Intrinsic Risk Factors for Inversion Ankle Sprains in Male Subjects

A Prospective Study

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Background: Many variables have been retrospectively associated with ankle sprains. However, very little is known about factors predisposing people to these injuries.

Hypothesis: Measurable intrinsic factors might predispose male athletes to ankle sprains.

Study Design: Cohort study; Level of evidence, 2.

Methods: A total of 241 male physical education students were evaluated for possible intrinsic risk factors for inversion sprains at the beginning of their academic study. The evaluated intrinsic risk factors included anthropometrical characteristics, functional motor performances, ankle joint position sense, isokinetic ankle muscle strength, lower leg alignment characteristics, postural control, and muscle reaction time during a sudden inversion perturbation. Subjects were followed prospectively for 1 to 3 years.

Results: A total of 44 (18%) of the 241 male subjects sustained an inversion sprain; 4 sprained both ankles. Cox regression analysis revealed that male subjects with slower running speed, less cardiorespiratory endurance, less balance, decreased dorsiflexion muscle strength, decreased dorsiflexion range of motion, less coordination, and faster reaction of the tibialis anterior and gastrocnemius muscles are at greater risk of ankle sprains.

Conclusion: Based on our findings, it is suggested that running speed, cardiorespiratory endurance, balance, dorsiflexion strength, coordination, muscle reaction, and dorsiflexion range of motion at the ankle are associated with the risk of ankle inversion sprains in male subjects.

Keywords: cause; anthropometrical characteristics; functional motor performance; proprioception; muscle strength; alignment; postural control; muscle reaction time

Lateral ankle sprain is an extremely common athletic injury. In view of the high frequency of injury, not only in professional sports but also during leisure-time activities, it is clear that analyses of risk factors for sports injuries are urgently required as a prerequisite to the development of prevention programs.[22] Murphy et al[43] recently reviewed the literature on the risk factors for lower extremity injuries and demonstrated that our understanding of injury causation is limited. They concluded that more prospective studies are needed, emphasizing the need for proper design and sufficient sample sizes.

Sports injuries are multirisk phenomena with various risk factors interacting at a given time.[40] In general, a distinction has been made between so-called intrinsic (person-related) and extrinsic (environment-related) risk factors.[36,51,55] The intrinsic risk factors are related to the individual characteristics of a person. Extrinsic risk factors relate to environmental variables such as the level of play, exercise load, amount and standard of training, position played, equipment, playing field conditions, rules, foul play, and so forth.

Although ankle sprains are frequently encountered in the sports injury clinic, the causes of this injury remain enigmatic. Beynnon et al[4] revealed that investigations on extrinsic risk factors for ankle sprains arrived at some agreements, but at this point there is little consensus with

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regard to the intrinsic risk factors. One of the most important reasons is probably the lack of well-designed prospective investigations designed to determine risk factors for inversion sprains. Therefore, the relationship between intrinsic parameters and ankle sprains is still obscure. With the current emphasis on injury prevention, studies designed to examine potential risk factors for ankle injury are imperative. Based on a review of the literature, several possible intrinsic risk factors were defined. Most of the evaluated variables have retrospectively been associated with ankle sprains. These variables range from diminished muscle strength,[20,42,48,57] diminished postural control,[17,18,30,33] diminished proprioception,[19,29,32] and malalignment[34,49,60] to delayed muscle reaction time.[6,23,44] However, it is unclear if any of these deficits were present before injury because of the retrospective design of these studies. Distinguishing among these possible intrinsic causes can be challenging.

The purpose of this investigation was to perform a comprehensive, prospective investigation of risk factors for inversion sprains. A prospective cohort study was conducted in a young, physically active, male population. The factors examined included anthropometrical characteristics, functional motor performances, ankle joint position sense, ankle muscle strength, lower leg alignment, postural control, and muscle reaction time.

MATERIALS AND METHODS

Subjects

The subjects were 241 male physical education students (age range, 17-28 years; mean age, 18.3 ± 1.1 years), who were freshman in 2000-2001, 2001-2002, and 2002-2003 in physical education at the Ghent University, Belgium. All students were tested at the beginning of their education for several possible intrinsic risk factors. Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria were history of a surgical procedure involving the foot or ankle, previous grade II or III inversion ankle sprains, or history of an injury to the lower leg, ankle, or foot within 6 months of the start of the study. None of the subjects used prophylactic ankle bracing or taping before or during the study. Information on foot dominance was obtained by asking the subjects which foot they normally use to kick a ball.

At the university level, the students all followed the same sports program under the same environmental conditions for 26 weeks per academic year. All students used the same sports facilities, and the safety equipment was uniform. The workout program in the first year consisted of 45 minutes of soccer, handball, basketball, and volleyball; 1 hour of track and field, gymnastics, karate, and swimming; and 2 hours of dance every week. In the second year, the weekly workout program consisted of half an hour of climbing; 1 hour of track and field, soccer, handball, basketball, volleyball, karate, and swimming; 1.5 hours of gymnastics; and 2 hours of dance. In the third year, the program consisted of half an hour of track and field, volleyball, soccer, gymnastics, orienteering, and swimming and 1 hour of handball, basketball, badminton, dance, and judo every week. Extramural activities, being the amount of physical activities students participate in beyond their sports lessons at school, were also registered.

All volunteers signed an informed consent form. The study was approved by the Ethical Committee of the Ghent University Hospital.

The students were followed weekly by the same sports physician for occurrence of injury throughout 3, 2, and 1 academic years for freshman in 2000-2001, 2001-2002, and 2002-2003, respectively. The subjects were asked to report all injuries resulting from sports activities to this physician. All sports injuries sustained during practice, lessons, and games were registered. The injury definition was based on that of the Council of Europe.[11] The definition requires that an injury have at least 1 of the following consequences: (1) a reduction in the amount or level of sports activity, (2) a need for (medical) advice or treatment, or (3) adverse social or economic effects.[11] Injury data were recorded on a standardized injury form that captured basic information about type of injury, the circumstances under which the injury occurred, and the treatment of the injury.

INSTRUMENTATION AND PROTOCOL

Before the start of their physical education, all students were tested for anthropometrical characteristics, functional motor performances, ankle joint position sense, muscle strength, lower leg alignment, postural control, and muscle reaction time.

Anthropometric Characteristics

The following anthropometric measurements were evaluated: height (in centimeters), mass (in kilograms), calf girth, humerus and femur width (epicondyle width), and biceps, triceps, subscapular, suprailiac, and medial calf skin folds. Measurements were carried out by the same trained anthropometrist after the procedures as described by Claessens et al.[9] The body mass indices [BMI = mass (kg)/height $(m)^2$] and ponderal indices [PI = height (m)/mass $(kg)^{1/3}$] were calculated. The 3 somatotype components (endomorphy, mesomorphy, and ectomorphy) were calculated using the anthropometric method of Carter and Heath.[7] Body composition characteristics (fat mass, percent fat and fat-free mass, density) were estimated based on the formula of Durnin and Womersley[12] using the Siri equation.[50]

Functional Motor Performances

Functional motor performances, such as general balance, explosive jump ability, and running speed, were evaluated using the European Test of Physical Fitness.[10] These performances were evaluated by means of a flamingo balance, a standing broad jump, and the shuttle run test, all of which have good validity and reliability.[10,35,45] Cardiorespiratory endurance was measured by the endurance shuttle run described by Leger et al.[31] All tests were performed with standard equipment and by trained observers, physical therapists, and physical educators who were educated to administer the tests.

Joint Position Sense

Active and passive joint position sense was assessed using the Biodex System 2 Isokinetic Dynamometer (Biodex Medical Systems Inc, Shirley, NY). Positioning of the subject has been described previously.[59] For passive testing, the subject's foot was first passively moved by the investigator to maximal eversion (for inversion test positions) or inversion (for eversion test position). The investigator then moved the foot to 1 of the 3 test positions (randomly determined): 15° of inversion, maximal active inversion minus 5°, or 10° of eversion. The test position was maintained for 10 seconds. During these 10 seconds, subjects were instructed to concentrate on the position of the foot. The foot was then passively brought to maximal eversion (for the inversion test positions) or to maximal inversion (for the eversion position) and moved passively back toward the other direction with a speed of 5°/s. The subject was instructed to push a stop button when he thought the test position had been reached. The subject was tested twice at each of the 3 test positions. The active test was performed in the same manner, except after having the foot passively placed in the test position and moved to maximal eversion or inversion, the subject was asked to move the foot actively back to the test position. The subject was again asked to push the stop button when he thought the test position was reached. The testing order, test positions, and side of body tested were randomly chosen. The amount of error in degrees was noted for further analysis.

We examined 2 types of errors in the subjects' ability to match the reference angles: the absolute error and the exact error.[59] Average scores of the 2 trials were used for analysis. Konradson et al[28] validated a comparable method of measuring ankle position sense and found it to be accurate, repeatable, and precise.

Muscle Strength

A Biodex System 3 Isokinetic Dynamometer and Biodex Advantage Software Package (Biodex Medical Systems Inc) were used to determine isokinetic peak torque and peak torque compared to body mass values for reciprocal concentric and eccentric eversion-inversion movements of the ankle and for concentric plantarflexion–dorsiflexion. Positioning and stabilization has been described elsewhere.[59] The protocol for testing plantar flexion–dorsiflexion and inversion-eversion muscle strength was recommended by Dvir[13] and was found to be reliable.[24]

The tested range of motion for the inversion-eversion test was maximal active inversion and eversion minus 5° for both directions and for plantarflexion–dorsiflexion it was maximal active plantar flexion and dorsiflexion. The first test consisted of 3 maximal repetitions of concentric-eccentric eversion at 30°/s to assess the strength of the eversion muscles. The second test for the same ankle consisted of 5 repetitions of concentric-eccentric eversion at 120°/s. The same 2 tests (concentric-eccentric at 30°/s and 120°/s) were performed for inversion to assess the strength of the inversion muscles. The same 4 tests were then performed with the contralateral limb. Next, plantar flexors and dorsiflexors were tested concentrically at 30°/s (3 repetitions) and at 120°/s (5 repetitions). The order of testing the ankles was randomized. Before data collection, each subject was provided an opportunity to become familiar with the testing procedure and to perform 3 warm-up repetitions. Consistent verbal encouragement for maximal effort was given to each subject throughout the testing procedure. None of the subjects felt any discomfort while testing.

Peak torque and peak torque compared to body mass values were obtained for each ankle motion of each limb at the 2 speeds. Eversion-to-inversion and dorsiflexion-to-plantar flexion strength ratios were calculated.

Lower Leg Alignment

Lower leg alignment characteristics were determined using goniometric measurements by the same experienced physical therapist. At the talocrural joint, plantar flexion and dorsiflexion range of motion with the knee straight and flexed were measured using the method described by Ekstrand et al.[14] Inversion and eversion at the subtalar joint and position of the calcaneus, unloaded with the subtalar joint in neutral position, were measured. In addition, position of the calcaneus was measured in stance with and without the subtalar joint in neutral position.[16] Flexion and extension range of motion at the first metatarsophalangeal joint was also determined. Hip external and internal rotation were measured using the method described by Khan et al.[26] Talocrural, subtalar, and hip goniometric measurements appear to be moderately to highly reliable.[14,15,26] We checked test-retest reliability of the goniometric measurements of the first metatarsophalangeal joint on 12 feet. The intraclass correlation coefficients were between .82 and .98.

Postural Control

Postural control was assessed through 5 tests using the Neurocom Balance Master (NeuroCom Int, Inc, Clackamas, Ore). The first test (weightbearing) evaluated the percentage of weight borne by each leg. The second test assessed sway velocity of the center of gravity in bilateral positions with eyes open and closed and on firm and foam surfaces. Three trials of each test condition were performed, each of which required 10 seconds. The third test evaluated sway velocity in unilateral stance with eyes open and closed. Again, 3 trials were performed for 10 seconds on both sides. The next test (limits of stability) quantified several movement characteristics associated with the subject's ability to voluntarily sway his center of gravity to various locations in space (forward, right, back, and left) and briefly maintain stability at those positions.

Subjects were asked to move as quickly and as straight as possible to a specific target. The measured parameters were reaction time, sway velocity, directional control, endpoint excursion (distance at which the initial movement attempt stops or reverses), and maximal excursion (furthest distance the subject reaches on any attempt at the target). The last test (forward lunge) quantified several movement characteristics. The subject was instructed to lunge forward with 1 leg and then to return to a standing position. The parameters measured were distance, time, impact index (impact force), and force impulse. The test was repeated 3 times. A mean value of the 3 trials was calculated for each condition and was used for analysis. Reliability of the postural control tests on the Neurocom Balance Master was good to excellent.[54]

Muscle Reaction Time

To measure the muscle reaction time to a sudden inversion perturbation, a specially designed platform that allowed each foot to drop into plantarflexion-inversion of 50° from standing in 40° plantar flexion and 15° adduction was used.[53] The movement of the platform was recorded by an electrogoniometer and an accelerometer installed on the tilting axis. Before electrode application, the skin was shaved, grazed with sandpaper, and cleaned with alcohol. Surface EMG was used to capture muscle activity of the following muscles: peroneus longus, peroneus brevis, tibialis anterior, and gastrocnemius. All electrodes were placed according to the protocol described by Basmajian and De Luca.[2] The correct placements were verified by particular movements of the foot, causing isolated contractions of the muscles to be examined, and specific EMG patterns were observed online on the monitor. Telemetric measurements were performed by means of the Myosystem (Noraxon USA Inc, Scottsdale, Ariz). All EMG signals were sampled and analog to digital converted (12-bit resolution) at 1000 Hz.

Subjects were asked to stand in their sport shoes fixed on the platform with their body mass equally distributed on each foot. Subjects were blindfolded and wore a headphone to eliminate visual and auditory cues to the platform release. In random order, 5 measurements were performed on each side. When EMG signals showed baseline activity, the tilting platform was released. All data were saved on computer for further analysis. The protocol used has been demonstrated to be satisfactorily to highly reproducible.[53]

A software package (Myoresearch 2.10, Noraxon USA Inc) was used for determination of the muscle reaction time. The beginning of the tilting movement by the accelerometer was marked visually. The muscle reaction time was determined by the period of time between the start of platform tilting and the onset of muscle activity. The threshold for muscle activity was set at 2 standard deviations above the baseline activity, and this activity had to last at least 3 milliseconds. The baseline activity in the muscles was measured during 1 second before the start of the tilting. Average scores of the 5 trials were used for statistical analysis.

ANALYSIS

SPSS for Windows (version 10.0, SPSS Science Inc, Chicago, Ill) was used for statistical analysis. The students were divided into 2 groups: an uninjured group as control group (group 1) and a group with subjects who sustained an inversion sprain (group 2). Group 1 consisted of the control subjects who did not have any injury to either leg in the period they were followed in this study. A stratified randomization technique was used: 1 of the 2 uninjured legs was randomly selected, taking into account the percentage of dominant legs in the inversion sprain group. Group 2 consisted of the subjects who sustained an inversion sprain. Only the data from the injured legs were used for analysis. A Cox proportional hazard regression was used to test the effect of each variable on the hazard of injury, taking into account differences in the length of time that the athletes were at risk. This approach has been chosen for statistical analysis because this method can adjust for the fact that the amount of sports participation can vary between the students. The time from the start of the follow-up period until the ankle sprain or the end of the follow-up period for students who were not injured was the main variable. Time was measured as the number of hours of sports exposure for each student. This was accomplished by computing time at risk as the total number of hours of sports lessons, practices for sports lessons, practices for recreational or competition sports, and games in which each subject participated until injury or, if uninjured, the end of the period students were followed. This analysis also took censorship into account, such as abbreviated length of follow-up for reasons other than injury (eg, not passing). The method assumes that risk factors affect injury in a proportional manner across time.[1]

RESULTS

During the follow-up period, 44 (18%) of the 241 subjects suffered 1 or more inversion sprains; 4 of the 44 subjects sprained both ankles. Only the initial sprain was used for analysis when repeated sprains occurred. A total of 108 (45%) of the 241 subjects did not sustain any injuries of the lower leg, ankle, or foot and served as the control group.

In 59% of the ankle sprains, the dominant foot was affected. Twenty-one (44% of all ankle sprains) ankle sprains were sustained during lessons at the university, 3 (6%) during practice for lessons, 12 (25%) during extramural competition, 9 (19%) during extramural training for competition, and 3 (6%) during extramural recreational sports. Twenty (42% of all ankle sprains) sprains occurred during soccer, 5 (10%) during basketball, 4 (8%) during volleyball, 8 (17%) during track and field, and 4 (8%) during gymnastics. The rest of the ankle sprains (15%) happened during other sports, in which the incidence of ankle sprains was low.

Figure 1 displays the survival curve of the students with an ankle sprain. Anthropometric data on the subjects are listed in Table 1. No significant differences were found between the uninjured group and the ankle sprain group

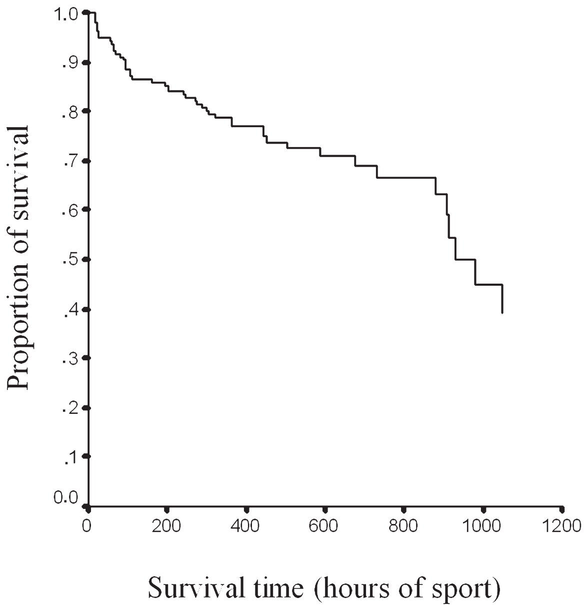

Figure 1. Survival curve of the students with an ankle sprain.

for any of the measured anthropometric data ($P > .05$). Table 2 represents the evaluated functional motor performances. Cox regression revealed that subjects who had poorer scores on the flamingo balance test were at greater risk of ankle sprains ($P = .001$). In addition, subjects with a slower running speed ($P = .019$) and decreased cardiorespiratory endurance ($P = .022$) had a higher incidence of inversion sprains. Results of the analysis performed for isokinetic muscle strength are presented in Table 3. Men with decreased concentric dorsiflexion muscle strength at 30°/s are at greater risk of ankle sprains ($P = .036$).

Table 4 represents the results of the Cox regression, performed for the lower leg alignment characteristics. The analysis showed that men with a decreased dorsiflexion range of motion with the knee straight are at greater risk of ankle sprains ($P = .013$). The results also showed a trend toward a higher extension range of motion at the first metatarsophalangeal joint in men susceptible to ankle sprains ($P = .052$). Results of the Cox regression performed for postural control are presented in Table 5. Ankle injuries were more common among men with decreased directional control ($P = .037$) tested by the limits of stability test. Men with a decreased reaction time in the tibialis anterior muscle ($P = .048$) and the gastrocnemius muscle ($P = .033$) were more likely to sprain their ankle (Table 6). No significant differences were observed between injured and uninjured male students for joint position sense.

DISCUSSION

In the current study, 18% of the 241 students sustained 1 or more inversion sprains; 4 of them had bilateral ankle sprains. This incidence is in agreement with the incidence of 18% lateral ankle sprains observed in male infantry recruits in basic training.[41] Similar ankle injury rates

TABLE 1
Means and Standard Deviations for Demographic Data for Uninjured and Injured Subjects

	Uninjured Subjects	Injured Subjects	P (Cox Regression)[a]
Age, y	18.33 ± 1.18	18.35 ± 0.78	NS
Height, cm	179.88 ± 6.26	180.73 ± 5.71	NS
Mass, kg	69.24 ± 7.19	71.14 ± 5.94	NS
Body mass index	21.37 ± 1.66	21.81 ± 1.71	NS

[a]NS, not significant.

TABLE 2
Means and Standard Deviations for Functional Motor Performances for Uninjured and Injured Subjects

	Uninjured Subjects	Injured Subjects	P (Cox Regression)
Flamingo balance	7.57 ± 3.64	9.40 ± 4.95	.001[a]
Standing broad jump, cm	227.64 ± 21.62	225.92 ± 22.04	NS[b]
Shuttle run, s	19.10 ± 1.09	19.68 ± 1.12	.019[a]
Endurance shuttle run, min	12.06 ± 1.50	11.13 ± 1.49	.022[a]

[a]Significant difference between the 2 groups ($P < .05$).
[b]NS, not significant.

TABLE 3
Means and Standard Deviations for Isokinetic Concentric and Eccentric Eversion and Inversion Muscle Strength and Concentric Plantar Flexion and Dorsiflexion Muscle Strength at 30°/s and 120°/s Compared to Body Weight for Uninjured and Injured Subjects[a]

	Uninjured Subjects	Injured Subjects	P (Cox Regression)
EV 30°/s conc/BW	.43 ± .12	.45 ± .14	NS
EV 30°/s ecc/BW	.46 ± .10	.48 ± .14	NS
EV 120°/s conc/BW	.38 ± .10	.39 ± .12	NS
EV 120°/s ecc/BW	.47 ± .10	.49 ± .16	NS
INV 30°/s conc/BW	.54 ± .16	.51 ± .12	NS
INV 30°/s ecc/BW	.56 ± .18	.53 ± .13	NS
INV 120°/s conc/BW	.51 ± .19	.48 ± .17	NS
INV 120°/s ecc/BW	.55 ± .17	.56 ± .16	NS
DF 30°/s conc/BW	.73 ± .30	.54 ± .21	.036[b]
DF 120°/s conc/BW	.24 ± .09	.25 ± .17	NS
PF 30°/s conc/BW	1.47 ± .38	1.32 ± .36	NS
PF 120°/s conc/BW	.56 ± .26	.65 ± .30	NS

[a]Expressed in N•m/kg. EV, eversion; conc, isokinetic concentric; BW, body weight; NS, not significant; ecc, eccentric; INV, inversion; DF, dorsiflexion; PF, plantar flexion.
[b]Significant difference between the 2 groups ($P < .05$).

TABLE 4
Means and Standard Deviations for Lower Leg Alignment Characteristics for Uninjured and Injured Subjects[a]

	Uninjured Subjects	Injured Subjects	P (Cox Regression)
Talocrural PF	52.39 ± 8.29	52.03 ± 8.64	NS
Talocrural DF (knee extended)	29.25 ± 7.38	25.88 ± 6.52	.013[b]
Talocrural DF (knee flexed)	34.85 ± 7.59	32.88 ± 6.06	.092
Subtalar INV	18.90 ± 6.49	19.41 ± 8.00	NS
Subtalar EV	10.55 ± 4.58	9.00 ± 5.59	NS
MTPIJ flexion	35.72 ± 10.51	31.97 ± 8.63	NS
MTPIJ extension	67.68 ± 15.17	71.50 ± 15.46	.052
Hip external rotation	38.04 ± 5.18	40.39 ± 6.79	NS
Hip internal rotation	34.56 ± 5.38	33.73 ± 4.67	NS
Position calc unloaded (STJN)	.40 var ± 3.60	.24 valg ± 3.75	NS
Position calc WB (STJN)	1.13 var ± 3.36	2.38 var ± 3.01	NS
Position calc WB	3.03 valg ± 3.04	2.41 valg ± 2.66	NS

[a]Expressed in degrees. PF, plantar flexion; NS, not significant; DF, dorsiflexion; INV, inversion; EV, eversion; MTPIJ, metatarsophalangeal I joint; calc, calcaneus; STJN, subtalar joint in neutral position; var, varus alignment; valg, valgus alignment; WB, weightbearing.
[b]Significant difference between the 2 groups ($P < .05$).

TABLE 5
Means and Standard Deviations for Postural Control for Uninjured and Injured Subjects[a]

	Uninjured Subjects	Injured Subjects	P (Cox Regression)
Weightbearing, % BW	49.67 ± 4.33	50.10 ± 3.53	NS
Bilat firm EO, °/s	.21 ± .08	.22 ± .07	NS
Bilat EC, °/s	.26 ± .08	.28 ± .09	NS
Bilat foam EO, °/s	.56 ± .11	.59 ± .12	NS
Bilat foam EC, °/s	1.44 ± .35	1.50 ± .38	NS
Unilat EO, °/s	.72 ± .12	.74 ± .16	NS
Unilat EC, °/s	2.47 ± 1.76	2.69 ± 1.23	NS
LOS reaction time, s	.65 ± .20	.60 ± .16	NS
LOS movement velocity, °/s	5.56 ± 1.57	5.61 ± 1.77	NS
LOS directional control, %	79.70 ± 5.57	77.85 ± 6.95	.037[b]
LOS endpoint excursion, %	80.47 ± 7.62	81.62 ± 9.17	NS
LOS max endpoint excursion, %	90.07 ± 5.04	91.50 ± 6.41	NS
FL distance, % BH	57.69 ± 6.05	57.73 ± 5.28	NS
FL contact time, s	.84 ± .22	.86 ± .21	NS
FL impact index, % BW	30.50 ± 9.67	31.99 ± 11.39	NS
FL force impulse, % BW	89.59 ± 22.22	91.69 ± 20.90	NS

[a]BW, body weight; NS, not significant; Bilat, bilateral stance; firm, firm surface; EO, eyes open; EC, eyes closed; foam, foam surface; unilat, unilateral stance; LOS, limits of stability; max, maximal; FL, forward lunge; BH, body height.
[b]Significant difference between the 2 groups ($P < .05$).

(20.3%) were reported in professional basketball players.[62] The survival curve of the students with an ankle sprain is shown in Figure 1. Most ankle sprains occur within the first 400 hours of sports participation, as seen by the many downward steps in the curve in this period.

Results of this study revealed no significant relationship between any of the anthropometrical characteristics and the occurrence of inversion sprains. Although a larger mass moment of inertia (mass × height^2) has been considered a risk factor for lateral ankle sprains in recruits,[41] most other studies on ankle sprain risk factors have reported no effect of height or mass on the incidence of ankle sprains.[3,5,39]

Our results confirm earlier statements that poor physical condition enhances the risk of a sports injury.[37] The present investigation identified decreased cardiorespiratory

TABLE 6
Means and Standard Deviations for Muscle Reaction Time of the Peroneus Longus, Peroneus Brevis, Tibialis Anterior, and Gastrocnemius Muscles for Uninjured and Injured Subjects

	Uninjured Subjects	Injured Subjects	P (Cox Regression)
Peroneus longus	83.12 ± 14.12	75.99 ± 10.06	NS[a]
Peroneus brevis	80.40 ± 13.25	73.55 ± 10.90	NS[a]
Tibialis anterior	89.80 ± 11.50	78.67 ± 10.45	.048[b]
Gastrocnemius	90.31 ± 16.09	79.76 ± 10.66	.033[b]

[a]NS, not significant.
[b]Significant difference between the 2 groups ($P < .05$).

endurance and slower running speed in men who sustain an ankle sprain. Diminished cardiorespiratory endurance could cause earlier fatigue, leading to a less accurate protective effect of the musculature on capsuloligamentous structures. Several other prospective studies on lower extremity injuries have shown a relationship between physical fitness and injury.[8,21,25,27,55] Therefore, we recommend that primary ankle injury prevention programs should include progressive cardiorespiratory endurance and speed training.

Interestingly, the variable "general balance" measured by the flamingo balance test showed a significant association with ankle sprains. Our results indicate that male students with a higher score on the flamingo balance test (ie, a higher number of attempts to keep in balance on the beam for 1 minute) show a higher risk for the development of ankle sprains. Watson[56] found comparable results in a prospective study on ankle sprain risk factors in male players of the field games Gaelic football and hurling. Surprisingly, we could not identify a predisposing factor in the unilateral balance test on the Neurocom Balance Master. Our results are therefore in contrast to those of other prospective studies[38,52] but are in accordance with those of Beynnon et al.[5] Although the flamingo balance test and the unilateral stance test on the Neurocom Balance Master both measure a variety of sensory input and motor outputs, the flamingo balance test may be a more adequate test for athletes because the task is more difficult. For athletes, keeping balance for only 10 seconds, as in the test on the Neurocom Balance Master, may be too short. Subtle changes may perhaps not manifest during this short period.

However, using the Neurocom Balance Master, we demonstrated that other postural control parameters could predict an ankle injury. Our results show that ankle injuries are more common among men with decreased directional control (limits of stability test). The subject was asked to go directly to the target; thus, a straight-line path to the target is desirable. However, the path to the space target in these subjects is less smooth and continuous, which reflects that the subject's movement coordination is decreased. To reduce the amount of ankle sprains in sports activities, we therefore suggest that balance and coordination training should be included in prevention programs.

Results of this study show no relationship between joint position sense and the risk of an ankle sprain in male athletes. These findings are therefore in contrast to previous findings in basketball teams, where ankle joint proprioceptive deficits were predictive of an ankle injury.[46] Because few studies have investigated joint position sense as a risk factor for ankle sprains, further research on this topic is needed.

Although it seems obvious that ankle muscle strength is related to the risk of suffering an ankle sprain, only a few prospective studies have investigated this relationship, and the findings from these studies differ. Our results show that decreased dorsiflexion muscle strength at 30°/s in men is a risk factor for ankle sprains. We suggest that these subjects cannot accurately perform a dorsiflexion in their ankle when an inversion action occurs. Payne et al[46] and Beynnon et al[5] could not associate ankle muscle strength with ankle sprains. In contrast, Baumhauer et al[3] found the eversion-to-inversion strength ratio and plantar flexion strength to be significantly greater and the dorsiflexion-to-plantar flexion ratio to be significantly smaller in the injured ankles. In the current study, we found no difference in inversion, eversion, or plantar flexion peak torques among athletes who subsequently sustained ankle sprains and those who did not. In addition, none of the calculated ratios was related to subsequent injury. Different results between previous studies and ours can probably be explained by the differences in the methods that were used to analyze the data and the differences in the investigated population. On the basis of our findings, we suggest that dorsiflexion strength training should be included in prevention programs for ankle sprains.

Ankle sprains occur within a time interval that is much faster than that required to develop peak torque during isokinetic testing and at much higher velocities than those used to measure peak torque.[4] From this perspective, in addition to force, temporal response of the muscles that span the ankle joint should be considered. In this study, we found a significant relationship between a faster muscle reaction time of the tibialis anterior muscle and the gastrocnemius muscle and the occurrence of ankle sprains, which suggests that the protective effect of the leg muscles on joint perturbation may have been compromised. Our results show that in the control group, the peronei—the evertor muscles—provide the first stabilization, followed by the tibialis anterior and the gastrocnemius muscles. In contrast, in men susceptible to ankle sprains, the 4 captured muscles demonstrate almost identical reaction times. Therefore, the accelerated reaction of the tibialis anterior and the gastrocnemius muscles can be considered as an alteration of the musculoskeletal system that compromises the protective effect of the leg muscles on ankle joint stability. Our results differ from the prospective study of Beynnon et al,[5] in which no significant relationship was found between muscle reaction times and ankle sprains. On the other hand, many retrospective studies found a relationship between delayed muscle reaction time of the peronei muscles after occurrence of an ankle sprain.[6,23,44] We recommend that prevention programs should pay attention to the recruitment pattern of the ankle musculature. If possible, exercises should be included to train ankle muscles to adequately react. Further investigation is necessary to elucidate the recruitment patterns of the ankle muscles.

Conspicuous in the present study is the finding of a trend toward a higher extension range of motion at the first metatarsophalangeal joint in subjects susceptible to ankle sprains. This higher extension range of motion at the first metatarsophalangeal joint probably causes diminished support at this joint during gait. Making the link with kinematics in the unrolling foot, we suggest that foot roll-off does not primarily occur across the hallux as normal but more laterally in subjects who will sustain an ankle sprain.[58] Because of the diminished support at the first metatarsophalangeal joint, it could be that these subjects, when landing from a jump, also make contact with the ground with the lateral part of the foot instead of with the hallux. This position is very susceptible to inversion sprains[61] and could explain the higher incidence of ankle sprains observed in this study in subjects with a higher extension range of motion at the first metatarsophalangeal joint compared to normal subjects. However, because no kinematic analysis from jumping was carried out in the current study or in previous studies, this finding remains hypothetical and should be investigated further.

Our results indicate that decreased dorsiflexion range of motion can be considered as a predictive factor of ankle sprains in men. The dorsiflexion range of motion is only significantly decreased in the alignment measurement with the knee straight and not with the knee flexed, which suggests that the gastrocnemius muscle is probably shortened. This shortened musculotendinous unit may place the foot in a position of greater plantar flexion in different sports tasks, increasing the risk of inversion injury. The present investigation supports the earlier findings of Pope et al in male recruits.[47] Therefore, we suggest that prevention programs should include strategies such as stretching to increase the dorsiflexion range of motion in the ankle.

One of the limitations of this study is that we only demonstrated an association between ankle inversion sprains and several intrinsic risk factors. Causation still needs to be proven.

CONCLUSION

In this investigation, several measurements of sensorimotor control of the ankle were performed to search for intrinsic risk factors for ankle sprains. Afferent and efferent signals were evaluated. Motor responses were evaluated on the 3 levels of motor control: spinal reflexes (through inversion perturbation of the foot), brain stem activity (through postural control), and cognitive programming (through joint position sense). In addition, static as well as dynamic stabilizers of the ankle joint were investigated. Results of this study show that especially dynamic stabilizers are compromised in men at risk. In summary, this study demonstrated that risk factors that predispose male athletes to ankle ligament injury are slower running speed, less cardiorespiratory endurance, less general balance, less movement coordination, decreased dorsiflexion range of motion, decreased dorsiflexion muscle strength, and decreased reaction time of the tibialis anterior and gastrocnemius muscles. Therefore, to reduce the incidence of ankle sprains, we recommend that prevention programs should include cardiorespiratory endurance, speed, balance, coordination, and dorsiflexion strength training and stretching exercises to increase dorsiflexion range of motion at the ankle.

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REFERENCES

1. Bahr R, Holme I. Risk factors for sports injuries: a methodological approach. *Br J Sports Med*. 2003;37:384-392.
2. Basmajian JV, De Luca CJ. *Muscles Alive: Their Functions Revealed by Electromyography*. 5th ed. Baltimore, Md: Williams & Wilkins; 1985.
3. Baumhauer JF, Alosa DM, Renstrom AF, et al. A prospective study of ankle injury risk factors. *Am J Sports Med*. 1995;23:564-570.
4. Beynnon BD, Murphy DF, Alosa DM. Predictive factors for lateral ankle sprains: a literature review. *J Athl Train*. 2002;37:376-380.
5. Beynnon BD, Renström PA, Alosa DM, et al. Ankle ligament injury risk factors: a prospective study of college athletes. *J Orthop Res*. 2001;19:213-220.
6. Brunt D, Andersen JC, Huntsman B, et al. Postural responses to lateral perturbation in healthy subjects and ankle sprain patients. *Med Sci Sports Exerc*. 1992;24:171-176.
7. Carter JEL, Heath BH. *Somatotyping: Development and Applications*. Cambridge, Mass: Cambridge University Press; 1990.
8. Chomiak J, Junge A, Peterson L, et al. Severe injuries in football players: influencing factors. *Am J Sports Med*. 2000;28:S58-S68.
9. Claessens A, Vanden Eynde B, Renson R, et al. The description of tests and measurements. In: Simons J, Beunen GP, Renson R, et al, eds. *Growth and Fitness of Flemish Girls: The Leuven Growth Study*. Champaign, Ill: Human Kinetics Publishers; 1990:21-39.
10. Council of Europe, Committee for the Development of Sports. *Eurofit, European Test of Physical Fitness*. Rome, Italy: Council of Europe; 1988.
11. Council of Europe, van Vulpen AV. *Sports for All: Sports Injuries and Their Prevention*. Scientific Report. Oosterbeek, the Netherlands: Oosterbeek National Institute for Sport Health Care; 1989.
12. Durnin J, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr*. 1974;32:77-97.
13. Dvir Z. *Isokinetics: Muscle Testing, Interpretation and Clinical Applications*. 2nd ed. London: Churchill Livingstone; 2004.
14. Ekstrand J, Wiktorsson M, Öberg B, et al. Lower extremity goniometric measurements: a study to determine their reliability. *Arch Phys Med Rehabil*. 1982;63:171-175.
15. Elveru RA, Rothstein JM, Lamb RL. Goniometric reliability in a clinical setting: subtalar and ankle joint measurements. *Phys Ther*. 1988;68:672-677.
16. Elveru RA, Rothstein JM, Lamb RL, et al. Methods for taking subtalar joint measurements: a clinical report. *Phys Ther*. 1988;68:678-682.
17. Freeman MAR, Dean MRE, Hanham IWF. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br*. 1965;47:678-685.
18. Fridén T, Zätterström R, Lindstrand A, et al. A stabilometric technique for evaluation of lower limb instabilities. *Am J Sports Med*. 1989;17:118-122.
19. Glencross D, Thornton E. Position sense following joint injury. *J Sports Med*. 1981;21:23-27.
20. Hartsell HD, Spaulding SJ. Eccentric/concentric ratios at selected velocities for the invertor and evertor muscles of the chronically unstable ankle. *Br J Sports Med*. 1999;33:255-258.
21. Jones B, Bovee M, Harris J, et al. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med*. 1993;21:705-710.
22. Junge A. The influence of psychological factors on sports injuries: review of the literature. *Am J Sports Med*. 2000;28:S10-S15.
23. Karlsson J, Peterson L, Andreasson G, et al. The unstable ankle: a combined EMG and biomechanical modeling study. *Int J Sports Biomech*. 1992;8:129-144.
24. Karnofel H, Wilkinson K, Lentell G. Reliability of isokinetic muscle testing at the ankle. *J Orthop Sports Phys Ther*. 1989;11:150-154.
25. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med*. 2000;18:54-63.

26. Khan K, Roberts P, Nattrass C, et al. Hip and ankle range of motion in elite classical ballet dancers and controls. *Clin J Sport Med*. 1997;7:174-179.
27. Knapik JJ, Sharp MA, Canham-Chervak M, et al. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc*. 2001;33:946-954.
28. Konradson L, Beynnon BD, Renström PA. Techniques for measuring sensorimotor control of the ankle: evaluation of different methods. In: Lephart SM, Fu FH, eds. *Proprioception and Neuromuscular Control in Joint Stability*. Champaign, Ill: Human Kinetics Publishers; 2000:139-144.
29. Konradson L, Olesen S, Hansen HM. Ankle sensorimotor control and eversion strength after acute ankle inversion injuries. *Am J Sports Med*. 1998;26:72-77.
30. Leanderson J, Wykman A, Eriksson E. Ankle sprain and postural sway in basketball players. *Knee Surg Sports Traumatol Arthrosc*. 1993;1:203-205.
31. Leger LA, Mercier D, Gadoury C, et al. The multistage 20 metre shuttle run test for aerobic fitness. *J Sports Sci*. 1988;6:93-101.
32. Lentell G, Baas B, Lopez D, et al. The contribution of proprioceptive deficits, muscle function, and anatomic laxity to functional instability of the ankle. *J Orthop Sports Phys Ther*. 1995;21:206-215.
33. Lentell GL, Katzman LL, Walters MR. The relationship between muscle function and ankle stability. *J Orthop Sports Phys Ther*. 1990;11:605-611.
34. Liu W, Siegler S, Techner L. Quantitative measurement of ankle passive flexibility using an arthrometer on sprained ankles. *Clin Biomech (Bristol, Avon)*. 2001;16:237-244.
35. Lysens R. *Study to the Intrinsic Risk Factors of Sports Injuries in Young Adults*. Louvain, Belgium: Acco; 1984.
36. Lysens R, Steverlynck A, van den Auweele Y, et al. The predictability of sports injuries. *Sports Med*. 1984;1:6-10.
37. Lysens RJ, de Weerdt W, Nieuwboer A. Factors associated with injury proneness. *Sports Med*. 1991;12:281-289.
38. McGuine TA, Greene JJ, Best T, et al. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*. 2000;10:239-244.
39. McKay GD, Goldie PA, Payne WR, et al. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med*. 2001;35:103-108.
40. Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med*. 1994;4:166-170.
41. Milgrom C, Shlamkovitch N, Finestone A, et al. Risk factors for lateral ankle sprain: a prospective study among military recruits. *Foot Ankle*. 1991;12:26-30.
42. Munn J, Beard DJ, Refshauge K, et al. Eccentric muscle strength in functional ankle instability. *Med Sci Sports Exerc*. 2003;35:245-250.
43. Murphy DF, Connolly DAJ, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. *Br J Sports Med*. 2003;37:13-29.
44. Nawoczenski DA, Owen MG, Ecker ML, et al. Objective evaluation of peroneal response to sudden inversion stress. *J Orthop Sports Phys Ther*. 1985;7:107-109.
45. Ostyn M, Simons J, Beunen G, et al. *Somatic and Motor Development of Belgian Secondary Schoolboys, Norms and Standards*. Louvain, Belgium: Leuven University Press; 1980.
46. Payne KA, Berg K, Latin RW. Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *J Athl Train*. 1997;32:221-225.
47. Pope R, Herbert R, Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in Army recruits. *Aust J Physiother*. 1998;44:165-172.
48. Ryan L. Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. *Aust J Physiother*. 1994;40:41-47.
49. Shambaugh JP, Klein A, Herbert JH. Structural measures as predictors of injury in basketball players. *Med Sci Sports Exerc*. 1991;23:522-527.
50. Siri W. The gross composition of the body. In: Tobias C, Lawrence J, eds. *Advances in Biological and Medical Physics*. New York, NY: Academic Press; 1956:239-280.
51. Taimela S, Kujala UM, Osterman K. Intrinsic risk factors and athletic injuries. *Sports Med*. 1990;9:205-215.
52. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. *Med Sci Sports Exerc*. 1984;16:64-66.
53. Vaes P, Van Gheluwe B, Duquet W. Control of acceleration during sudden ankle supination in people with unstable ankles. *J Orthop Sports Phys Ther*. 2001;31:741-752.
54. Van de Vijver I, Wynant K. *New Balance Master: Research to the Reliability in a Healthy Population* [thesis]. Ghent, Belgium: Rehabilitation Sciences and Physiotherapy, Ghent University; 1999.
55. Van Mechelen W. Running injuries: a review of the epidemiological literature. *Sports Med*. 1992;14:320-335.
56. Watson AWS. Ankle sprains in players of the field-games Gaelic football and hurling. *J Sports Med Phys Fitness*. 1999;39:66-70.
57. Wilkerson GB, Pinerola JJ, Caturano RW. Invertor versus evertor peak torque and power deficiencies associated with lateral ankle ligament injury. *J Orthop Sports Phys Ther*. 1997;26:78-86.
58. Willems TM, Witvrouw E, Delbaere K, et al. Relationship between gait biomechanics and inversion sprains: a prospective study on risk factors. *Gait Posture*. In press.
59. Willems TM, Witvrouw E, Verstuyft J, et al. Proprioception and muscle strength in patients with a history of ankle sprains and functional instability. *J Athl Train*. 2002;37:487-493.
60. Williams DS, McClay IS, Hamill J. Arch structure and injury patterns in runners. *Clin Biomech (Bristol, Avon)*. 2001;16:341-347.
61. Wright IC, Neptune RR, van den Bogert AJ, et al. The influence of foot positioning on ankle sprains. *J Biomech*. 2000;33:513-519.
62. Zelisko JA, Noble HB, Porter M. A comparison of men's and women's professional basketball injuries. *Am J Sports Med*. 1982;10:297-299.