

SYSTEMATIC REVIEW OF THE ASSOCIATION BETWEEN PHYSICAL FITNESS AND MUSCULOSKELETAL INJURY RISK: PART 3—FLEXIBILITY, POWER, SPEED, BALANCE, AND AGILITY

SARAH J. DE LA MOTTE, ATC,¹ PETER LISMAN, ATC,^{1,2} TIMOTHY C. GRIBBIN, ATC,¹ KAITLIN MURPHY, MS,¹ AND PATRICIA A. DEUSTER, PHD, MPH¹

¹Consortium for Health and Military Performance, Uniformed Services University of the Health Sciences, Bethesda, Maryland; and ²Department of Kinesiology, Towson University, Towson, Maryland

ABSTRACT

de la Motte, SJ, Lisman, P, Gribbin, TC, Murphy, K, and Deuster, PA. Systematic review of the association between physical fitness and musculoskeletal injury risk: part 3—flexibility, power, speed, balance, and agility. *J Strength Cond Res* 33(6): 1723–1735, 2019—We performed a systematic review and evaluation of the existing scientific literature on the association between flexibility, power, speed, balance, and agility, and musculoskeletal injury (MSK-I) risk in military and civilian populations. MEDLINE, EBSCO, EMBASE, and the Defense Technical Information Center were searched for original studies published from 1970 to 2015 that examined associations between these physical fitness measures (flexibility, power, speed, balance, and agility) and MSK-I. Methodological quality and strength of the evidence were determined after criteria adapted from previously published systematic reviews. Twenty-seven of 4,229 citations met our inclusion criteria. Primary findings indicate that there is (a) moderate evidence that hamstring flexibility, as measured by performance on a sit-and-reach test or active straight leg raise test assessed with goniometry, and ankle flexibility, assessed with goniometry, are associated with MSK-I risk; (b) moderate evidence that lower body power, as measured by performance on a standing broad jump or vertical jump with no countermovement, is associated with MSK-I risk; (c) moderate evidence that slow sprint speed is associated with MSK-I risk; (d) moderate evidence that poor performance on a single-leg balance test is associated with increased risk for ankle sprain; and (e) insufficient evidence that agility is associated

with MSK-I risk. Several measures of flexibility, power, speed, and balance are risk factors for training-related MSK-I in military and civilian athletic populations. Importantly, these findings can be useful for military, first responder, and athletic communities who are seeking evidence-based metrics for assessing or stratifying populations for risk of MSK-I.

KEY WORDS military, athletes, first responders, risk factors, injury

INTRODUCTION

Musculoskeletal injury (MSK-I) remains a significant health problem for all active populations (24,37,43) despite it being mostly preventable through primary and secondary prevention strategies. Improving physical fitness, including cardiorespiratory endurance, muscular strength, muscular endurance, and flexibility, power, speed, balance, and agility, shows promise in the ability to affect high rates of MSK-I (1,27,34,40). However, current evidence regarding the relationships among MSK-I and specific components of physical fitness in military and athletic populations is mixed (1,21,22,27,29,32,34,40).

To effectively prevent MSK-I, specific modifiable risk factors must first be understood, and then targeted. Injury prevention programs commonly include exercises that focus on flexibility, power, speed, balance, and agility, and when properly conducted and adhered to, have been shown to reduce injury (35,41,42). However, the ability of such measures to predict risk has yet to be firmly established.

The Consortium for Health and Military Performance conducted a systematic review to evaluate existing scientific literature regarding the association between physical fitness components and MSK-I in military and civilian athletic populations. Although the review was conducted in support of the US Army Training and Doctrine Command's initiative to develop and validate baseline physical performance assessments for all US Army Soldiers, independent of age

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (<http://journals.lww.com/nsca-jscr>).

Address correspondence to Peter Lisman, plisman@towson.edu.

33(6)/1723–1735

Journal of Strength and Conditioning Research
© 2017 National Strength and Conditioning Association

and sex, the results should be useful for civilian communities as well. This article is the last in a 3-part series written from this review. In parts 1 and 2 of our series, we focused on cardiorespiratory endurance (31) and muscular strength and endurance (8). Here, the authors review the literature on the relationship of MSK-I in military and active civilian populations to several remaining components of fitness: flexibility, power, speed, balance, and agility.

METHODS

Experimental Approach to the Problem

Search Strategy. After the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see checklist, Supplemental Digital Content 1, <http://links.lww.com/JSCR/A66>), we conducted a systematic review of the research literature to evaluate published, peer-reviewed studies, and military technical reports examining the association between components of physical fitness and the risk of sustaining an MSK-I in a military or civilian population between the ages of 18 and 65 (see PRISMA flow diagram, Supplemental Digital Content 2, <http://links.lww.com/JSCR/A67>). In consultation with a research librarian, the following databases were searched for relevant articles published from 1970 to December 2015: MEDLINE, EBSCO, EMBASE, and the Defense Technical Information Center. A combination of the following search items was used to capture all relevant studies: “injury,” “musculoskeletal diseases,” “musculoskeletal injury,” “sprain,” “strain,” “fracture,” “athletic injury,” “dislocation,” “tendonitis,” “bursitis,” “fasciitis,” “joints,” “risk assessment,” “injury prevention,” “attrition,” “physical fitness,” “exertion,” “physical endurance,” “physical education,” “training,” “exercise intervention,” “physical exercise,” “flexibility,” “muscular strength,” “muscular endurance,” “muscular power,” “aerobic fitness,” “aerobic capacity,” “aerobic power,” “anaerobic fitness,” “anaerobic capacity,” “anaerobic power,” “speed,” “balance,” “agility,” “maximal oxygen consumption,” “maximum oxygen consumption,” “ $\dot{V}O_2$ Max,” “ $\dot{V}O_2$ Peak,” “military personnel,” “emergency medical technician,” “athletes,” “dancer,” “emergency responder,” “police,” “firefighter,” “soldier,” “army,” and “navy.” The search was last performed in February 2016. This brief review was approved by Towson University.

Study Inclusion/Exclusion Criteria

Included articles met the following criteria: original research; full-text available; populations aged 18–65; reported measures of physical fitness; study outcomes included acute/traumatic (e.g., dislocation, fracture, sprain/strain, etc.) or overuse (e.g., stress fractures, tendonitis, bursitis, etc.) MSK-I (36); and a reported measure of association with injury (e.g., odds, hazard, risk or rate ratio). Musculoskeletal injury was defined as an event that resulted in damage to the musculoskeletal system for which the subject visited a medical care provider or went to the emergency room (28). Publications were excluded if (a) injury data reported were

related to heat or cold injuries, animal bites, or other non-musculoskeletal MSK-I; (b) injury data were self-report in nature; (c) study populations were composed of children, elderly, or adults with ill health or physically/mentally disabled; or (d) studies were systematic reviews, literature reviews, case studies, or case series in design.

Data Abstraction

Data extraction was split among the study investigators, with articles evenly divided among the authors. Relevant data were independently extracted using a standardized set of abbreviations and reporting methods and finally compiled in a single database. Data abstraction categories included population characteristics: MSK-I type and assessment, fitness components measured, fitness measurement tests, statistical analysis performed, and the reported odds, risk, or hazard ratios of injury with and without adjustments.

Methodological Quality Assessment

Each study was assessed for methodological quality using one of 2 modified assessments from Bullock et al. (5) (see quality assessments, Supplemental Digital Content 3, <http://links.lww.com/JSCR/A68>). The assessment tools were composed of 3 sections: (a) problem (1 item); (b) study design and methodology (6 items); and (c) data presentation and statistical analysis (4 items). Each question was scored from 0 to 2, with a maximum total score of 22. After initial scoring, the investigators met to compare scores and a discussion ensued (in cases of disagreement) until consensus was reached.

As all studies received maximum points for clearly identifying the research problem, scores were converted to a 20-point scale and expressed as a percentage. Studies were then ranked according to their methodological quality based on percentage of total possible points, resulting in the following groups: (a) poor (below 70th percentile: ≤ 13.5 points); (b) fair (70–79th percentile: 14–15.5 points); (c) good (80–89th percentile: 16–17.5 points); or (d) excellent (90th percentile and above: > 18 points).

Assessment of Evidence Summary—Strength of the Evidence

Studies that found significant crude or adjusted associations between measures of flexibility, power, speed, balance, and agility were distinguished from those that did not with symbols representing the level and direction of association. Significant associations between low levels of flexibility, power, speed, balance, and agility (less fit), and elevated MSK-I risk with univariate and multivariate analyses were denoted by the symbols “+” and “++,” respectively, whereas associations between high levels of flexibility, power, speed, balance, and agility (more fit), and elevated MSK-I risk were noted with “→” and “→ →”. Next, the overall strength of the evidence was compiled and rated after criteria adapted from previous systematic reviews (5,6,19). The level of evidence for the relationship between flexibility, power, speed, balance,

and agility, and MSK-I was ultimately determined to be as follows:

- Strong: three studies of at least good methodological quality or at least 2 studies of excellent methodology with consistent multivariate findings
- Moderate: consistent results from 2 studies of good methodology or one study of excellent methodology with multivariate findings
- Limited: one study of good or fair methodological quality with multivariate findings and multiple studies of good methodology with univariate findings
- Insufficient: results from studies of exclusively poor methodology and no evidence from multivariate analyses in excellent quality studies

RESULTS

Search Results

The database search yielded 4,229 articles. In addition, 5 potential articles were identified from a manual search and subject matter expert recommendations. After duplicates were removed, the 3,321 remaining articles were divided alphabetically into 4 groups (one group per author). The titles and abstracts were reviewed for inclusion or exclusion, and full-text articles were retrieved if exclusion could not be determined by title and abstract alone, or if the article passed the first eligibility screening. After preliminary review for inclusion, 234 full-text articles were reviewed for associations between MSK-I and one or more fitness components. Ultimately, 27 articles met final inclusion criteria for this systematic review and reported the association between MSK-I and flexibility, power, speed, balance, or agility in military or athletic populations. The primary reasons for exclusion were (a) no objective assessment of fitness; (b) outcome data not specific to MSK-I; and (c) statistical analyses did not include measures of association, such as odds, hazard, or risk ratios.

Characteristics of Included Studies

Sixteen of the 27 studies (59.3%) investigated the association between MSK-I and fitness (flexibility, power, speed, and balance) in athletic populations, 9 (33.3%) were composed of military cohorts, and one each (3.7%) was composed of Federal Bureau of Investigation trainees or foreign physical education students. Of the 16 studies composed of athletic populations, 5 included collegiate athletes, 3 each were composed of Australian football or professional soccer players, 2 each included Australian rugby or professional hockey players, and one study included male volleyball players. Five of the 9 military studies were composed of basic training populations. Of the 27 studies, 25 (92.5%) used a prospective cohort study design, and one each used a retrospective cohort or nonrandomized control study design. Nineteen studies (70.4%) included only male participants, 2 (7.4%) were limited to female participants, and 6 (22.2%) studies included both male and female participants.

Twelve of the 27 articles (44.4%) examined multiple components within the same study. The most commonly investigated components in order were flexibility (18 studies; 67.7%), power (11 studies; 40.7%), speed, and balance (5 studies each; 18.5%). Our search did not yield any studies that investigated the association between agility and MSK-I and met our inclusion criteria.

Musculoskeletal Definitions and Injury Ascertainment

Most studies (15 of 27; 55.6%) used a broad definition of MSK-I and reported “acute/traumatic” and/or “overuse” injury as their outcome variable. Eleven studies (40.7%) specified a particular anatomical site and/or injury of interest, including ankle injuries ($n = 4$), hamstring ($n = 4$), or hip adductor/groin strains ($n = 2$), and Achilles tendon overuse injury ($n = 1$). Last, one study investigated “contact injury” in Australian professional rugby players. Injury data were obtained directly from health care professionals responsible for the medical care of the athletic teams or military members in 20 studies (74.1%), whereas 6 studies (22.2%) obtained injury data from review of medical records and/or electronic administrative clinical encounter databases. One study obtained injury data using uniform injury-reporting forms filled out by the coaching staff.

Methodological Quality

Four studies were categorized as “excellent,” 14 were classified as “good,” 8 were categorized as “fair,” and one had “poor” methodological quality. The mean quality score \pm SD of the studies was 16.1 ± 1.6 , ranging from 14 to 19. Strengths of most studies were noted in the 4 items categorized in the data presentation and statistical analysis section. By contrast, weaknesses of some studies were noted in the study design and methodology category. The most common items receiving either partial or no credit in order were (a) failure to state whether a power analysis was conducted, (a) inadequate description of the source of subjects including inclusion and exclusion criteria, and (c) insufficient inclusion of relevant confounders in the data collection. Table 1 provides a summary of the study characteristics, quality ratings and scores, and outcomes and directions of associations for all studies of “excellent” and “good” methodological quality that investigated the association between flexibility and MSK-I. Table 2 presents these results for all studies of “excellent” and “good” methodological quality that investigated the association between MSK-I and power, speed, and balance. Supplemental Digital Content 4 (see Table, <http://links.lww.com/JSCR/A69>) presents results for all studies of “fair” and “poor” methodological quality that investigated the association between flexibility and MSK-I while Supplemental Digital Content 5 (see Table, <http://links.lww.com/JSCR/A70>) presents these results for studies that examined the association between MSK-I and power, speed, and balance. Studies were grouped into tables by physical fitness measures; therefore, studies that investigated the association between

TABLE 1. Study methodological characteristics and results for the association between flexibility and MSK-I.*

Author, country, population	Quality rating (score)	Sample size	Follow-up	MSK-I type	Flexibility measurement	Strength of association							
						Crude association	Association with adjustments	Direction of association					
Quadriceps and Hip Arnason et al. (2), Iceland, Pro Soccer	Good (16.5)	$M = 249$	4 mo	A/T & O	Thomas test	No data provided	NS	≠					
					Passive knee flexion	NS	NS	≠					
					Passive hip abduction	No data provided	NS	≠					
Gabbe et al. (12), Australia, Football (community level)	Good (17)	$M = 126$	1 season	Hamstring injury	Modified Thomas test	–	Greater quad flexibility: RR = 0.3 (0.1–0.8, $p = 0.02$) [†]	++					
					Active hip ER & IR	–	NS	≠					
Knapik et al. (25), USA, College Athletes	Good (16)	$F = 138$	3 y	A/T & O	Active hip extension	Right/left asymmetry >15%: RR = 2.63 ($p < 0.001$)	NS	+					
					Active knee flexion	NS	NS	≠					
					Active hip ER	NS	NS	≠					
					Active hip abduction	NS	NS	≠					
Hamstring Arnason et al. (2), Iceland, Pro Soccer	Good (16.5)	$M = 249$	4 mo	A/T & O	Passive knee extension	NS	NS	≠					
					Bell et al. (4), USA, Army (BCT)	Good (16.5)	$M = 509$ $F = 352$	8 wk	A/T & O	Sit-and-reach	–	NS	≠
					Cowan et al. (7), USA Army (BCT)	Good (17)	$M = 303$	13 wk	A/T & O	Sit-and-reach	NS	Most flexible quintile: OR = 2.88 (1.16–7.17) Least flexible quintile: OR = 3.30 (1.33–8.18)	– ++
Gabbe et al. (12), Australia, Football (community level)	Good (17)	$M = 126$	1 season	Hamstring injury	Active knee extension	–	NS	≠					
					Passive SLR	–	NS	≠					
					Sit-and-reach	–	NS	≠					
Henderson et al. (20), England, Pro Soccer	Good (16.5)	$M = 36$	1 season	Hamstring injury	Active SLR	–	Increased AROM: OR = 0.77 (0.62–0.97, $p = 0.02$)	++					
					Passive SLR	–	NS	≠					

Knapik et al. (25), USA, College Athletes	Good (16)	$F = 138$	1 y	A/T & O	Active hip flexion	NS	NS	≠
Knapik et al. (28), USA, Army (BCT)	Good (17)	$M = 169$	8 wk	A/T & O	Sit-and-reach	Least flexible: RR = 2.4 (1.1–5.0, $p =$ 0.02)	NS	+
Reynolds et al. (38), USA, Army	Good (16.5)	$F = 164$ $M = 181$	1 y	A/T & O	Sit-and-reach	NS	NS	≠
Yeung et al. (52), China, Amateur & College Sprinters	Good (17)	Total = 44 ($M =$ 35; $F = 9$)	1 y	Hamstring injury	Passive SLR	–	NS	≠
Ankle								
Fousekis et al. (10), Greece, Pro Soccer	Good (17)	$M = 100$	10 mo	Ankle sprain	Active DF	–	NS	≠
Gabbe et al. (12), Australia, Football (community level)	Good (17)	$M = 126$	1 season	Hamstring injury	Active PF	–	NS	≠
					DF lunge‡	–	NS	≠
Knapik et al. (25), USA, College Athletes	Good (16)	$F = 138$	1 y	A/T & O	Active DF	NS	NS	≠
Mahieu et al. (33), Belgium, Army (BCT)	Good (17)	$M = 69$	6 wk	Achilles tendon (overuse)	Active DF (knee extended)	–	NS	≠
					Passive DF (knee extended)	–	Increased Passive DF: OR = 1.23 (1.03– 1.46, $p = 0.02$)	--
					Active DF (knee 45° flex)	–	NS	≠
					Passive DF (knee 45° flex)	–	NS	≠
					Active PF (knee extended)	–	NS	≠
					Passive PF (knee extended)	–	NS	≠
					Active PF (knee 45° flex)	–	NS	≠
					Passive PF (knee 45° flex)	–	NS	≠

(continued on next page)

Teyhen et al. (45), USA, Army	Excellent (18)	M = 188	1 y	A/T & O	DF lunge‡	-	Right/left asymmetry ≥6.5°; Comprehensive Injury Index: OR = 4.1 (1.4–11.7); Overuse Injury Index: OR = 5.0 (1.6–15.5)	++
Other Measures of Flexibility								
Gabbe et al. (12), Australia, Football (community level)	Good (17)	M = 126	1 season	Hamstring injury	Active lumbar spine extension	-	NS	≠

*. - = Significant multivariate association between high levels of flexibility and increased MSK-I risk; + = Significant univariate association between low levels of flexibility and increased MSK-I risk; ++ = Significant multivariate association between low levels of flexibility and increased MSK-I risk; ≠ = No significant association; A/T & O = Acute/Traumatic & Overuse; BCT = basic combat training; DF = dorsiflexion; ER = external rotation; F = Female; FLEX = flexion; IR = internal rotation; M = Male; MSK-I = musculoskeletal injury; NS = nonsignificant; OR = odds ratio; PF = plantarflexion; ROM = range of motion; RR = risk ratio; SLR = straight leg raise.
 †Knee flexion >51° at decreased risk of injury.
 ‡Assessment of ankle joint DF ROM in weight-bearing position.

several measures of fitness and MSK-I are listed more than once.

EVIDENCE SUMMARY—STRENGTH OF EVIDENCE

Flexibility

Hip and Quadriceps Flexibility. Seven studies investigated the association between hip or quadriceps flexibility and MSK-I in athletic populations (2,9,11,12,25,48,50), 2 of which were composed of women only (25,50). Assessments of hip flexibility consisted primarily of active range of motion measured with goniometry in any of the 6 possible directions for the hip (2,9,11,12,25,48,50), whereas quadriceps (namely rectus femoris) flexibility was assessed with either the modified (11,12) or standard Thomas test (2,48). One additional study used a prone knee flexion measure to assess quadriceps flexibility (2). In one study of good methodological quality, greater quadriceps flexibility, as determined by a modified Thomas test, was found to be an independent risk factor for hamstring injury occurrence in Australian rules football players; players with greater flexibility were 70% less likely to suffer a hamstring injury than those with poor flexibility (12). An additional study of good methodological quality reported a significant univariate association between active hip extension asymmetry (right-to-left, >15%) and MSK-I in female collegiate athletes (25). Overall, the evidence supporting the association between hip and/or quadriceps flexibility and MSK-I is limited.

Hamstring Flexibility. Ten studies investigated the association between hamstring flexibility and MSK-I; of these, 6 included athletic populations (2,11,12,20,25,52), whereas 4 were composed of military cohorts (4,7,28,38) and 3 of which were basic training populations (4,7,28). Four studies specifically looked at hamstring injury risk (11,12,20,52), whereas the remaining 6 studies used any acute/traumatic or overuse injury as their outcome of interest (2,4,7,25,28,38). Assessments of hamstring flexibility included a sit-and-reach test (6 studies) (4,7,11,12,28,38), active (2 studies) (11,12) or passive knee extension (1 study) (2), and active (2 studies) (20,25) or passive (3 studies) (12,20,52) straight leg raise (SLR) tests. One study of good methodological quality reported a multivariate association between performance on a sit-and-reach test and incidence of MSK-I in male US Army basic trainees; recruits with the highest and lowest hamstring flexibility were 2.9 and 3.3 times more likely to suffer a hamstring injury compared with those with average flexibility (7). Another study of good methodological quality reported that poor hamstring flexibility, as determined performance on a SLR test measured with a goniometer, was an independent risk factor for hamstring injury in English professional soccer players; athletes with lower flexibility had roughly a 30% greater risk of injury than those with higher flexibility measurements (20). Finally, an additional study of good methodological quality reported a univariate association between poor hamstring flexibility and elevated MSK-I

TABLE 2. Study methodological characteristics and results for the association between power, speed, balance, and MSK-I.*

Author, country, population	Quality rating (score)	Sample size	Follow-up	MSK-I type	Fitness test	Strength of association		
						Crude association	Association with adjustments	Direction of association
Power								
Arnason et al. (2), Iceland, Pro Soccer	Good (16.5)	M = 217	4 mo	A/T & O	Squat†	NS	NS	≠
					Vertical jump‡	NS	NS	≠
					CMJ	NS	NS	≠
					Single-leg CMJ	NS	NS	≠
Gabbett et al. (13), Australia, Sub-elite Rugby	Excellent (18)	M = 153	1 to 4 seasons	A/T & OS	CMJ	-	NS	≠
Grant et al. (17), USA, Hockey	Excellent (18)	M = 79	8 successive seasons	A/T & O	CMJ	NS	NS	≠
Henderson et al. (20), England, Pro Soccer	Good (16.5)	M = 36	1 season	Hamstring injury	Vertical jump‡	-	Increased jump height: OR = 1.47 (1.02–2.21)	- -
					CMJ	-		NS
Knapik et al. (28), USA, Army (BCT)	Good (17)	M = 182 F = 168	8 wk	A/T & O	CMJ	NS	NS	≠
					CMJ	NS	NS	≠
Mahieu et al. (33), Belgium, Army (BCT)	Good (17)	M = 69	6 wk	Achilles tendon (overuse)	Standing broad jump	-	NS	≠
Roos et al. (39), Switzerland, Army (BCT)	Good (16)	M = 619	21 wk	A/T & O	Standing broad jump	NS	-	≠
					Seated shot put	NS	-	≠
Taanila et al. (44), Finland, Military	Good (17)	M = 1,411	180 d	A/T & O	Standing broad jump	Shortest quartile: Severe acute: HR = 3.3 (1.5–7.1) Overuse: HR = 1.6 (1.2–2.0) Severe overuse: HR = 2.3 (1.5–3.6)	Shortest quartile: Severe acute: HR = 2.8 (1.2–6.4) Severe overuse: HR = 1.8 (1.1–3.0)	++
Teyhen et al. (45), USA, Army	Excellent (18)	M = 188	1 y	A/T & O	Triple cross-over hop	NS	NS	≠
Speed								

(continued on next page)

Gabbett et al. (13), Australia, Sub-elite Rugby	Excellent (18)	$M = 153$	1 to 4 seasons	A/T & O§	10-m sprint	-	Lower speed: OR = 10.28 (1.40–75.67, p = 0.022)	++
					40-m sprint	-	Lower speed: OR = 9.93 (1.30–75.62, p = 0.027)	++
Knapik et al. (26), USA, FBI trainees	Good (17)	$M = 426$ $F = 105$	21 wk	A/T & O	300-m sprint	Slowest quartile: HR = 1.71 (1.03–2.84, p = 0.04)	Slowest 2 quartiles: HR = 1.84 (1.31–3.00, p = 0.01); HR = 1.75 (1.01–3.04, p < 0.01)	++
						Slowest tertile: HR = 2.23 (1.06– 4.70, p = 0.04)	NS	+
Balance								
Roos et al. (39), Switzerland, Army (BCT)	Good (16)	$M = 619$	21 wk	A/T & O	Single leg balance test¶	NS	-	≠
Teyhen et al. (45), USA, Army	Excellent (18)	$M = 188$	1 y	A/T & O	Y-balance test	NS	NS	≠
Trojjan et al. (47), USA, College athletes	Excellent (19)	Total = 230 (M = 150; F = 80)	1 season	Ankle sprain	Single leg balance test	Positive SLB test#: RR = 2.43 (1.15– 5.14)	Positive SLB test#: OR = 2.54 (1.0d2–6.03, p ≤ 0.05)	++

*- = Significant multivariate association between high levels of power, speed, or balance and increased MSK-I risk; - = Significant univariate association between high levels of power, speed, or balance and increased MSK-I risk; + = Significant univariate association between low levels of power, speed, or balance and increased MSK-I risk; ++ = Significant multivariate association between low levels of power, speed, or balance and increased MSK-I risk; ≠ = No significant association; A/T & O = Acute/Traumatic & Overuse; BCT = basic combat training; CMJ = countermovement jump; F = Female; HR = hazard ratio; M = Male; MSK-I = musculoskeletal injury; NS = non-significant; OR = odds ratio; RR = risk ratio.

‡Maximal average power measured during extension phase of a squat (tests performed with external loads of 20, 40, 60, and 80 kg).

‡Standing jump (participant bent knees to 90°, paused for 1–3 s, then extended knees and hips with no countermovement of the trunk or knee permitted).

§Injuries included all injuries and contact injuries.

||Odds of sustaining a hamstring injury increased with every additional 1 cm achieved in vertical jump test.

¶Assessed single-leg balance duration (average and right-to-left asymmetry).

#Test performed with eyes closed for duration of 10 s. Positive test defined as participant describing a sense of imbalance or displaying an inability to perform the test on either or both legs without error.

risk in male but not female US Army basic trainees (28). Collectively, there is moderate evidence supporting the association between hamstring flexibility and MSK-I risk, although the exact direction of the association cannot be stated.

Ankle Flexibility. Eight studies investigated the association between ankle flexibility and MSK-I. Five of the 8 studies were composed of athletic populations (10–12,18,25), 2 were military cohorts (33,45), and one included college physical education students (50). The most commonly performed ankle flexibility assessment was non-weight-bearing active dorsiflexion (DF) (5 studies) (10,18,25,33,50) and plantarflexion (PF) (4 studies) (10,18,33,50) measured with a goniometer. One of these studies (33) obtained both DF and PF measurements with the knee in 2 positions, 45° of flexion and extended, while another measured DF in both knee positions and included a measurement of subtalar inversion and eversion (50). Three additional studies used a weight-bearing measure of DF, which was obtained during a forward lunge (11,12,45). Injury outcomes for these studies included ankle sprains (3 studies) (10,18,50), hamstring injury (2 studies) (11,12), Achilles tendon overuse injury (1 study) (33), and any MSK-I (2 studies) (25,45). One study of excellent methodological quality reported a multivariate association between ankle DF asymmetry and incidence of MSK-I in male US Army Rangers; Rangers with asymmetry $\geq 6.5^\circ$ were 4.0 and 5.1 times more likely to suffer any and overuse MSK-Is, respectively, than those without asymmetry (45). Another study of good methodological quality reported that increased passive DF ROM was an independent risk factor for overuse Achilles tendon injuries; Belgian Army basic trainees with increased DF ROM were 1.2 times more likely to suffer an injury than those with less ROM (33). Overall, there is moderate evidence supporting the association between ankle flexibility and MSK-I risk, although the exact direction of the association cannot be stated.

Other Measures of Flexibility. Three studies investigated additional measures of flexibility not previously discussed, including lumbar spine extension ROM from standing (12), metatarsal phalangeal joint flexion and extension ROM (50), and the TIGHT score (30), which assessed overall muscle tightness by combining measures of flexibility for the iliopsoas, iliotibial band, hamstring, rectus femoris, and gastrocnemius muscles. In one study of fair methodological quality, collegiate athletes with a higher TIGHT score, which signified greater muscular tightness, were 1.2 times more likely to suffer a MSK-I than those with lower scores (30). Based on this study alone, the evidence supporting the association between other measures of flexibility and MSK-I is limited.

Power

Eleven studies investigated the association between power and MSK-I (2,13–15,17,20,28,33,39,44,45). Five of the 11

studies were conducted in military populations (28,33,39,44,45), with 3 during basic training (28,33,39). The most commonly performed power assessment was the countermovement vertical jump (CMJ) (6 studies) (2,13,14,17,20,28); other assessments of lower body power included the standing broad jump (3 studies) (33,39,44), vertical jump without countermovement (2 studies) (2,20), weighted jump squat (2 studies) (14,15), single-leg CMJ (2), weighted squat (2), and triple cross-over hop for distance (45) (1 study each). Upper body power assessments included the bench press throw (14) and seated shot (39) put (1 study each) while total body power was assessed with the Olympic clean (17) and power clean (14) (1 study each). Two studies of good methodological quality reported that lower body power, as measured by a standing broad jump or vertical jump with no countermovement, was an independent risk factor for injury when considered in the multivariate models (20,44). Finnish conscripts with shorter standing broad jump distances were 2.8 and 1.8 times more likely to suffer severe acute and overuse injuries, respectively, than those with longer jump distances (44). By contrast, professional soccer players who jumped higher during a vertical jump with no countermovement test were 1.5 times more likely to suffer a hamstring injury than those with lower jump heights (20). Collectively, moderate evidence supports the association between lower body power and MSK-I risk, although the exact direction of the association cannot be stated.

Speed

Five studies investigated the association between speed and risk of MSK-I (13–15,26,49); only one study included women (26) or was comprised of a military population (49). Speed assessments included sprints of varying length—from 10 to 300 m. In one study of excellent methodological quality, slower sprint speeds on 10- and 40-m sprints were both found to be independent risk factors for MSK-I in Australian rugby players; athletes with low 10- and 40-m speeds were 10.3 and 9.9 times more likely to be injured than those with faster speeds (13). Similarly, a study of good methodological quality reported a multivariate association between slower speed on a 300-m sprint and incidence of injury in male FBI trainees and a univariate association in female trainees (26). Consequently, there is moderate evidence that slower sprint speed is associated with increased MSK-I risk.

Balance

Five studies investigated the association between balance and MSK-I, with 2 each composed of athletic (18,47) or military populations (39,45) and one collegiate physical education student (50). Three studies investigated ankle sprains as their sole injury outcome (18,47,50). Two studies used instrumented measures of balance (i.e., stability limits as assessed by the Neurocom Balance Master or force plate measures) (18,50), whereas 3 others used clinical assessments, such as the single-leg balance test (39,47), which measured static balance, and the Y-balance test (45), an assessment of

dynamic balance. One study of excellent methodological quality reported a multivariate association between single-leg balance test performance and incidence of ankle sprains in male and female collegiate athletes; athletes who failed the test, as determined by an inability to maintain single-leg balance without error on both legs for 10 seconds, were 2.5 times more likely to suffer an ankle sprain vs. those who passed (47). Consequently, there is moderate evidence supporting an association between poor balance and eventual ankle sprain injury.

DISCUSSION

Physical fitness is a broad concept that includes many different components. This paper specifically focused on 5 important but often neglected components that might be associated with MSK-I: flexibility, power, speed, balance, and agility. Based on our synthesis of the evidence, our primary findings were that there is (a) moderate evidence that hamstring flexibility, as measured by performance on a sit-and-reach test or active straight leg raise test assessed with goniometry, and ankle flexibility, assessed with goniometry, are associated with MSK-I risk; (b) moderate evidence that lower body power, as measured by performance on a standing broad jump or vertical jump with no countermovement, is associated with MSK-I risk; (c) moderate evidence that slow sprint speed is associated with risk for MSK-I; (d) moderate evidence that poor performance on a single-leg balance test is associated with increased risk for ankle sprain; and (e) insufficient evidence that agility is associated with MSK-I risk. Notably, our search did not yield any studies that investigated the association between agility and MSK-I and met our inclusion criteria.

Our examination of the scientific literature led to several interesting findings. First, slower sprint speed was positively associated with increased risk for injury in both rugby players (13) and FBI trainees (26). Notably, sprint speeds were measured across both short (10 and 40 m) and long (300 m) distances. The reason that slower times were associated with increased risk is unclear, but speed may be a surrogate for aerobic fitness, and the evidence for associations between MSK-I risk and aerobic fitness is strong (31). In FBI trainees, Cox regression analyses determined the slowest 2 quartile-sustained MSK-I at greater rates compared with the fastest. Those with slower 1.5-mile run times and lower overall physical fitness test scores were also at increased risk (26), which again is consistent with the findings for our systematic review on cardiorespiratory endurance (31).

The finding with balance is also of interest, but the specific measures used seem to be important as well: clinical performance measures which are noninstrumented and require little or no equipment vs. those instrumented requiring specialized equipment. A meta-analysis by Arnold et al. (3) found poorer noninstrumented balance (foot lifts during a static balance task and the Star Excursion Balance Test) and instrumented measures (time to stabilization and

other force plate measures) to be highly associated with chronic ankle instability, but no study outside of the current review has systematically examined balance in nonpathologic populations within our search and inclusion criteria. For the purposes of this study, poor balance as measured by noninstrumented tasks in collegiate athletes was associated with greater risk of ankle sprain (47), whereas no such association was noted for the instrumented tests investigating ankle sprain (18,50). Performance-based noninstrumented measures of balance are widely used and easy to implement but do not identify the underlying mechanisms of balance impairments, meaning instrumented assessments still remain relevant. The expediency and ease of use of clinical balance measures, together with the moderate level of evidence, make for an attractive assessment in prospectively examining ankle sprain risk. However, as all balance studies looked at ankle sprain outcomes, we cannot generalize these findings to other types of MSK-I.

The moderate yet conflicting evidence for hamstring and ankle flexibility and injury also warrants further discussion. More than half (6 of 10; 60%) of the studies on hamstring flexibility used a broad MSK-I definition as their outcome (2,4,7,25,28,38), whereas 4 specifically studied hamstring injury (11,12,20,52). Only one of these was significant, albeit in a small sample of male professional soccer players, with results revealing an association between greater hamstring flexibility as measured by performance on an active SLR test and decreased injury risk (20). By contrast, one study reported a bimodal association between hamstring flexibility, as measured by sit-and-reach test performance and injury risk (acute or overuse injury) in male basic trainees (7). Similar findings of conflicting directions of association were found with regard to ankle ROM and risk of injury in military populations (33,45). For ankle flexibility, ankle dorsiflexion active ROM asymmetry was found to be a significant predictor of MSK-I risk in US Army Rangers (45), whereas greater DF-passive ROM was associated with elevated risk of overuse Achilles tendon injuries in Belgian basic trainees (33). Although it is routinely accepted that poor flexibility is related to increased injury risk and stretching is widely recommended as an injury prevention practice, the evidence remains equivocal on the influence of flexibility on training and sport-related injury (16,23,46,51). Authors have suggested that muscles with less compliant musculo-tendinous units (low level of flexibility) are more susceptible to strains during stretch-shortening cycles (16,51), which are especially potent and frequent during sport- and training-related jumping and sprinting activities. By contrast, proposed explanations for studies relating high levels of flexibility to increased injury risk include the potential effects ROM has on decreasing overall joint stability and positioning joints in positions where static (ligaments) and dynamic (muscle) stabilizing tissues are more prone to sprain or strain when loaded (46). Given the findings for both hamstring and ankle flexibility/ROM, it is

clear that future research investigating the potential link between flexibility and injury is warranted.

Similar to flexibility, results from this review revealed inconsistent findings related to the association between power and injury risk (2,13,17,20,28,33,39,44,45). Professional soccer players who demonstrated increased vertical jump height were at greater risk for hamstring injury (20). As most hamstring injuries occur with explosive movements within this sport, this finding is not wholly surprising. It is reasonable to suggest that athletes who generated greater explosive force production, as measured by performance on a non-countermovement jump test, were more likely to achieve greater limb accelerations and decelerations during play, which may have increased their risk for hamstring injury. By contrast, Taanila et al. (44) reported that lower levels of lower body power, as measured by standing broad jump performance, were predictive of acute and chronic injury in a large cohort of Finnish military conscripts. Given this test requires both vertical and horizontal displacement during performance, higher levels of both power and motor control are needed for successful jump completion. These factors, in addition to the population tested and use of a broad injury definition (all acute and overuse injuries), may help explain the relationship found. Conscripts with lower levels of lower body power and motor control may have perceived formal physical and field training exercises, such as obstacle courses and runs/marches over various terrains, as more difficult and thus had an increased likelihood for injury. Given these collective findings, future studies may want to further investigate associations between various measures of power and injury across a multitude of populations.

This systematic review has several limitations, many of which have been presented in parts 1 and 2 of this series (8,31). For instance, an important limitation is that some studies may have been missed from the current literature search. Our search strategy used broad injury search terms (e.g., “injury,” “musculoskeletal injury,” “sprain,” “strain,” etc.) and thus may not have captured all relevant literature measuring the association between fitness components (flexibility, power, speed, balance, and agility) and a specific injury and/or injury to a particular anatomical location. Consequently, future systematic reviews and meta-analyses that use search terms specific to particular injuries and/or anatomical locations are warranted to investigate these potential associations. Furthermore, we excluded all studies with injury data that were self-report in nature due to the potential variance in both validity and reliability of self-reported injury outcome measures across studies. Investigators may also want to include self-report measures of injury in future systematic reviews albeit taking into consideration the reliability and validity characteristics of self-report injury assessments.

Specific to this study, an important limitation was the number of various assessments used to measure each

component of fitness, which made comparing fitness components across studies difficult. Ultimately, this limitation led to numerous additional questions. For example—hamstring flexibility can be measured in different ways—are the ones used assessing flexibility or range of motion? What is the best assessment for upper and lower body power? Should a standardized noninstrumented measure of balance be used? As suggested, a major limitation was that we made a number of assumptions to try to bring the literature into a coherent framework, and our assumptions could be challenged. However, this is an attempt to help develop a scientific approach to synthesizing the vast and diverse literature, so the results can be applied in practical ways. Finally, we modified previous methodological scoring rubrics and developed our own level of evidence determinations for this study. Both these metrics were modified from previously published systematic reviews and both were made specific to our questions of interest. However, as these are new measures, the measurement properties of each could be questioned.

PRACTICAL APPLICATIONS

This is the last in a 3-part series of articles that systematically reviewed the evidence and assessed the quality of relevant scientific literature published on physical fitness and MSK-I among military and civilian populations. Findings from this article indicate that several measures of flexibility, power, speed, and balance are moderately associated with increased risk for MSK-I. Notably, our results also revealed conflicting directions of association for the relationships between both flexibility and power, and injury risk. When results from this entire series of reviews are considered, several important findings emerge. First, it is important to note that this review was conducted in support of the US Army Training and Doctrine Command’s initiative to develop and validate baseline physical performance assessments for all US Army Soldiers, independent of age and sex. Given that most studies were conducted in military populations, many of the assessments used to measure components of physical fitness were specific to military training, particularly branch-specific physical fitness tests. Consequently, the most frequently reported fitness components were cardiorespiratory endurance and muscular endurance, which were commonly assessed with set distances run for time, and push-up and sit-up tests. Our review also revealed that studies assessing the relationship between muscular strength, flexibility, power, speed, and agility, and MSK-I were more scarce, and in the case of agility, non-existent. It is clear that further study on these associations and their implications for injury prevention programming is warranted. Despite this disparity in the quantity of reviewed studies examining the various components of fitness, we believe our results can still be of use for military, first responder, and athletic communities who are seeking evidence-based metrics for assessing or risk-stratifying populations or individuals for risk of MSK-I. Second, our results indicate that the scientific literature supports the association

between low levels of cardiorespiratory endurance and muscular endurance, especially of the upper body, and increased MSK-I risk. The evidence is particularly strong because it pertains to the relationship between low CRE and injury; therefore, including an assessment of CRE when stratifying these populations for injury risk is advised. Finally, although much work remains with regard to prioritizing what measures would be most useful in various situations and across multiple populations, selected tests presented in this series of articles could be used now to help mitigate injury risk by providing countermeasures to improve functional limitations.

ACKNOWLEDGMENTS

The authors report no conflicts of interest. The opinions or assertions contained herein are the private ones of the author(s) and are not to be construed as official or reflecting the views of the Uniformed Services University, Department of the Army, Department of the Air Force, Department of the Navy or the United States Department of Defense.

REFERENCES

- Almeida, SA, Maxwell, WK, Shaffer, RA, Luz, JT, Badong, KE, and Brodine, SK. A physical training program to reduce musculoskeletal injuries in U.S. Marine Corps recruits. San Diego, CA: Center NHR, 1997.
- Arnason, A, Sigurdsson, SB, Gudmundsson, A, Holme, I, Engebretsen, L, and Bahr, R. Risk factors for injuries in football. *Am J Sports Med* 32: 5S–16S, 2004.
- Arnold, BL, De La Motte, S, Linens, S, and Ross, SE. Ankle instability is associated with balance impairments: A meta-analysis. *Med Sci Sports Exerc* 41: 1048–1062, 2009.
- Bell, N, Amoroso, P, Hemenway, D, Mangione, T, and Jones, B. *Race and Injury Among Army Basic Trainees*. Natick, MA: Defense Technical Information Center, 1994. Available at: <http://www.dtic.mil/docs/citations/ADA306072>. Accessed March 1, 2014.
- Bullock, SH, Jones, BH, Gilchrist, J, and Marshall, SW. Prevention of physical training-related injuries recommendations for the military and other active populations based on expedited systematic reviews. *Am J Prev Med* 38: S156–S181, 2010.
- Bulzacchelli, MT, Sulsky, SI, Rodriguez-Monguio, R, Karlsson, LH, and Hill, MO. Injury during U.S. Army basic combat training: A systematic review of risk factor studies. *Am J Prev Med* 47: 813–822, 2014.
- Cowan, D, Jones, B, Tomlinson, P, Robinson, J, Polly, D, Frykman, P, and Reynolds, K. *The Epidemiology of Physical Training Injuries in U.S. Army Infantry Trainees: Methodology, Population, and Risk Factors*. Natick, MA: Defense Technical Information Center, 1988. Available at: <http://www.dtic.mil/dtic/tr/fulltext/u2/a206551.pdf>. Accessed March 1, 2014.
- de la Motte, SJ, Gribbin, TC, Lisman, P, Murphy, K, and Deuster, PA. A systematic review of the association between physical fitness and musculoskeletal injury risk: Part 2—muscular endurance and muscular strength. *J Strength Cond Res* 31: 3218–3234, 2017.
- Emery, CA and Meeuwisse, WH. Risk factors for groin injuries in hockey. *Med Sci Sports Exerc* 33: 1423–1433, 2001.
- Fousekis, K, Tsepis, E, and Vagenas, G. Intrinsic risk factors of noncontact ankle sprains in soccer: A prospective study on 100 professional players. *Am J Sports Med* 40: 1842–1850, 2012.
- Gabbe, BJ, Bennell, KL, and Finch, CF. Why are older Australian football players at greater risk of hamstring injury?. *J Sci Med Sport* 9: 327–333, 2006.
- Gabbe, BJ, Finch, CF, Bennell, KL, and Wajswelner, H. Risk factors for hamstring injuries in community level Australian football. *Br J Sports Med* 39: 106–110, 2005.
- Gabbett, TJ and Domrow, N. Risk factors for injury in subelite rugby league players. *Am J Sports Med* 33: 428–434, 2005.
- Gabbett, TJ, Ullah, S, and Finch, CF. Identifying risk factors for contact injury in professional rugby league players—application of a frailty model for recurrent injury. *J Sci Med Sport* 15: 496–504, 2012.
- Gastin, PB, Meyer, D, Huntsman, E, and Cook, J. Increase in injury risk with low body mass and aerobic-running fitness in elite Australian football. *Int J Sports Physiol Perform* 10: 458–463, 2015.
- Gleim, GW and McHugh, MP. Flexibility and its effects on sports injury and performance. *Sports Med* 24: 289–299, 1997.
- Grant, JA, Bedi, A, Kurz, J, Bancroft, R, Gagnier, JJ, and Miller, BS. Ability of preseason body composition and physical fitness to predict the risk of injury in male collegiate hockey players. *Sports Health* 7: 45–51, 2015.
- Hadzic, V, Sattler, T, Topole, E, Jarnovic, Z, Burger, H, and Dervisevic, E. Risk factors for ankle sprain in volleyball players: A preliminary analysis. *Isokinet Exerc Sci* 17: 155–160, 2009.
- Hegedus, EJ, McDonough, S, Bleakley, C, Cook, CE, and Baxter, GD. Clinician-friendly lower extremity physical performance measures in athletes: A systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med* 49: 642–648, 2015.
- Henderson, G, Barnes, CA, and Portas, MD. Factors associated with increased propensity for hamstring injury in English Premier League soccer players. *J Sci Sport Med* 13: 397–402, 2010.
- Hootman, JM, Macera, CA, Ainsworth, BE, Martin, M, Addy, CL, and Blair, SN. Association among physical activity level, cardiorespiratory fitness, and risk of musculoskeletal injury. *Am J Epidemiol* 154: 251–258, 2001.
- Hootman, JM, Macera, CA, Ainsworth, BE, Martin, M, Addy, CL, and Blair, SN. Predictors of lower extremity injury among recreationally active adults. *Clin J Sport Med* 12: 99–106, 2002.
- Jones, BH and Knapik, JJ. Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations. *Sports Med* 27: 111–125, 1999.
- Kerr, ZY, Marshall, SW, Dompier, TP, Corlette, J, Klossner, DA, and Gilchrist, J. College sports-related injuries—United States, 2009–10 through 2013–14 academic years. *MMWR Morb Mortal Wkly Rep* 64: 1330–1336, 2015.
- Knapik, JJ, Bauman, CL, Jones, BH, Harris, JM, and Vaughan, L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *Am J Sports Med* 19: 76–81, 1991.
- Knapik, JJ, Grier, T, Spiess, A, Swedler, DI, Hauret, KG, Graham, B, Yoder, J, and Jones, BH. Injury rates and injury risk factors among Federal Bureau of Investigation new agent trainees. *BMC Public Health* 11: 920, 2011.
- Knapik, JJ, Scott, SJ, Sharp, MA, Hauret, KG, Darakjy, S, Rieger, WR, Palkoska, FA, VanCamp, SE, and Jones, BH. The basis for prescribed ability group run speeds and distances in U.S. Army basic combat training. *Mil Med* 171: 669–677, 2006.
- Knapik, JJ, Sharp, MA, Canham-Chervak, M, Hauret, K, Patton, JF, and Jones, BH. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc* 33: 946–954, 2001.
- Knapik, JJ, Swedler, DI, Grier, TL, Hauret, KG, Bullock, SH, Williams, KW, Darakjy, SS, Lester, ME, Tobler, SK, and Jones, BH. Injury reduction effectiveness of selecting running shoes based on plantar shape. *J Strength Cond Res* 23: 685–697, 2009.
- Krivickas, LS and Feinberg, JH. Lower extremity injuries in college athletes: Relation between ligamentous laxity and lower extremity muscle tightness. *Arch Phys Med Rehabil* 77: 1139–1143, 1996.

31. Lisman, PJ, de la Motte, SJ, Gribbin, TC, Jaffin, DP, Murphy, K, and Deuster, PA. A systematic review of the association between physical fitness and musculoskeletal injury risk: Part 1- cardiorespiratory endurance. *J Strength Cond Res* 31: 1744–1757, 2017.
32. Macera, CA, Jackson, KL, Hagenmaier, GW, Kronenfeld, JJ, Kohl, HW, and Blair, SN. Age, physical activity, physical fitness, body composition, and incidence of orthopedic problems. *Res Q Exerc Sport* 60: 225–233, 1989.
33. Mahieu, NN, Witvrouw, E, Stevens, V, Van Tiggelen, D, and Roget, P. Intrinsic risk factors for the development of Achilles tendon overuse injury: A prospective study. *Am J Sports Med* 34: 226–235, 2006.
34. Nindl, BC, Williams, TJ, Deuster, PA, Butler, NL, and Jones, BH. Strategies for optimizing military physical readiness and preventing musculoskeletal injuries in the 21st century. *US Army Med Dep J*: 5–23, 2013.
35. Noyes, FR and Barber Westin, SD. Anterior cruciate ligament injury prevention training in female athletes: A systematic review of injury reduction and results of athletic performance tests. *Sports Health* 4: 36–46, 2012.
36. O'Connor, FG, Deuster, PA, Davis, J, Pappas, CG, and Knapik, JJ. Functional movement screening: Predicting injuries in officer candidates. *Med Sci Sports Exerc* 43: 2224–2230, 2011.
37. Pitts, SR, Niska, RW, Xu, J, and Burt, CW. National Hospital Ambulatory Medical Care Survey: 2006 emergency department summary. *Natl Health Stat Report*: 1–38, 2008.
38. Reynolds, KL, Heckel, HA, Witt, CE, Martin, JW, Pollard, JA, Knapik, JJ, and Jones, BH. Cigarette smoking, physical fitness, and injuries in infantry soldiers. *Am J Prev Med* 10: 145–150, 1994.
39. Roos, L, Boesch, M, Sefidan, S, Frey, F, Mader, U, Annen, H, and Wyss, T. Adapted marching distances and physical training decrease recruits' injuries and attrition. *Mil Med* 180: 329–336, 2015.
40. Schwellnus, MP, Jordaan, G, and Noakes, TD. Prevention of common overuse injuries by the use of shock absorbing insoles. A prospective study. *Am J Sports Med* 18: 636–641, 1990.
41. Steffen, K, Emery, CA, Romiti, M, Kang, J, Bizzini, M, Dvorak, J, Finch, CF, and Meeuwisse, WH. High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: A cluster randomised trial. *Br J Sports Med* 47: 794–802, 2013.
42. Sugimoto, D, Myer, GD, Bush, HM, Klugman, MF, Medina McKeon, JM, and Hewett, TE. Compliance with neuromuscular training and anterior cruciate ligament injury risk reduction in female athletes: A meta-analysis. *J Athl Train* 47: 714–723, 2012.
43. Swenson, DM, Yard, EE, Fields, SK, and Comstock, RD. Patterns of recurrent injuries among US high school athletes, 2005–2008. *Am J Sports Med* 37: 1586–1593, 2009.
44. Taanila, H, Suni, JH, Kannus, P, Pihlajamaki, H, Ruohola, JP, Viskari, J, and Parkkari, J. Risk factors of acute and overuse musculoskeletal injuries among young conscripts: A population-based cohort study. *BMC Musculoskelet Disord* 16: 104, 2015.
45. Teyhen, DS, Shaffer, SW, Butler, RJ, Goffar, SL, Kiesel, KB, Rhon, DI, Williamson, JN, and Plisky, PJ. What risk factors are associated with musculoskeletal injury in US Army rangers? A prospective prognostic study. *Clin Orthop Relat Res* 473: 2948–2958, 2015.
46. Thacker, SB, Gilchrist, J, Stroup, DF, and Kimsey, CD Jr. The impact of stretching on sports injury risk: A systematic review of the literature. *Med Sci Sports Exerc* 36: 371–378, 2004.
47. Trojjan, TH and McKeag, DB. Single leg balance test to identify risk of ankle sprains. *Br J Sports Med* 40: 610–613, 2006.
48. Tyler, TF, Nicholas, SJ, Campbell, RJ, and McHugh, MP. The association of hip strength and flexibility with the incidence of adductor muscle strains in professional ice hockey players. *Am J Sports Med* 29: 124–128, 2001.
49. Wang, X, Wang, PS, and Zhou, W. Risk factors of military training-related injuries in recruits of Chinese People's Armed Police Forces. *Chin J Traumatol* 6: 12–17, 2003.
50. Willems, TM, Witvrouw, E, Delbaere, K, Philippaerts, R, De Bourdeaudhuij, I, and De Clercq, D. Intrinsic risk factors for inversion ankle sprains in females—a prospective study. *Scand J Med Sci Sports* 15: 336–345, 2005.
51. Witvrouw, E, Mahieu, N, Danneels, L, and McNair, P. Stretching and injury prevention: An obscure relationship. *Sports Med* 34: 443–449, 2004.
52. Yeung, SS, Suen, AMY, and Yeung, EW. A prospective cohort study of hamstring injuries in competitive sprinters: Preseason muscle imbalance as a possible risk factor. *Br J Sports Med* 43: 589–594, 2009.