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Original research

Trunk endurance, posterior chain flexibility, and previous history of musculoskeletal pain predict overuse low back and lower extremity injury: a prospective cohort study of 545 Navy Cadets

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ABSTRACT

Objective: To investigate predictors of low back and lower extremity musculoskeletal injury in a cohort of Naval cadets.
Design: Prospective Cohort Study
Methods: 545 Naval cadets (Males, n = 394, 72%) were followed-up over eight months. Nine variables were investigated as predictors: history of musculoskeletal symptoms in the last 12 months, ankle dorsiflexion range of motion, sit and reach test, isometric hip abduction and external rotation strength, alignment during the single leg squat test, single leg hop test for distance, prone plank and side plank tests. All injuries that required medical attention were registered. Predictive associations were examined using univariable and multivariable logistic regression analyses.
Results: The incidence of all injuries was 7%. Cadets who failed the 60-second plank test (OR = 3.3; 95% CI, 1.2−8.8, P = 0.04), had ≤18 cm in the sit and reach test (OR = 4.0; 95% CI, 1.4−11.2, P = 0.01), or reported pain in the last 12 months in two or more body regions (OR = 2.7; 95% CI, 1.02−7.3, P = 0.04), had greater odds of sustaining an overuse injury. No predictors were identified for acute injuries.
Conclusion: Decreased trunk endurance on the prone plank test, reduced posterior chain flexibility on the sit and reach test, and a history of pain reported in two or more sites in the last 12 months were predictors of overuse injuries in Naval cadets. Assessment and intervention of these modifiable risk factors may be clinically relevant in injury screening and prevention.

1. Introduction

Non-fatal musculoskeletal injuries to military service members have monumental financial, health, and performance impacts.[1,2] In the United States alone, these injuries are the foremost contributor to servicemen disability, account for US$500−700 million in direct patient care costs, and amount to an excess of 25 million limited-duty days.[2] Beginning servicemen are especially susceptible to injury during the basic training program phase because of sudden spikes in physical activity.[3] These injuries largely affect the low back and lower extremities, possibly due to the high volumes of marching, jumping, and running activities during basic training.[2,3] To complement the urgent need to reduce risk of future injuries, further elucidation of trunk and lower extremity injury aetiology and risk factors in beginning servicemen are necessary.

Several modifiable and non-modifiable risk factors for injuries have been previously identified, including age,[4,5] sex,[4,5] previous injury,[6] reduced ankle dorsiflexion flexibility,[6] reduced lower limb and trunk and hip strength and endurance,[7–9] and reduced performance in hop testing distance.[10] However, most of these risk factors have been identified in isolation and in cohorts not generalizable to the navy. The naval cohort is unlike other military cohorts and general sporting athletes because the wide-ranging terrestrial and maritime environments the navy operates in attracts incoming

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cadets across a broad physical fitness continuum with no homogeneity in prior physical preparation.[11] Therefore, the goal of this study is to identify a field-expedient and naval-cohort specific test battery that can predict future trunk and lower extremity injury risk in naval cadets. This test battery will combine previously identified variables including injury history screening, anthropometric measurements, flexibility assessment, biomechanics, and strength measurements.[12]

2. Methods

This prospective cohort study was conducted at the Brazilian Naval School. Participants were 688 incoming Navy cadets (516 males) in the 2016 academic year undergoing an eight month training program. Data were collected at the beginning of the academic year. All cadets followed the same weekly physical training routine. Inclusion criteria were: over 18 years, no lower extremity surgery in the last 12 months, no current trunk or lower extremity pain, and no medical or neuromusculoskeletal disorders that would limit participation in the assessment. The study was approved by the Naval Hospital's ethical committee and participants gave their written consent.

Participants were followed-up for eight months. Injuries, defined as any pain or physical injury (illness excluded) to the low back and lower extremities that led cadets to seek medical care from a medical doctor or a physiotherapist at the academy's health clinic, were recorded as per the International Classification of Diseases (ICD-10) guidelines. These records were provided to the main author weekly. The injuries were further classified into acute or overuse injuries. Acute injuries were non-contact injuries due to trauma, while overuse injuries were characterized by pain with an insidious onset.[13]

Personal characteristics such as date of birth, sex, and their 12-month lower extremity and lower back pain history were obtained from a questionnaire. Participants then underwent the following tests: ankle dorsiflexion range of motion (ROM), sit and reach test, isometric abduction hip abduction and external rotation strength, alignment during the single leg squat test, single leg hop test for distance, prone plank and side plank tests. Details, including the validity and reliability, of each test have been presented in a previous paper, and will only be briefly mentioned here.[12] The order of the unilateral tests was cluster randomized, with all participants for each day assigned the same starting limb (right or left) on which to commence all unilateral tests for that day. Tests were conducted by nine experienced exercise physiologists and physiotherapists, each allocated to the same station throughout the entire data collection period.

For the sit and reach test, participants sat down on the floor with knees extended, positioned their feet against and placed one hand on top of the other.[12] They were then instructed to flex their trunk to reach the most distant point with their fingertips while keeping their knees extended (Appendix A). We collected three trials and averaged the best two for analysis. Ankle dorsiflexion ROM was assessed using a digital inclinometer (Baseline, Fabrication Enterprises Inc, White Plains, NY) through the weight-bearing lunge test.[14] Participants were positioned facing the wall and kept their tested foot and heel on the floor while they lunged forward and moved their knee toward the wall. The maximum ankle dorsiflexion ROM was measured by placing the inclinometer on the Achilles tendon's midpoint.[15] The average of three measures were included in the analysis. Previous studies have reported a very high intra and inter-rater reliability for the weight-bearing lunge test[14] and the sit and reach test.[16]

A calibrated hand-held dynamometer (Lafayette Manual Muscle Tester Model 01163; IN, USA) was used to assess hip abductor and external rotator isometric strength. Reliability and testing set-up for supine hip abduction and sitting external rotation tests have been previously described (Appendix B).[12,17] Participants had one practice trial at submaximal effort followed by three maximal voluntary isometric contractions of five seconds each with five seconds rest in between each trial. Raw scores were normalized to body weight. For statistical analysis, Hip Strength Asymmetry Index (HSAI) was calculated as (weaker hip strength/stronger hip) x 100, with strength being determined by the maximum force measured.[18]

Knee frontal plane projection angle (FPPA) was assessed on the single-leg squat test.[19] Participants were instructed to stand on one leg on a "T" marked on the ground, with their foot aligned with the vertical line and the hallux positioned right before the horizontal line. With hands on their hips and the contralateral knee flexed to 90º, participants were asked to bend their knee and squat until the knee crossed the horizontal line on the "T" (~50º of knee flexion).[19] Participants performed two practice trials followed by five squat repetitions for each leg. A video camera (Logitech C920x Pro HD Webcam) fixed on a tripod three meters away and directly in front of the participant was used to capture images at 1080p and 30fps. FPPA was calculated from the videos of the participant's dominant leg using a movement analysis software (Kinovea version 0.8. 15; www.kinovea.org) where the ASIS of the pelvis, the mid-point between the medial and lateral femoral epicondyles and the halfway inter-malleoli location were used as visual landmarks.[19] Knee FPPA was calculated by subtracting the angle at the beginning of the squat from the angle at maximum knee flexion. The average of the final three trials were used for analysis.

For the single-leg hop test, participants were instructed to stand on one leg behind a starting line marked out on the floor and instructed to hop forward as far as possible (Appendix A).[20,21] To reduce injury risk and to assess lower limb power but not balance, participants were instructed to push-off with one leg and land with both legs. The hop distance was measured from the starting line to the heel of the rearmost leg. The mean of the three trials of each leg was normalized to participant's height.[20] Between-leg asymmetry was measured through the Limb Symmetry Index (LSI) and calculated by dividing the lowest single-leg hop result by the highest single-leg hop result and multiplying by 100.[20]

The prone and side plank tests were used to assess trunk endurance (Appendix C). For the plank test, participants were instructed to support their body weight, keeping their forearms and feet on the floor with elbows positioned at 90° of flexion underneath the shoulders, while hip and neck were maintained in a neutral position.[22] The protocol used by Tong et al.[22] was adapted by placing a pair of vertical parallel pipes connected by a horizontal elastic string in order to standardize our assessment and avoid unwanted movement compensations. Tests were ended if participants maintained the required position for 60 s, or if the pelvis dropped below the reference string after two consecutive warnings.

For the anthropometric measurements, means and standard deviations (SD) were calculated. Injury incidence proportion was calculated by dividing the number of injured cadets by the total number of cadets and multiplying the value by 100.[5] Normality was tested using Q-Q plots, whereas outliers were tested by inspecting a boxplot for values greater than 1.5 box lengths from the edge of the box. Data were presented as mean values and SD. Regarding the sit and reach test, as data were normally distributed, an independent T-test was used to determine whether a difference existed between sexes. Nevertheless, for the plank test and side plank test, as data were not normally distributed, the nonparametric Mann-Whitney U-test was performed to determine whether there were differences between sexes. We used the dominant limb in unilateral tests, since there was no difference between limbs in a previous study.[12]

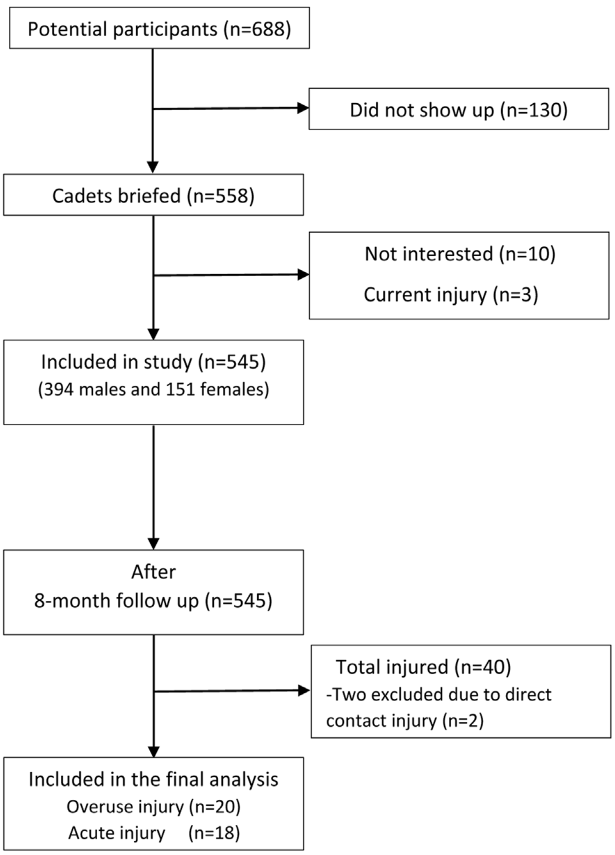

Fig. 1. Flow of participants during the study.

To determine predictors (independent variables) of overuse or acute injury, we performed binary logistic regressions.[23] In logistic regressions, although the explanatory variables can be continuous or categorical, a binary variable is recommended.[23] Therefore, maximal hip isometric strength and single-leg hop test results were dichotomized based on previous clinical cut-off points (LSI or HSAI of 10%),[18] while the plank and side plank tests were dichotomized based on whether participants completed or failed the test (60 s). For previous history of pain, responses were categorized into two categories, "pain reported in one site or less" and "pain reported in two sites or more". In the absence of well-defined cut-off points, we used the 80th percentile to dichotomize the following variables: performance on the lunge weight-bearing test, sit and reach test and single-leg squat tests.

Univariable logistic regression analysis was first used to identify variables associated with injury with odds ratio as measures of effect. Variables with a significance level of $p \leq 0.1$ were retained for further multivariable logistic regression analysis to identify the most accurate and parsimonious set of predictors.[1] The level of significance for the multivariable model was set, *a priori*, at α = 0.05.[23] Nagelkerke's pseudo-R^2 was calculated to quantify the overall model fit, with a range of 0 (no variation explained) to 1 (all variation explained). The model was assessed for collinearity using variance inflation factors where values between 1 and 10 suggest no multicollinearity. All analyses were performed using IBM SPSS Statistics 22.0 for Windows (IBM Corporation, Armonk, New York).

3. Results

A total of 545 of 688 cadets (394 males) participated in the study. Of those excluded, three were currently injured, 10 declined to participate, and 130 did not participate in the baseline assessment (Fig. 1). Participant demographics can be found in Table 1.

Table 1
Characteristics of the sample at baseline (mean ± SD).

Variable	Male (n = 394)	Female (n = 151)
Age (y)	20.7 ± 1.7	20.6 ± 1.7
Weight (kg)	75.5 ± 12.0	61.2 ± 8.2*
Height (m)	1.75 ± 0.07	1.62 ± 0.05*
BMI (kg·m^{-2})	24.6 ± 3.2	23.3 ± 2.8*
Ankle dorsiflexion (°)	32.7 ± 6.6	32.2 ± 7.1
Sit and Reach (cm)	24.4 ± 8.2	28.8 ± 8.2*
Hip Abduction (Kg/BW)[¥]	0.18 ± 0.04	0.16 ± 0.04*
Hip External Rotation (Kg/BW)[Ω]	0.28 ± 0.07	0.19 ± 0.05*
Single Leg Hop (%height)	85.5 ± 11.9	69.4 ± 9.9*
Plank Test (s)	57.5 ± 7.6	52.8 ± 11.4*
Side Plank Test (s)[#]	50.8 ± 13.4	39.2 ± 18.5*
Knee FPPA	−4.35 ± 5.94	−5.03 ± 5.40

*Statistically significant difference between male and female ($P < 0.001$), BMI – body mass index. DS - Dominant side, NDS - Non-dominant side and BW – body weight; FPPA: Frontal Plane projection angle; [€]Significant leg ($p \leq 0.05$) and *sex differences ($p < 0.001$); [#]males (n = 393) and females (n = 150) due to missing data; [¥]males (n = 392) and **Ω**females (n = 150) due to some outliers.

Missing data from the sit and reach test (<1% of all data), side plank test (<1%), and knee FPPA test (<2%) were assumed to be missing at random. Multiple imputation was performed to evaluate the effect of excluding data on the univariate regression results. No change in the results of the univariate analysis was identified (Appendix D and E) and the original multivariable model was retained.

Forty cadets sustained a lower back or lower extremity injury, which resulted in an incidence proportion of 7%. Of the 40 injuries, two were excluded as they were non-training related injuries (one suffered a contact foot fracture during a soccer match; the other had a knee injury after tripping down the stairs). This resulting in 38 total injuries with an incidence proportion of 4% and 3% for overuse and acute injuries respectively. The incidence proportion for low back pain and lower extremity injuries were 0.4 and 6.6%, respectively. The incidence proportions in men and women were 6% and 9% respectively. Injuries were mainly sustained during running-related activities (36% of all injuries) (Appendix F). The knee was the most commonly injured anatomical region (42%), followed by the ankle (26%) (Appendix F). Further information on breakdown of overuse and acute injuries based on anatomical region and activity, and classification based on the ICD-10, can be found in Appendix F and G.

Ten variables were included in the univariable analysis (Table 2). Three variables were significantly associated with overuse injuries and were included in the multivariable logistic regression analysis (Table 3). Multivariable analysis revealed that predictors of overuse injuries were decreased trunk endurance on the prone plank test (OR 3.3, 95% CI 1.2–8.8, p = 0.02), reduced posterior chain flexibility on the sit and reach test (OR 4.0, 95% CI 1.4–11.2, p = 0.01), and a history of two or more sites of pain in the last 12 months (OR 2.7, 95% CI 1.02–7.3, p = 0.04) (R^2 = 0.14). In other words, cadets who were unable to maintain the plank position for 60 s, achieved a score of ≤18 cm in the sit and reach test, or with a history of pain in the 12 months prior to the assessment, had 3.3, 4.0, and 2.7 times higher odds of sustaining an overuse injury over the follow-up period, respectively. There were no variables significantly associated with acute injuries after univariable analysis and therefore no multivariable analysis was performed.

4. Discussion

This is the first large-scale prospective study investigating the combination of anthropometric measurements, flexibility assess-

Table 2
Univariate models for risk of overuse and acute injury (n = 545).

Variables	Overuse injury OR (95% CI)	*P*	Acute injury OR (95% CI)	*P*
Sex				
Male	(ref)			
Female	2.21 (0.90–5.44)	0.09*	0.74 (0.24–2.28)	0.60
Ankle Dorsi-flexion				
>26.6°	(ref)			
≤26.6°	1 (0.33–3.05)	1.00	1.15 (0.37–3.56)	0.81
Sit and reach test¥				
>18 cm	(ref)			
≤18 cm	2.83 (1.13–7.09)	0.03*	0.80 (0.23–2.82)	0.73
Knee FPPA€				
> −9°	(ref)			
≤ −9°	1.61 (0.60–4.28)	0.34	0.21 (0.03–1.59)	0.13
Pain in the last 12-month				
0 or 1 site	(ref)			
≥ 2 sites	2.67 (1.06–6.69)	0.04*	0.47 (0.11–2.07)	0.32
Hip Strength Asymmetry Index				
Hip Abduction				
≤10%	(ref)			
>10%	1.04 (0.42–2.55)	0.94	1.73 (0.64–4.66)	0.28
Hip External Rotation				
≤10%	(ref)			
>10%	1.00 (0.41–2.45)	1.00	0.81 (0.32–2.08)	0.66
Limb Symmetry Index (SL Hop Test)				
≤10%	(ref)			
>10%	3.03 (1.06–8.68)	0.04*	1.07 (0.24–4.79)	0.93
Trunk endurance				
Prone plank test				
60 s	(ref)			
<60 s	3.57 (1.44–8.84)	0.01*	0.23 (0.03–1.78)	0.16
Side plank test£				
60 s	(ref)			
<60 s	1.08 (0.44–2.63)	0.87	0.53 (0.19–1.42)	0.21

¥ (n = 544), £ (n = 539) and € (n = 533), Ref, Reference; FPPA, Frontal Plane projection angle; *$P \leq 0.05$.

Table 3
Multivariable model for risk of overuse injury.

Variable	Unadjusted (R^2 = 13.2%)		Adjusted (R^2 = 13.9%)	
	OR (95% CI)	*P*	OR (95% CI)	*P*
Plank test				
60 s	(ref)			
<60 s	3.8 (1.5–9.8)	0.01*	3.3 (1.2–8.8)	0.02*
Sit and reach test€				
>18 cm	(ref)			
≤18 cm	3.4 (1.3–9.0)	0.01*	4.0 (1.4–11.2)	0.01*
Pain in the last 12-month				
0 or 1 site	(ref)			
≥ 2 sites	3.1 (1.2–8.0)	0.02*	2.7 (1.02–7.3)	0.04*
Sex				
Male			(ref)	
Female			1.8 (0.62–5.2)	0.28

Sex was included in the adjusted model as a covariate. €(n = 544). R^2 = Nagelkerke R square. *$P \leq 0.05$.

ment, biomechanics, and strength measurements as risk factors for future trunk and lower extremity injury risk in naval cadets. The main finding of this study was that decreased trunk endurance on the prone plank test, reduced posterior chain flexibility on the sit and reach test, and a history of pain reported in two or more sites in in the last 12 months were predictors of overuse injuries in both male and female cadets. It is important to note, that even though individually and collectively these predictors demonstrate high odds ratios, the overall explanation of variance is low suggesting that other factors not measured in this study may also be associated with overuse injuries.

The prone plank test was found to predict overuse injury. Our findings were comparable to another cohort study that reported a 1% increase in injury risk for every 1-second decrease in plank test performance.[8] However, remaining evidence supporting trunk endurance as a predictor for lower extremity injuries remain conflicting.[7,9] A possible explanation for the lack of agreement could be due to cohort (general sporting populations vs military populations) and differences in dependent variable (general/acute lower extremity vs knee injuries). There remains strong theoretical support for reduced trunk strength, endurance and control as a predictor for lower extremity injury[9,24] and further research in military-specific cohorts would further elucidate this relationship.

The finding that posterior chain flexibility was a predictor of overuse injury is promising as it is a modifiable risk factor that is easily measured. This finding is indirectly supported by a quasi-experimental study that demonstrated that soldiers who followed a hamstring stretching program three times a day across 13 weeks had a significantly lower incidence rate (16.7%) of lower extremity overuse injuries compared to the control group (29.1%) at the end of the military basic training course.[25] Similarly, evidence of decreased flexibility as a risk factor for lower extremity injuries also exists in the general sporting literature.[26]

Pain in two or more body regions in the last 12 months was a risk factor for overuse injury. This finding is not surprising considering the general consensus in studies investigating both military and general sporting cohorts that previous injury history is a predictor of future injury.[6,27] To our knowledge, this is the first prospective cohort study confirming that previous history of pain is a predictor of future overuse injury in Naval cadets.

Several variables previously identified as predictors of injury, including increased knee FPPA and reduced isometric hip strength, were not found to be predictors in our study. A plausible explanation for conflicting findings could be the wide variation in testing procedures which limit the comparability and generalizability of findings. In our study, the single leg squat test was performed to 50° knee flexion and hip strength testing was performed isometrically.[17,19] However, recent studies have suggested that going into deeper knee flexion on the single leg squat to further challenge lower limb control and assessing hip strength eccentrically to mimic functional movement would be more appropriate.[28] While these predictors are interesting and hypothesis-generating, they need to be further investigated before being considered as predictors of injury.[9,28]

Identification of modifiable risk factors for trunk and lower extremity injury aetiology is necessary to reduce injury incidence and burden resulting from military training. The prone plank test, sit and reach test, and recording of pain and injury history are easily administered screening tests that may help stratify cadets at higher risk of future overuse injury. When combined,23 participants with all three risk factors are approximately 35 times greater odds of sustaining an overuse injury than cadets without these impairments. Being able to stratify cadets at high risk of injury would enable the utilization and prescription of primary and secondary prevention strategies with known efficacy, like exercise-based injury risk reduction programs, to reduce future injury risk and symptoms.[29]

Strengths of the study include the use of accessible and easy to administer screening tools, a large cohort size with a substantial proportion (28%) of female cadets, injury surveillance led by trained health professionals, and low proportion of missing data. This study has some limitations. Recall bias may have influenced questionnaire results on history of musculoskeletal pain. A lack of significant predictors for acute injuries and the poor fit of our multivariable regression model ($R^2 = 0.14$) for overuse injuries suggests that injury prediction remains a challenging issue. Injuries are an emergent phenomenon arising from complex, non-linear, time-varying relationships between multiple risk factors and because our study only assessed nine variables at a single time point, our efforts may have been inadequate in fully assessing injury risk. Future studies should consider investigating a wider breadth of risk factors at several time points throughout the observation period to more accurately assess injury causality.[30] Using technology like wearable sensors and global positioning systems may circumvent some barriers to data collection, but these efforts remain labour-intensive, expensive, and time-consuming.

5. Conclusion

This study demonstrated that the combination of decreased trunk endurance on the prone plank test, reduced posterior chain flexibility on the sit and reach test, and a history of pain reported in two or more sites in the last 12 months were predictors of overuse injuries in Naval cadets while no predictors were identified for acute injuries. Assessment and intervention of these modifiable risk factors are clinically relevant in injury screening and prevention.

Practical implications

- Trunk endurance, posterior chain flexibility, and previous history of musculoskeletal pain predict overuse low back and lower extremity injury in Naval cohorts
- No predictors for acute injuries were identified
- The low overall explanation of variance suggests that injury causality is multifactorial; other factors not measured in this study may be associated with injuries

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Data sharing statement

Raw data from data analysis are available upon reasonable request by contacting the corresponding author.

Patient and public involvement in research

Patients or public partners were not involved in the design, conduct or interpretation of this study.

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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.2020.11.020.

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