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JSAMS-1738; No. of Pages 6
ARTICLE IN PRESS
Journal of Science and Medicine in Sport xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Journal of Science and Medicine in Sport
journal homepage: www.elsevier.com/locate/jsams

Original research

Poor anaerobic power/capability and static balance predicted prospective musculoskeletal injuries among Soldiers of the 101st Airborne (Air Assault) Division

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ARTICLE INFO

Article history:
Received 20 April 2017
Received in revised form 11 October 2017
Accepted 14 October 2017
Available online xxx

Keywords:
Risk factors
Physiological
Neuromuscular
Musculoskeletal
Predictors

ABSTRACT

Musculoskeletal injuries have negatively impacted tactical readiness. The identification of prospective and modifiable risk factors of preventable musculoskeletal injuries can guide specific injury prevention strategies for Soldiers and health care providers.

Objectives: To analyze physiological and neuromuscular characteristics as predictors of preventable musculoskeletal injuries.

Design: Prospective-cohort study.

Methods: A total of 491 Soldiers were enrolled and participated in the baseline laboratory testing, including body composition, aerobic capacity, anaerobic power/capacity, muscular strength, flexibility, static balance, and landing biomechanics. After reviewing their medical charts, 275 male Soldiers who met the criteria were divided into two groups: with injuries (INJ) and no injuries (NOI). Simple and multiple logistic regression analyses were used to calculate the odds ratio (OR) and significant predictors of musculoskeletal injuries ($p < 0.05$).

Results: The final multiple logistic regression model included the static balance with eyes-closed and peak anaerobic power as predictors of future injuries ($p < 0.001$).

Conclusions: The current results highlighted the importance of anaerobic power/capacity and static balance. High intensity training and balance exercise should be incorporated in their physical training as countermeasures.

1. Introduction

The military recognizes that musculoskeletal injuries have become costly to force readiness and healthcare budgets.[1] Musculoskeletal injury frequency among Soldiers of the US Army's 101st Airborne (Air Assault) Division has been investigated through self-reports and medical chart reviews and revealed common anatomic sub-locations for injuries (the lower extremity and low back) and common types of injuries (pain, sprains, and strains) in this group.[2,3] Understanding modifiable risk factors for common musculoskeletal injuries in military is an integral part of the comprehensive injury prevention research model; it could lead to the implementation of evidence-based intervention programs and result in a significant reduction in musculoskeletal injuries.[3–5]

Specifically, these modifiable risk factors include physiological, neuromuscular, balance, and biomechanical characteristics.[3] Previous studies have indicated that suboptimal body composition has negative impacts on several of these characteristics, including both aerobic and anaerobic capacity, while also influencing injury risk.[6,7] Similarly, lower aerobic capacity has revealed injury risk within the military.[8–10] These findings are likely explained by the fact that Soldiers or athletes with less physical fitness are prone to fatigue earlier and cannot tolerate high training volume/intensity, resulting in alterations in the neuromuscular control and diminished ability to achieve functional joint stability.[11]

Strength, flexibility, landing biomechanics, and balance characteristics in combination with intrinsic factors and physiological attributes can compound injury risk in military, particularly in the lower extremity, shoulder, and back.[12,13] Isokinetic strength

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https://doi.org/10.1016/j.jsams.2017.10.023
1440-2440/

Please cite this article in press as: Nagai T, et al. Poor anaerobic power/capability and static balance predicted prospective musculoskeletal injuries among Soldiers of the 101st Airborne (Air Assault) Division. *J Sci Med Sport* (2017), https://doi.org/10.1016/j.jsams.2017.10.023

deficits have shown to be prospective risk factors for overuse knee injuries, knee joint trauma, and muscle strains of the thigh.[14,15] For the upper extremity, the strength of an injured rotator cuff was weaker than that of the injured counterparts.[16] Detriments in trunk strength were predictors of core and lower extremity sprains and strains and low back injuries in collegiate athlete populations.[17,18]

Decreased flexibility was related to lower extremity injury,[19] tendinopathy,[20,21] and shoulder conditions[22,23] within military and athletic cohorts. Landing biomechanics/technique was identified as a risk factor of ACL injury in female athletes.[24] Another study demonstrated altered landing biomechanics with additional combat gear among Soldiers, highlighting the importance of this domain.[25] Reduced balance was predictive of ankle injuries in professional athletes.[26]

There is a major gap in the current literature. The aforementioned physiological and neuromuscular prospective injury risk factors have rarely been examined collectively in a single prospective-cohort study, making it difficult for researchers and military leaders to select one or two field-expedient tests to assess Soldiers' potential injury risk and design intervention programs. The purpose of this study was to analyze physiological and neuromuscular characteristics as predictors of preventable musculoskeletal injuries. It was hypothesized that Soldiers with injuries would have reduced physiological and neuromuscular characteristics, as measured at baseline.

2. Methods

This study is a prospective cohort study comparing baseline physiological characteristics, muscular strength, flexibility, balance, and landing biomechanics between Soldiers who ultimately developed at least one preventable musculoskeletal injury and those who did not develop injuries within a year after baseline tests. All baseline testing was performed at the University of Pittsburgh Human Performance Research Center at Fort Campbell, Kentucky. Testing was performed on two separate days, with at least 24 h between test days. The subject's approval was obtained from the respective civilian and military Institutional Review Boards. Investigators explained the study and went over consent forms and HIPAA authorization forms with volunteering subjects prior to data collection and accessing their medical charts, respectively. All forms were signed by the participants. There were over 20,000 Soldiers in the 101st Airborne Division (Air Assault). The baseline tests took place in 2007, 2008, and 2009, and their medical records were accessed in 2008, 2009, and 2010, respectively, 1 year after their baseline tests. Study participants/volunteers were recruited through flyers, briefings in front of each unit, and orientation. A total of 491 Soldiers consented and completed the baseline testing.

The participants' medical charts were electronically assessed for musculoskeletal injuries by medical officers using the Armed Forces Health Longitudinal Technology Application. A musculoskeletal injury is operationally defined as an injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc.).[2] Preventable injuries are operationally defined as those musculoskeletal injuries that can be reduced through injury prevention programs that are developed to improve neuromuscular and physiological characteristics related to musculoskeletal injury risk.[2] Of the 491 Soldiers' medical charts reviewed, depending on their medical charts, Soldiers with a previous history of any injuries or medical conditions up to 2 years prior to testing or Soldiers who sustained non-preventable musculoskeletal injuries such as motor vehicle accidents, direct trauma, and falls, or other medical conditions were excluded from this analysis (n = 183). Of 308 Soldiers, there were total 179 (162 males/17 females) Soldiers who ultimately did not develop an injury within the year following the baseline tests (NOI) and 129 (113 males/16 females) Soldiers who ultimately developed at least one injury within the year following the baseline tests (INJ). Because of a small number of female Soldiers (17 in NOI and 16 in INJ) in the study and potential gender differences in musculoskeletal characteristics, only data of male Soldiers were used in this study. Therefore, there were a total of 162 male Soldiers in the NOI group (age: 26.9 ± 6.0 years, height: 176.7 ± 6.7 cm, weight: 81.0 ± 13.0 kg) and 113 male Soldiers in the INJ group (age: 27.1 ± 6.1 years, height: 176.8 ± 7.7 cm, weight: 82.6 ± 13.2 pounds).

Baseline testing included body composition, anaerobic power/capacity, aerobic capacity, muscular strength, flexibility, balance, and landing biomechanics. Body composition, expressed as percent body fat (%BF), was measured by air displacement plethysmography (Bod Pod Body Composition System, Cosmed, Italy).[7] Aerobic capacity (VO_{2max}) was measured during an incremental treadmill protocol using a portable metabolic system (Oxycon Mobile; Viasys, San Francisco, California) and heart rate monitor (Polar USA, Lake Success, New York).[3,5] Subjects performed a warm-up at a self-selected pace on the treadmill for 5 min before testing. The treadmill test protocol started after warm-up and was completed when volitional fatigue occurred.[3,5] Aerobic capacity was normalized to body weight (ml/kg/min) to evaluate differences in aerobic fitness between subjects.

Anaerobic power and capacity were measured using an electronically braked Velotron cycling ergometer (Racermate, Seattle, Washington) during a Wingate protocol.[3,5] After warming up at a self-selected pace, subjects pedaled at 100 RPM at 125 W for 20 s and then performed a maximal effort sprint for 30 s against a braking torque of 9% body weight. Anaerobic power was reported as the peak watts normalized to body weight (w/kg) during the first 5 s of the test, and anaerobic capacity was reported as the average watts normalized to body weight produced during the entire 30 s (w/kg).

Isokinetic strength of the shoulder internal/external rotation, trunk rotation, and knee flexion/extension muscles were measured using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Shirley, New York).[3,5] The subject performed three practice trials at 50% maximal effort and three warm-up trials at maximal effort, followed by 1 min of rest. Peak isokinetic torque was then recorded across five maximal effort repetitions (concentric/concentric at 60°/s) and reported normalized to percent body weight (%BW). Isometric strength of the ankle inversion/eversion muscles were measured using the hand-held dynamometer (Lafayette Instruments, Lafayette, IN). Similar to other strength testing, the subjects warmed up first and then took three maximal effort trials. The average peak force values (kg) were normalized to percent body weight (%BW) for statistical analysis.

For flexibility measurement, passive range of motion of the shoulder internal/external rotation, extension, and posterior tightness and hip extension were assessed using the same procedures as previously.[3,5] Active range of motion of the trunk rotation, knee extension, and ankle dorsiflexion/plantarflexion were also assessed.[3,5] Range of motion in degrees was reported as the average of three trials for each side.

Balance and biomechanical data were collected and analyzed using a Vicon motion capture system (Vicon, Centennial, CO, USA) and two Kistler (Kistler Corp, Amherst, New York) force plates, with sampling frequencies of 200 and 100 Hz, respectively.[3,5] Single-leg balance was assessed on a single force plate, eyes open and eyes closed, barefoot, and with hands on hips, for three 10-s trials on each foot.[3,5] Standard deviations of the ground reaction forces (in Newtons) in the anterior–posterior, medial–lateral, and vertical directions were used for statistical analyses.[3,5] A double-leg stop-jump task was used to assess landing kinematics at the hip and knee.[3,5] Subjects were instructed to perform a standing broad jump onto the force plates from a distance of 40% of the participant's