < 24 yrs (N = 1711)	9.2%	25.9%	57.4%	78.8%
Normals age 24 < 28 yrs (N = 2175)	8.6%	22.6%	49.3%	69.5%
Male				
Male athletes (N = 515)	0.8%	3.5%[c]	14.8%[d,e]	28.9%[d,e]
Normals age 20 < 24 yrs (N = 720)	0.4%	2.4%	9.3%	19.3%
Normals age 24 < 28 yrs (N = 1085)	0.2%	1.2%	6.1%	14.0%

N, number of subjects. Values for normal population from Custer et al.[21]
[a] Significantly different from women age 20 to <24 yrs, $p < 0.05$.
[b] Significantly different from women age 20 to <24 yrs, $p < 0.01$.
[c] Significantly different from men age 24 to <28 yrs, $p < 0.01$.
[d] Significantly different from men age 24 to <28 yrs, $p < 0.001$.
[e] Significantly different from men age 20 to <24 yrs, $p < 0.001$.

Table 3
Serum ferritin percentiles for selected groups.

Group	N	2.5%	15.9%	25%	50%	75%	84.1%	97.5%
Female athletes	570	8.9	16.7	20.7	33	51.3	64.5	112
Normals (20 to <24 yrs)	1711	7.5	14.7	18.6	31.8	52.3	65.3	128
Normals (24 to <28 yrs)	2175	7.2	16.1	21.1	35.1	57.5	71.2	140
Male athletes	515	17.9	35.0	45.5	74.0	112	141	250
Normals (20 to < 24 yrs)	720	20.4	46.7	58.6	90.2	131	155	259
Normals (24 to < 28 yrs)	1085	25.3	53.3	67.0	105	159	194	311

N, number of subjects. Values for normal population from Custer et al.[21]

tions that iron screening is not warranted in this population.[14–16] Intense physical training increases iron metabolism, which can shift iron balance towards deficiency,[25] so this outcome is not surprising. Utilizing the second criterion of Herman,[30] we believe iron screening in athletic cohorts of both sexes is justified, as being an actively training athlete and being a woman are both risk factors for developing iron deficiency.[7,18] The task then becomes satisfying Herman's first criterion, specifically to determine what SF level is the appropriate threshold for early detection of iron deficiency and treatment intervention.

We believe the data from our athlete population can be used as normative data for clinicians developing screening programs, regardless of the threshold they prefer. This is useful, as a universal criterion level for SF to denote iron deficiency and for instigating iron supplementation in athletes remains a point of debate among researchers and clinicians.[10,11,18] Ultimately, in the absence of guidelines from established clinical societies or universally accepted position papers, it remains up to the clinician to determine what SF level should trigger treatment interventions for their patients/athletes. For example, in an inquiry to 26 sports medicine facilities in Germany,[25] the lower limit of SF for intervention in women athletes ranged from values <15 ng/mL (7% of clinics), 15–25 ng/mL (43% of clinics), 26–35 ng/mL (28% of clinics) to >35 ng/mL (21% of clinics). In the same inquiry, the lower SF limit for intervention in male athletes ranged from <20 ng/mL to >40 ng/mL (21% and 14% of clinics, respectively), with other criterion values between.

To aid the discussion, we determined iron deficiency prevalence rates at four different SF criterion levels suggested in the literature as thresholds for iron supplementation treatment (Table 2), from 12 ng/mL to 50 ng/mL. For example, at <35 ng/mL, 82 out of 515 men athletes (15%) were identified as meeting the criteria for stage-one iron deficiency. By comparison, at roughly the same percentile (15.9%) in the normal men population of Custer et al., SF values were significantly different than the athlete cohort (46.7 and 53.5 ng/mL for ages 20 to <24 and 24 to <28 yrs. respectively). Contrary to our hypothesis, the distribution of SF values in our elite female athletes is nearly identical to the normal population (Fig. 1); however, over 50% of elite women athletes met the <35 ng/mL criterion threshold for stage-one iron deficiency. Additionally, SF is an acute phase reactant, which causes SF to increase disproportionately to actual bone marrow iron stores. Therefore, we would anticipate athletes to have some level of training-induced inflammation, which can inflate SF measures and decrease the number of athletes identified with suboptimal iron status.

While the reason for the blood draw was not recorded in the USOC EHR database, in the USOC clinical setting it is common for athlete labs to be ordered as part of training camps or on a routine basis for wellness screening. It is possible that some of the athletes in the population tested may have been unhealthy at the time of the blood draw. Athletes may have had previous blood draws as part of their overall health care or wellness screening and may have been supplemented at the time of the blood draw in this data set. Similarly, dietary intake of iron from food or any iron supplementation routine at the time of blood sampling was not recorded. We did not measure transferrin saturation values, which is one of three criteria (along with SF and hemoglobin concentration) used to categorize the three stages of iron deficiency[2,23] and may provide the clinician with additive information on which to base treatment decisions.

5. Conclusion

While it is established that chronic exercise training in athletes places considerable stress on multiple factors affecting iron uptake, storage and loss, it previously has not been established whether the distribution of SF levels in athletes and normal individuals are similar or different. Our SF data from the largest elite athlete cohort to appear in the literature indicates that the SF distribution is different between elite athletes and normal men. While there was no difference in the SF distribution between elite athlete and normal women, a substantial portion of both groups can be considered iron deficient. Our findings suggest that routine iron screening should be recommended in both male and female athlete populations.

Acknowledgments

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jsams.2019.12.027.

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SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

July 18, 2017

TO: Dustin Nabhan, DC

FROM: Christine Lemke, DC, Chair, Institutional Review Board, Human Subjects Protection

RE: IRB Review of project titled: Utility of Hematological and Biochemical Laboratory Testing in Elite Athletes

Dear Dr. Nabhan:

This letter confirms that the final draft, dated 6/25/17, for the above-named project has been approved through an expedited process (not convened) and meets exempted criteria, based on the following reasons:

1. The study presents minimal risk to the participants, AND
2. The participation is voluntary, AND
3. The research belongs to the following category of exempted research:
4. Research involving the collection or study of existing data sets:

    a. Research involving the collection or study of existing data sets, documents, records, or specimens, but only if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, either directly or through identifiers linked to subjects. ***Research involving one of more of these existing data sets may require you to obtain, prior to using and/or disclosing identifiable health information from the existing data set, either a HIPAA research subject authorization or a waiver of a research subject authorization granted by the SCU IRB.***

This approval is for only the study submitted and length of time as designated in the proposal, and is not subject to continued review. The current approval is for the dates 7/18/17 through 7/18/18. Extension of proposal completion date may be made by filing a continuing review application.

The application for waiver of informed consent has also been approved through an expedited process, based on the following reasons:

1. That the only record linking the participant and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality; and the

research is not FDA-regulated. In each circumstance, the participant should be asked whether they want documentation linking them with the research, and their wishes will govern; or

2. That the research presents no more than minimal risk of harm to participants and involves no procedures for which written consent is normally required outside of the research context.

The application for HIPAA Waiver has also been approved through an expedited process, based on the following reasons:

1. That the use of disclosure of PHI involves no more than a minimal risk to the privacy of individuals based on criteria i – iii below; and

    i. Adequate plan to protect the identifiers from improper use or disclosure; and

    ii. Adequate plan to destroy the identifiers at the earliest opportunity, unless retention of identifiers is required by law or is justified by research or health issues; and

    iii. Adequate written assurance that the PHI will not be used or disclosed to a third party except as required by law or permitted by an authorization signed by the research subject.

2. That the research could not practicably be conducted without the waiver or alteration; and

3. That the research could not practicably be conducted without access to and use of the protected health information.

Should the investigators wish to alter the protocol of this project in any manner for the current study (including data collection, survey format or contents, etc), or there is an alteration of any kind in the protocol from what is included in the proposed documents, the project must stop, the IRB chair notified in writing, and the protocol for this project will need to be resubmitted for review prior to continuing.

All adverse or unanticipated events should be reported to the IRB within 10 days. Unplanned, unapproved protocol deviations should also be reported to the IRB within 10 days. Forms for both of these items are available from the IRB Chair.

A completion report is due by 7/18/18 for this project or within 6 weeks of the project ending. Once your project has been finished, please email your completion report so it can be included in your project file for the IRB records. Templates of the project modification form, completion report, and continuing review, are available when you need them. If you have any questions, please do not hesitate to contact me at christinelemke@scuhs.edu.

Please print this letter for your records.

Sincerely,

Christine Lemke, DC
Chair, Institutional Review Board, Human Subjects Protection

SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

April 24, 2018

TO: Dustin Nabhan, DC

FROM: Christine Lemke, DC, Chair, Institutional Review Board, Human Subjects Protection

RE: IRB Review of project titled: A comparative effectiveness approach to maximize training availability in elite athletes.

Dear Dr. Nabhan:

This letter confirms that the final draft, submitted 11/7/2017, was approved for the period of time 10/10/2017 through 10/10/2020 with continuing review due 10/6 each year until complete. In addition, the request for modification for the above-named project has been approved.

This approval is for only the requested modifications (see below) to the prior approved study and will remain in effect for the length of time as designated in the original proposal (or request for continuation/extension if applicable), and is to be renewed annually, via application for extension/status report, through the proposed study completion date of 10/10/2020.

Modifications approved:

1. Addition of study purpose: Comparison written vs. oral patient reports of injury and illness
2. Change it procedure/protocol: Generation of deidentified data set recording the written and/or oral report of injury and illness

Should the investigators wish to alter the protocol of this project in any manner for the current study (including data collection, survey format or contents, etc), or there is an alteration of any kind in the protocol from what is included in the proposed documents, the project must stop, the IRB chair notified in writing, and the protocol for this project will need to be resubmitted for review prior to continuing.

All adverse or unanticipated events should be reported to the IRB within 10 days. Unplanned, unapproved protocol deviations should also be reported to the IRB within 10 days. Forms for both of these items are available from the IRB Chair.

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Annual status reports and requests for project continuance are due by 10/6 annually. A completion report is due by 10/10/2020 for this project or within 6 weeks of the project ending. Once your project has been finished, please email your completion report so it can be included in your project file for the IRB records. Templates of the project modification form, completion report, and continuing review, are available when you need them. If you have any questions, please do not hesitate to contact me at christinelemke@scuhs.edu.

Please print this letter for your records.

Sincerely,

Christine M. Lemke, DC

Christine Lemke, DC
Chair, Institutional Review Board, Human Subjects Protection

SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

October 6, 2017

TO: Dustin Nabhan, DC

FROM: Christine Lemke, DC, Chair, Institutional Review Board, Human Subjects Protection

RE: IRB Review of project titled: A comparative effectiveness approach to maximize training availability in elite athletes.

Dear Dr. Nabhan:

This letter confirms that the final draft, dated 7/29/2017, for the above named epidemiological data proposal has been approved through an expedited process (not convened) and meets exempted criteria, based on the following reasons:

1. The study presents minimal risk to the participants, AND
2. The participation is voluntary, AND
3. The research belongs to the following category of exempted research:
4. Research involving the collection or study of existing data sets and **data collected for non-research purposes (routine healthcare data collection):**

    a. Research involving the collection or study of existing data sets, documents, records, or specimens, but only if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, either directly or through identifiers linked to subjects. ***Research involving one of more of these existing data sets may require you to obtain, prior to using and/or disclosing identifiable health information from the existing data set, either a HIPAA research subject authorization or a waiver of a research subject authorization granted by the SCU IRB.***

This approval is for only the study submitted and length of time as designated in the proposal, and is not subject to continued review. The current approval is for the dates 10/10/2017 through 10/10/2020. Extension of proposal completion date may be made by filing a continuing review application.

The application for waiver of informed consent has also been approved through an expedited process, based on the following reasons:

1. That the only record linking the participant and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality; and the

research is not FDA-regulated. In each circumstance, the participant should be asked whether they want documentation linking them with the research, and their wishes will govern; or

2. That the research presents no more than minimal risk of harm to participants and involves no procedures for which written consent is normally required outside of the research context.

The application for HIPAA Waiver has also been approved through an expedited process, based on the following reasons:

1. That the use of disclosure of PHI involves no more than a minimal risk to the privacy of individuals based on criteria i – iii below; and

    i. Adequate plan to protect the identifiers from improper use or disclosure; and

    ii. Adequate plan to destroy the identifiers at the earliest opportunity, unless retention of identifiers is required by law or is justified by research or health issues; and

    iii. Adequate written assurance that the PHI will not be used or disclosed to a third party except as required by law or permitted by an authorization signed by the research subject.

2. That the research could not practicably be conducted without the waiver or alteration; and

3. That the research could not practicably be conducted without access to and use of the protected health information.

Should the investigators wish to alter the protocol of this project in any manner for the current study (including data collection, survey format or contents, etc), or there is an alteration of any kind in the protocol from what is included in the proposed documents, the project must stop, the IRB chair notified in writing, and the protocol for this project will need to be resubmitted for review prior to continuing.

All adverse or unanticipated events should be reported to the IRB within 10 days. Unplanned, unapproved protocol deviations should also be reported to the IRB within 10 days. Forms for both of these items are available from the IRB Chair.

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The continuing review report is due by 10/06/2017 annually. The completion report or request for continuation is due by 10/06/2020 for this project or within 6 weeks of the project ending. Once your project has been finished, please email your completion report so it can be included in your project file for the IRB records. Templates of the project modification form, completion report, and continuing review, are available when you need them. If you have any questions, please do not hesitate to contact me at christinelemke@scuhs.edu.

Please print this letter for your records.

Sincerely,

Christine Lemke, DC
Chair, Institutional Review Board, Human Subjects Protection

SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

July 1, 2019

TO: Dustin Nabhan, DC

FROM: Christine Lemke, DC, Chair, Institutional Review Board, Human Subjects Protection

RE: IRB Review of project titled: Survey of Medical Screening Methods of Elite Sport Organizations

Dear Dr. Nabhan:

This letter confirms that the final draft, dated 4/21/2019, for the above named project has been approved through an expedited process (not convened) and meets exempted criteria, based on the following reasons:

1. The study presents minimal risk to the participants, AND
2. The participation is voluntary, AND
3. The research belongs to the following category of exempted research:
    a. Research involving the use of educational tests (cognitive, diagnostic, aptitude, or achievement tests), **survey procedures**, interview procedures or observation of public behavior if:
        i. The information is gathered in such a manner that subjects cannot be identified, either directly (such as if you use photographs, video tapes, or voice recordings) or indirectly through identifiers (e.g., codes) linked to individuals; **and**
        ii. Any disclosure of the subjects' responses outside of the research will not be damaging to the subject in any way (e., subject him/her to criminal or civil liability, damage financial standing, reputation, etc).

This approval is for only the study submitted and length of time as designated in the proposal, and is not subject to continued review. The current approval is for the dates 6/30/2019 through 6/30/2020. Extension of proposal completion date may be made by filing a continuing review application.

Should the investigators wish to alter the protocol of this project in any manner for the current study (including data collection, survey format or contents, etc), or there is an alteration of any kind in the protocol from what is included in the proposed documents, the project must stop, the IRB chair notified in writing, and the protocol for this project will need to be resubmitted for review prior to continuing.

All adverse or unanticipated events should be reported to the IRB within 10 days. Unplanned, unapproved protocol deviations should also be reported to the IRB within 10 days. Forms for both of these items are available from the IRB Chair.

A completion report is due by 6/30/2020 for this project or within 6 weeks of the project ending. Once your project has been finished, please email your completion report so it can be included in your project file for the IRB records. Templates of the project modification form, completion report, and continuing

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review, are available when you need them. If you have any questions, please do not hesitate to contact me at christinelemke@scuhs.edu.

Please print this letter for your records.

Sincerely,

Christine M. Lemke, DC

Christine Lemke, DC
Chair, Institutional Review Board, Human Subjects Protection

SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

November 26, 2019

TO: Dustin Nabhan, DC,

FROM: Christine Lemke, DC, Chair, Institutional Review Board, Human Subjects Protection

RE: IRB Review of project titled: Health conditions reported by electronic pre-participation health histories in elite athletes

Dear Dr. Nabhan:

This letter confirms that the final draft, dated 11/12/2019, for the above-named project has been approved through an expedited process (not convened) and meets exempted criteria, based on the following reasons:

1. The study presents minimal risk to the participants, AND
2. The participation is voluntary, AND
3. The research belongs to the following category of exempted research:

    (4) Secondary research for which consent is not required: Secondary research uses of identifiable private information or identifiable biospecimens, if at least one of the following criteria is met:

    (i) The identifiable private information or identifiable biospecimens are publicly available;

    (ii) Information, which may include information about biospecimens, is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained directly or through identifiers linked to the subjects, the investigator does not contact the subjects, and the investigator will not re-identify subjects;

    (iii) The research involves only information collection and analysis involving the investigator's use of identifiable health information when that use is regulated under 45 CFR parts 160 and 164, subparts A and E, for the purposes of "health care operations" or "research" as those terms are defined at 45 CFR 164.501 or for "public health activities and purposes" as described under 45 CFR 164.512(b); or

    (iv) The research is conducted by, or on behalf of, a Federal department or agency using government-generated or government-collected information obtained for nonresearch activities, if the research generates identifiable private information that is or will be maintained on information technology that is subject to and in compliance with section 208(b) of the E-Government Act of 2002, 44 U.S.C. 3501 note, if all of the identifiable private information collected, used, or generated as part of the activity will be maintained in systems of records subject to the Privacy Act of 1974, 5 U.S.C. 552a, and, if applicable, the information used in the research was collected subject to the Paperwork Reduction Act of 1995, 44 U.S.C. 3501 et seq.

This approval is for only the study submitted and length of time as designated in the proposal and is not subject to continued review. The current approval is for the dates through 11/26/2019 – 11/26/2020. Extension of proposal completion date may be made by filing a continuing review application.

SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

The application for waiver of informed consent has also been approved through an expedited process, based on the following reasons:

1. That the only record linking the participant and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality; and the research is not FDA-regulated. In each circumstance, the participant should be asked whether they want documentation linking them with the research, and their wishes will govern; or
2. That the research presents no more than minimal risk of harm to participants and involves no procedures for which written consent is normally required outside of the research context.

The application for HIPAA Waiver has also been approved through an expedited process, based on the following reasons:

1. That the use of disclosure of PHI involves no more than a minimal risk to the privacy of individuals based on criteria i – iii below; and
   i. Adequate plan to protect the identifiers from improper use or disclosure; and
   ii. Adequate plan to destroy the identifiers at the earliest opportunity, unless retention of identifiers is required by law or is justified by research or health issues; and
   iii. Adequate written assurance that the PHI will not be used or disclosed to a third party except as required by law or permitted by an authorization signed by the research subject.
2. That the research could not practicably be conducted without the waiver or alteration; and
3. That the research could not practicably be conducted without access to and use of the protected health information.

Should the investigators wish to alter the protocol of this project in any manner for the current study (including data collection, survey format or contents, etc), or there is an alteration of any kind in the protocol from what is included in the proposed documents, the project must stop, the IRB chair notified in writing, and the protocol for this project will need to be resubmitted for review prior to continuing.

All adverse or unanticipated events should be reported to the IRB within 10 days. Unplanned, unapproved protocol deviations should also be reported to the IRB within 10 days. Forms for both of these items are available from the IRB Chair.

A completion report is due by 11/26/2020 for this project or within 6 weeks of the project ending. Once your project has been finished, please email your completion report so it can be included in your project file for the IRB records. Templates of the project modification form, completion report, and continuing review, are available when you need them. If you have any questions, please do not hesitate to contact me at christinelemke@scuhs.edu.

Please print this letter for your records.

SOUTHERN CALIFORNIA UNIVERSITY OF HEALTH SCIENCES

Sincerely,

Christine Lemke, DC
Chair, Institutional Review Board, Human Subjects Protection

Dustin Nabhan // Preventive medicine in elite sport: the role of the periodic health evaluation