# Musculoskeletal Risk Factors as Predictors of Injury in Community-Dwelling Women

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**ABSTRACT**

TRUDELLE-JACKSON, E., D. LEONARD, and J. R. MORROW, Jr. Musculoskeletal Risk Factors as Predictors of Injury in Community-Dwelling Women. *Med. Sci. Sports Exerc.*, Vol. 46, No. 9, pp. 1752–1757, 2014. **Background**: Participating in health-related physical activity (PA) may increase risk for musculoskeletal injury (MSI). **Purpose**: This study aimed to estimate the prevalence of structural/biomechanical risk factors in community-dwelling women and associated risk for incidence of MSI in women who are physically active. **Methods**: The Women's Injury study is a surveillance of PA behaviors and MSI in women age 20–83 yr. An orthopedic examination was performed before entry into the study to assess presence of structural/biomechanical risk factors. A total of 886 women completed data collection by reporting weekly PA behavior and MSI for up to 3 yr (2007–2009), with the average participant enrolled for 98 wk. To estimate MSI risk associated with each risk factor separately, time to first MSI was modeled using proportional hazard regression with time-dependent PA covariates, controlling for age, body mass index, and previous injury. **Results**: Over the course of the study, 236 of the women (26.6%) reported at least one MSI that was PA related. We found a significant association between the number of high flexibility risk factors and PA-related injury at all levels of PA exposure (HR = 1.15 and confidence interval (CI) = 1.04–1.27 for moderate-to-vigorous PA; HR = 1.16 and CI = 1.05–1.28 for moderate PA; HR = 1.15 and CI = 1.04–1.27 for vigorous PA). **Conclusions**: When participating at any level of PA for health benefits, women with hypermobility in multiple muscle groups or joints should be watchful for musculoskeletal symptoms and should be counseled not to ignore symptoms when they first occur. **Key Words:** PHYSICAL ACTIVITY BEHAVIOR, HYPERMOBILITY, PHYSICAL ACTIVITY GUIDELINES, STRUCTURAL FACTORS



In 2008, 63% of deaths were due to noncommunicable diseases (NCD) (40). Smoking and physical inactivity are the two primary risk factors for NCD, with each contributing to approximately 5 million deaths annually (25). Reducing physical inactivity has and will continue to be a public health priority to reduce NCD and the associated burden. The recommendation for a minimum of 150 $min \cdot wk^{-1}$ of moderate aerobic physical activity (PA) for all adults is an example of a public health effort to improve health by reducing physical inactivity (38).

Participating in PA for health benefits is a long-term behavior choice that is difficult for some people and not without potential drawbacks. Meeting the U.S. Department of Health and Human Services PA guidelines has been associated with increased risk for musculoskeletal injury (MSI) (30). In a surveillance study of 909 community-dwelling women over a period of up to 3 yr, women who met the PA guidelines for moderate-to-vigorous activity were more likely to report PA injuries than women who did not meet guidelines (HR = 1.39; confidence interval (CI) = 1.05–1.85) (30). There are studies examining associations of intensity and duration of PA on MSI in healthy, recreationally active adults (19) and studies regarding associations of structural/biomechanical factors on MSI in selective sports (15,17), on runners, (8,27) and in training of military recruits (10). However, we are unaware of any studies addressing structural/biomechanical risk factors for MSI in people participating in PA sufficient for health benefits. Understanding structural/biomechanical risk factors for MSI when undertaking PA for health benefits would be valuable for educating people about these risk factors and potentially preventing MSI. The purpose of this study was to estimate the prevalence of specific structural/biomechanical risk factors in community-dwelling women and the associated risk for incidence of MSI in women who are physically active.

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## METHODS

The Women's Injury study is a surveillance of PA behaviors and MSI in adult community-living women age 20–83 yr. Participants were recruited from the general population in the Dallas, TX, area. Recruitment efforts included contacting women who had previously expressed interest or been involved in other Cooper Institute studies. Additional recruitment strategies included advertisements, health fairs, word of mouth, and community meetings. Women who needed an assistive device to ambulate or who had a disease or condition that limited their mobility or limited or interfered with their usual daily or recreational activities were excluded. Details of the Women's Injury study are presented elsewhere (2). Study procedures were approved annually by the Cooper Institute's institutional review board. Upon entry into the study, informed consent for participation was obtained, a questionnaire of demographic and medical history information was completed, and a baseline orthopedic examination was conducted by a physical therapist.

## Measurements

Anthropometric, muscle strength, muscle length/flexibility, structural, and ligament laxity measures were taken during the baseline orthopedic examination. A description of the orthopedic tests and measures is presented, followed by a description of PA and injury surveillance. Orthopedic tests and measures were taken once at the start of the study, whereas PA and injury were surveyed over the duration of the study for up to 3 yr.

**Anthropometric measurements.** Height and weight were measured with a stadiometer (Meyer Distributing, Twinsburg, OH) and digital scale (Tanita Corp., Arlington Heights, IL), respectively. Skinfold measurements were taken at three sites (triceps, suprailiac, and thigh) with a Lange caliper (Beta Technology, Santa Cruz, CA), and percentage of body fat was estimated using the Jackson–Pollock equation (20).

**Muscle strength measurements.** For strength measurements, two trials were performed for each side and the mean for the two trials was recorded. Grip strength was measured with a Jamar grip dynamometer (Sammons Preston Inc., Bolingbrook, IL) according to standardized testing procedures developed by the American Society for Hand Therapists (16).

Lower extremity muscle strength was measured with the Human Performance Measurement (HPM) system (Human Performance Measurement Inc., Arlington, TX). HPM is a computer-automated system that assesses a selection of sensorimotor functions called basic elements of performance (BEP). The BEP IIIa is a handheld dynamometer (HHD) and a component of the HPM system that measures and records isometric muscle strength in newton-meters (N·m) of torque. Lower extremity muscle strength testing was performed bilaterally on the following muscle groups: hip abductors, hip external rotators, knee extensors, and knee flexors. Previous studies show that strength of the tester can be a factor in the reliability of forces measured with an HHD (1,39). To remove tester strength as a variable, straps were used to stabilize the dynamometer during testing of all lower extremity muscle groups. Reliability of strength testing of the hip abductors and external rotators (intraclass correlation coefficient $(ICC)_{3,3}$ = 0.97 and 0.85, respectively) (6) and knee extensors and flexors ($ICC_{3,2}$ = 0.93 and 0.84, respectively) (34) using an HHD stabilized with a strap has been demonstrated. For all lower extremity muscle tests, the examiner used one hand to stabilize the body part tested while maintaining the position of the HHD under the stabilization strap with the other hand. All strength values were adjusted for body weight before data analysis.

**Muscle length and flexibility measurements.** Lumbar spine flexion and extension flexibility and muscle length of the hamstrings and gastrocnemius were assessed using the BEP VIIa, an electronic inclinometer component of the HPM system.

To measure lumbar spine flexion, participants stood upright with arms at the side. The tester demonstrated the motion to the participant and instructed her to bend forward as far as possible, keeping her knees straight. Lumbar spine extension was measured in the same manner except that the participant was instructed to lean back as far as possible, keeping her knees straight. Three test trials were performed for each, and the mean of the two closest trials was recorded. A full description of lumbar spine flexion and extension measurement methodology is published elsewhere (37). Intrarater reliability of lumbar spine measurements using the BEP VIIa electronic inclinometer and the measurement procedures described above has been excellent for lumbar flexion ($ICC_{3,2}$ = 0.97) and extension ($ICC_{3,2}$ = 0.94) (37). Interrater reliability for the same measurements yielded an $ICC_{2,2}$ of 0.90 and 0.78 for lumbar spine flexion and extension, respectively (37).

For muscle length measurements of the hamstring, the active knee extension test was performed. The participant lay supine with the test hip and knee each flexed 90°, while the opposite leg was kept supported on the table in an extended position. The tester then stabilized the flexed hip while the participant actively extended her knee as far as possible. The degree to which she could actively extend the knee while the hip was kept flexed 90° was measured using the inclinometer and recorded in degrees of knee flexion. Reliability of the active knee extension test has been demonstrated (ICC = 0.94–0.96) (7,34) and is commonly used in the clinic to quantify hamstring muscle length. Muscle length of the gastrocnemius muscle was measured as degrees of ankle dorsiflexion attainable when measured with the knee extended, effectively lengthening the gastrocnemius muscles across the knee and ankle simultaneously. Reliability of this measurement was previously demonstrated ($ICC_{3,2}$ = 0.94–0.96) (34). Muscle length tests of the hamstrings and gastrocnemius were performed bilaterally.

**Measures of structural factors and ligament laxity.** A battery of clinical tests assessed the presence of structural factors believed to be predictors of MSI on the basis of previous studies of military recruits (10), sports participants (35), and runners (8,28,36) or on clinical judgment. Clinical tests included measurement of *genu recurvatum* and *genu varum/valgum* as determined by pelvic–patellar ratio, true leg length difference, functional leg length difference, knee

*Q*-angle, and navicular drop test. In addition, three ligament laxity tests were conducted. Anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) laxity was assessed using a MEDmetric KT 1000™ arthrometer (MEDmetric, San Diego, CA), with the knee flexed 20°, in neutral rotation, and an applied force of 89 N (11,18). Laxity of the anterior talofibular ligament was assessed using a noninstrumented anterior drawer test. Clinical judgment of a positive anterior drawer test of the ankle as determined by presence of ligament laxity is commonly used in the clinic. Although there have been attempts to implement instrumentation of the ankle drawer test, the manual test remains the most important clinical test for assessing anterolateral ankle ligament stability, and the test has been shown to have acceptable reliability (ICC = 0.94) (12). Space limitation does not allow a description of each test, but a description and relevant references are available from the author.

**Website surveillance of PA and injury.** PA and injury surveillance started once the baseline orthopedic examination was completed. Participants entered information weekly on moderate and vigorous aerobic PA via the Internet. Moderate PA included activities such as brisk walking, bicycling, gardening, or any PA that caused small increases in breathing or heart rate that would not make one strain. Vigorous PA included running, heavy yard work, or any PA causing large increases in breathing or heart rate and would eventually make one strain. Women reported weekly participation in PA as days and minutes per week. Using the recommendation by the *2008 Physical Activity Guidelines for Americans* (38), total moderate-to-vigorous PA (MVPA) was calculated by summing the number of minutes of moderate PA with two times the number of minutes of vigorous PA per week. It should be noted that participants were not asked to *change* their level of PA but simply to report it weekly as described below.

For injury surveillance, participants responded weekly to the question "Did you have an injury (new, old, or recurrent) this week that caused you to see a health care provider or interrupted your daily activities for two or more days?" Study personnel then followed up with a telephone call, typically within 48–72 h of a reported injury, to confirm that the injury truly was an MSI and to obtain additional information such as how the injury occurred and whether it was related to performing PA.

### Data Analysis

To determine the prevalence of structural/biomechanical risk factors in community-dwelling women, values outside the normal range as defined in the literature were used. When normative values were not defined in the literature, the top or bottom quintile values were used as potential risk factors for MSI. The practice of using the top or bottom quintile of values as being "outside of normal" when a specific value has not been identified is common practice in the literature (10,21).

Presence of risk factors was assessed in four categories: a) muscle strength, b) muscle length and flexibility, c) structural, and d) ligament laxity. For each of the categories, a score determined by the total number of positive tests in that category was assigned as follows.

For all muscle strength variables, tests were coded as being positive for presence of a risk factor when the measure was in the bottom quintile of our sample distribution for any of the muscle groups on the right or left side. Because strength measures were obtained bilaterally on five different muscle groups, a participant's score could range from 0 (not in the bottom quintile for any muscle group) to 10 (in the bottom quintile for all five muscle groups bilaterally). For muscle length and flexibility variables, two categories of risk factors were identified: hypermobility and hypomobility. Tests were coded as being positive for presence of hypermobility when the measure was in the top quintile and positive for presence of hypomobility when the measure was in the bottom quintile of our sample distribution. Because there were mobility measures for lumbar flexion and extension, right and left gastrocnemius, and hamstring muscle groups, a participant's score could range from 0 to 6 for hypermobility and from 0 to 6 for hypomobility. For structural risk factors, a participant's score could range from 0 to 10 (right and left *recurvatum* >5° (33), right and left *Q*-angle ≥20° (14,28), right and left navicular drop ≥10 mm (3,31), true leg length difference ≥10 mm (5,32), functional leg length difference ≥10 mm (5,32), top quintile pelvic–patellar ratio for *genu valgum* and bottom quintile pelvic–patellar ratio for *genu varum* (10)). For ligament laxity variables, scores could range from 0 to 5 (right and left ACL ≥6 mm (11,18), positive anterior talofibular ligament test result (12), and excessive PCL difference (>2 mm) between sides (13)).

We identified the 20th ($P_{20}$) and 80th ($P_{80}$) sample percentiles of continuous risk. Next, we estimated HR for MSI risk factors using Cox regression with time-dependent PA covariates and discrete (weekly) time scale. Length in minutes of time-dependent PA (moderate, vigorous, or MVPA) used to predict injury in each week was determined by averaging the reported activity from baseline to the previous week. We initially included risk factor–age and risk factor–PA interaction terms in each model but removed these if they were not statistically significant. All models included age and BMI as additional covariates and were stratified by previous injury. We justified the proportional hazard assumption by testing cumulative sums of residuals (26). SAS/STAT® version 9.2 (SAS Institute Inc., Cary, NC) was used for all analyses.

## RESULTS

An orthopedic examination was conducted on 918 women, but nine never completed any weekly PA reports. For the remaining 909 women, age ranged from 20 to 83 yr (mean, 52.7 ± 12.5 yr) and body mass index ranged from 16.7 to 67.1 kg·m$^{-2}$ (mean, 27.6 ± 6.2 kg·m$^{-2}$). Our goal was to recruit a minimum of 25% minority participation, and this goal was nearly achieved, with 77% of our participants being White and the remaining being non-White (Black, Hispanic/Latina, other). Although participants reported weekly PA behavior and MSI for up to 3 yr, the average participant was enrolled for 98 wk and submitted an average of 92 weekly reports of PA and injury. An additional 23 participants had missing values for one or more of the predictor variables, bringing the total number of participants excluded from data analysis to 32 and a total sample size of 886 women. Over the course of the study, 236 of the women (26.6%) reported at least one MSI that was PA related. A more complete description of the injuries sustained, including the body part affected, cause of injury, and number of women sustaining more than one injury, is reported elsewhere (30).

Table 1 lists the muscle strength and flexibility values at $P_{20}$ and $P_{80}$. For the structural and ligament laxity variables, the number and percentage of participants who demonstrated presence of risk as defined in the literature are presented in Table 2, along with the number of participants with presence of the risk factor who reported an injury. Pelvic–patellar ratio is presented differently from other structural variables because presence of risk is defined in the literature as the top quintile (*genu varum*) or bottom quintile (*genu valgum*) (10). Therefore, $P_{20}$ represents the value of *genu varum*, below which the extremes of *genu varum* fall, and $P_{80}$ represents the value of *genu valgum*, above which the extremes of *valgum* fall (Table 1).

We calculated HR to identify the risk of MSI for women having risk factors in the categories of muscle strength, muscle length/flexibility, structural factors, or ligament laxity, taking into consideration the number of hours of MVPA, moderate PA, or vigorous PA. We found no interaction effects between any of the categories of risk factors and either age or number of hours of exposure to MVPA, moderate PA, or vigorous PA. The main effects of risk factor category and PA exposure were then explored. A statistically significant association was found between the number of high-flexibility risk factors and occurrence of PA-related injury at all levels of PA exposure (HR = 1.15 and CI = 1.04–1.27 for MVPA exposure; HR = 1.16 and CI = 1.05–1.28 for moderate PA; HR = 1.15 and CI = 1.04–1.27 for vigorous PA). That is, a woman's risk of PA-related injury increases by 15%–16% with presence of each additional high-flexibility risk factor at any age or level of PA exposure. All other categories of risk factors (muscle strength, low muscle length/flexibility, structural factors, and ligament laxity) had no significant effect on risk of injury.

TABLE 1. $P_{20}$ and $P_{80}$ values for muscle strength, length/flexibility, and pelvic–patellar ratios.

| Measure | $P_{20}$ Right | $P_{20}$ Left | $P_{80}$ Right | $P_{80}$ Left |
|---|---|---|---|---|
| Muscle strength[a] | | | | |
| Hand grip | 0.29 | 0.27 | 0.47 | 0.43 |
| Hip abductors | 0.41 | 0.38 | 0.87 | 0.76 |
| Hip external rotators | 0.24 | 0.25 | 0.47 | 0.48 |
| Knee flexors | 0.38 | 0.37 | 0.72 | 0.71 |
| Knee extensors | 0.82 | 0.81 | 1.46 | 1.46 |
| Flexibility/muscle length (°) | | | | |
| Lumbar flexion | 7.75 | | 24.10 | |
| Lumbar extension | 43.20 | | 63.10 | |
| Hamstrings[b] | 38.80 | 35.10 | 13.50 | 11.20 |
| Gastrocnemius | 94.65 | 93.60 | 106.35 | 105.60 |
| Pelvic–patellar ratio | | | | |
| *Genu varum* | 1.53 | | | |
| *Genu valgum* | | | 1.96 | |

[a]Muscle strength values are adjusted for body mass.
[b]Values for hamstring length are the number of degrees of knee flexion during the active knee extension test, and therefore, larger values represent a greater degree of hypomobility ($P_{20}$), whereas lower values represent a greater degree of hypermobility ($P_{80}$).

TABLE 2. Prevalence of at-risk musculoskeletal factors.

| Musculoskeletal Factor | No Injury[a] (*n* = 650) *n* (%) | ≥1 Injury[b] (*n* = 236) *n* (%) | All[c] (*n* = 886) *n* (%) |
|---|---|---|---|
| Structural factors | | | |
| True LLD | 73 (11.2) | 33 (14.0) | 106 (12.0) |
| Functional LLD | 35 (5.4) | 22 (9.3) | 57 (6.4) |
| *Q*-angle | | | |
| Unilateral risk | 137 (21.1) | 66 (28.0) | 203 (22.9) |
| Bilateral risk | 319 (49.1) | 104 (44.1) | 423 (47.7) |
| Excessive *genu recurvatum* | | | |
| Unilateral risk | 23 (3.5) | 11 (4.7) | 34 (3.8) |
| Bilateral risk | 20 (3.1) | 6 (2.5) | 26 (2.9) |
| Positive navicular drop test | | | |
| Unilateral risk | 61 (9.4) | 25 (10.6) | 86 (9.7) |
| Bilateral risk | 70 (10.8) | 18 (7.6) | 88 (9.9) |
| Ligament laxity | | | |
| *Excessive ACL laxity* | | | |
| Unilateral risk | 39 (6.0) | 13 (5.5) | 52 (5.9) |
| Bilateral risk | 18 (2.8) | 8 (3.4) | 26 (2.9) |
| *Excessive PCL laxity*[d] | 13 (2.0) | 6 (2.5) | 19 (2.1) |
| Ankle anterior drawer sign | | | |
| Unilateral risk | 122 (18.8) | 45 (19.1) | 167 (18.8) |
| Bilateral risk | 22 (3.4) | 8 (3.4) | 30 (3.4) |

[a]Represents the number and percentage of participants who reported no injuries.
[b]Represents the number and percentage of participants who reported at least one injury.
[c]Represents the total number and percentage of participants.
[d]Only one value is shown because presence of excessive PCL laxity was determined by a difference in arthrometer readings between the right and left sides being >2 mm.
LLD, leg length difference.

## DISCUSSION

We found a significant association between the number of high-flexibility risk factors and occurrence of MSI in women regardless of PA exposure. Measures of lumbar flexion and extension flexibility, right and left gastrocnemius, and right and left hamstring flexibility were all examined, so a woman's hypermobility score could range from 0 to 6. Our results revealed that a woman's risk for MSI increased by 15%–16% for each additional high-flexibility risk factor, and this risk did not vary significantly with age or level of PA exposure. Reduced flexibility was not associated with increased MSI. The body of literature as regards reduced flexibility and MSI has been mixed but mostly supportive of no association. A Cochrane review of 25 trials assessing the effects of interventions for preventing soft tissue running injuries revealed that there was no evidence that stretching decreases lower limb soft tissue injuries (41). Several authors found a U-shaped relation between flexibility and MSI, meaning that injuries in infantry soldiers

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were more common in the most flexible and least flexible quintiles (9,22). Blair et al. (4) studied flexibility of the gastrocnemius, hamstrings, and back extensors using the sit-and-reach test in sedentary workers who started a fitness program and found that those with higher flexibility were slightly more likely to be injured (4). In a study of predictors of injury in 532 novice runners preparing for a 4-mile running event, measures of hip internal and external rotation and ankle dorsiflexion were not related to injury (8).

The main difficulty in comparing the results of our study with previous findings is that most studies of potential predictive factors for MSI have been conducted on mostly male military recruits who are subjected to intense and rapid increases in training volume to which they are unaccustomed. In our study of community-dwelling women, participants were not asked to change their habitual activity. To confirm that our participants' habitual activity did not change, we assessed the long-term stability of reported PA measures across the study period and found the reported PA behaviors to be remarkably consistent (29). The consistent PA behavior throughout our study could explain why biomechanical factors found to be predictive of MSI in other studies were not associated with injury in ours. For example, in an earlier study of lower extremity structure and alignment as predictors of overuse injury, increased *genu valgum* was predictive of overuse injury (relative risk = 1.9; 95% CI = 1.1–3.3), but the study included only male infantry recruits. The recruits participated in 12 wk of basic army training where they ran or marched an average of 40 min on each of 5–6 $d \cdot wk^{-1}$.(9) In another study, predictors of running-related injuries were examined in novice runners who started training for a 4-mile running event (8). Degree of navicular drop was a significant predictor of injury in female participants (HR = 0.87; 95% CI = 0.77–0.98) but not in male participants. Participants in this Buist (8) study of novice runners could only be included if they had not been running on a regular basis. Therefore, the training for a 4-mile running event represented a change in their habitual training.

In our study, community-dwelling women were studied for an average of 98 wk. They were not asked to change their habitual PA, so they likely avoided the common "training errors" that frequently lead to injury. Because the women were not asked to participate in PA at levels that they were unaccustomed to, it may simply take longer for an injury to develop, even in the presence of risk factors. Women who did not sustain an injury in the period studied may sustain one later. A study of musculoskeletal factors as predictors of MSI in community-dwelling women should be conducted over a longer period to validate the results of our study.

In a previously published article regarding MSI and self-reported PA behavior, we provide evidence that community-dwelling women who met the PA guidelines for 150 $min \cdot wk^{-1}$ was associated with an increase in PA-related MSI and that further increasing PA to ≥300 $min \cdot wk^{-1}$ resulted in even higher rates of PA-related MSI when compared with women not meeting guidelines (30). Because the injuries were self-reported, with a relatively small portion of women seeking medical intervention for their injuries, we did not have a medical diagnosis for most of the MSI sustained. Similarly, in our current study of musculoskeletal risk factors as predictors of MSI, we have no way of knowing the specific injury or severity of injury that women with excessive mobility sustained. We do know, however, that the majority of injuries sustained overall were minor and that associated large expenses were uncommon (23).

When participating at any level of PA for health benefits, women should be concerned about increased risk of injury if they have hypermobility in multiple muscle groups or joints. Unfortunately, there is no known resolution to the problem of hypermobility other than avoiding activities that may cause further stretching of the muscles or joints. Perhaps the most important information to provide women with hypermobility risk factors is not to ignore musculoskeletal symptoms when they first occur. Muscle weakness, hypomobility, and other biomechanical and structural characteristics studied do not appear to put women at increased risk when participating in PA for health benefits. Given that hypomobility did not increase risk for MSI although hypermobility did increase risk in women participating in PA, the results of our study in combination with previous studies (24,41) do not support the practice of stretching for warm-up before PA.

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The authors have no conflict of interest to declare.

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