

Internal Risk Factors for Low Back Pain in Pole Vaulters and Decathletes

A Prospective Study

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Background: Pole vaulters and decathletes frequently experience several types of injuries to their lower back, often resulting in mechanical low back pain (LBP). However, the risk factors for the occurrence of LBP in these athletes have not been defined.

Purpose: To determine the physical factors that relate to LBP occurrence for collegiate pole vaulters and decathletes.

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

Methods: We observed 31 pole vaulters and decathletes for 1 year. At the start of the observation period, isokinetic flexion and extension muscle strength of the knee and hip joints were recorded along with active and passive range of motion (ROM) and muscle tightness. Participants were then divided into 2 groups using the median value of each measurement: those below the median (low group) and those above the median (high group). The log-rank test was used to compare LBP occurrence between the low group and high group for all measurements. Multivariate regression analyses were thereafter applied using the Cox proportional hazards regression.

Results: Log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the participants with chronic LBP ($P = .037$), the low group for hip flexion peak torque per body weight on the non-takeoff leg ($P = .047$), and the low group for passive hip flexion angle on both legs (takeoff leg: $P = .034$; non-takeoff leg: $P = .023$). In addition, log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the low group for passive hip extension angle on the takeoff leg only for the participants without chronic LBP ($P = .014$).

Conclusion: It may be necessary to acquire sufficient ROM and hip flexion to prevent LBP occurrence in pole vaulters and decathletes.

Keywords: lumbago; sports injury; injury prevention; track and field; athletics

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Pole vaulters encounter several types of injuries: some acute^{1,2} and others chronic. Rebella¹⁶ reported that the lower back is the most common injury location in collegiate pole vaulters. He discussed that pole vaulters might be particularly susceptible to such injuries because the plant and takeoff phases place the spine in forced hyperextension as the athlete drives forward off the ground. A previous study⁹ reported that a maximum angular acceleration of 150 rad/s² occurs during takeoff. It is possible that the body suddenly extends at takeoff. The lumbar spine may overextend, and the load on the lumbar spine may be great. Thus, it is possible that the limited range of motion (ROM) in the shoulder joint, hip joint, and lower back causes a compensatory motion that leads to low back pain (LBP). Previous studies have reported that a limited ROM of hip extension and shoulder flexion was related to LBP in swimmers¹² and male elite divers.¹⁴ Furthermore, physical factors of the

sagittal plane, such as the lack of leg strength during the run-up, takeoff, and pole-bending phases, are inferred to be associated with LBP.

Enoki et al⁶ previously analyzed associations between chronic LBP and physical factors in a related cross-sectional study of 20 male collegiate pole vaulters. The results indicated that the personal best record and active straight-leg raise (SLR) angle on the takeoff leg in the chronic LBP group were significantly lower and smaller than in the nonchronic LBP group. The difference between the passive SLR angle and active SLR angle was also significantly larger in the chronic LBP group than in the nonchronic LBP group. In addition, a significantly greater proportion of the chronic LBP group had a Functional Movement Screen (FMS) composite score of ≤ 14 . However, the risk factors associated with LBP specific to pole vaulters have not been studied outside of the abovementioned study.

The purpose of this study was to determine the physical factors that relate to LBP occurrence in collegiate pole vaulters and decathletes. We hypothesized that a limited ROM in the shoulder joint or hip joint and decreased muscle strength in the hip would be positively associated with the occurrence of LBP.

METHODS

Participants

Athletes for this study were evaluated during September 2016. This longitudinal study involved 20 collegiate pole vaulters (12 male, 8 female) and 11 male collegiate decathletes (mean age, 19.6 ± 1.1 years; mean height, 173.3 ± 8.6 cm; mean body weight [BW], 66.1 ± 8.7 kg). Athletes with any pain at the time of measurements or with pain or anxiety that made them unable to practice were excluded from this study. All participants provided written informed consent, and the study was approved by the ethics committee of our institution.

The observation period for each participant was 1 year. We decided to include freshmen in May 2017 at the beginning of the study because the statistical power was expected to be low. Physical measurements were performed 1 time and included ROM and isokinetic muscle strength stratified by side (takeoff leg and non-takeoff leg). Participants were then divided into 2 groups using the median value of each measurement: those below the median (low group) and those above the median (high group).

Additionally, a questionnaire was used to collect information on the takeoff leg. This study measured factors based on the takeoff leg or non-takeoff leg.

Definition of LBP and Occurrence of LBP

Low back pain (LBP) was defined as an ache, pain, or discomfort in the region of the low back whether or not it extended to one or both legs (sciatica). In addition, LBP caused by extension and/or flexion of the lumbar spine in clinical examinations was defined as mechanical LBP. In

this study, the occurrence of LBP was defined as the occurrence of pain caused by training related to pole vaulting, which (1) caused the athlete to cease participation that day or miss a subsequent practice or competition^{16,17} (time-loss injury [TLI]) or (2) assumed that performance was limited because of pain, as indicated on the monthly questionnaire (non-time loss injury [NTLI]).

When LBP occurred, a physical examination was performed by a physician (T.S.) at the health service center or by a student trainer, and an interview was conducted by the first author (S.E.). Physicians evaluated all patients with TLIs, and a student trainer evaluated all patients with NTLIs. Through clinical tests, pain was characterized as present in 3 positions (lumbar flexion, lumbar extension, and both). Therefore, the occurrence of LBP was divided into 3 types (flexed, extended, and combined). Furthermore, at the beginning of each month, questionnaires were administered to investigate non-time loss LBP during the previous month. For non-time loss LBP, the questionnaire asked the following: "Has LBP adversely affected your performance?"

Injury History

The study involved obtaining information regarding each participant's history of LBP, defined as any injury that "caused the athlete to cease participation that day or miss a subsequent practice/competition." Chronic LBP was attributed to those with an awareness of their vulnerability to LBP. Participants who answered yes to the following question were assigned to the chronic LBP group: "Do you often feel LBP?"

Active and Passive ROM, Muscle Tightness, and Spinal Column Alignment

We used a camera (EX-F1; Casio) to measure active and passive ROM and muscle tightness of the shoulders, ankles, knees, and hip joints. The resulting photographs were analyzed using image analysis software (ImageJ Version 14.4; National Institutes of Health). The participants wore compression garments at the time of measurements, and a reference point was attached to these garments. We also calculated the difference between the active and passive ROM measurements (Δ).

Spinal column alignment in various postures (erect position and extended and flexed positions of crawling on hands and knees) was measured using the Spinal Mouse system (Spinal Mouse; Idiag).^{7,13} This device was guided along the midline of the spine beginning at the spinous process of C7 and finishing at S3. These landmarks were initially determined by palpation and marked on the skin surface using a cosmetic pencil. Thereafter, 2 rolling wheels were used to follow the contour of the spine and were interfaced with a personal computer. For each posture tested, the position of the thoracic (T1-T2 to T11-T12) and lumbar (T12-L1 to the sacrum) spine was recorded. The same examiner evaluated each participant in a single session.

Hip Flexion, Knee Flexion, and Isokinetic Extension Strength

Measurements were taken as described in a previous study.¹⁹ Isokinetic strength tests were performed using an isokinetic dynamometer (Biodex System 3; Biodex). The following testing protocol was used: isokinetic bilateral, extension/flexion pattern, isokinetic mode, concentric contraction, and 60 deg/s (3 repetitions) both for extension and flexion. Examiners also performed hip and knee strength tests on different days to exclude fatigue effects. The peak torque per BW (%) was analyzed.

During testing of the knee, the participant was seated on the dynamometer with his or her body stabilized by straps across the chest, pelvis, and thigh of the untested leg. The knee ROM was fixed at 90° of flexion from full extension.

During testing of the hip, each athlete was instructed to lie supine on the dynamometer with his or her body stabilized using straps across the chest, pelvis, and thigh of the untested leg. To reduce errors due to compensatory movements of the core, participants sought to fix their pelvis by maximally flexing their neck and contracting their rectus abdominis muscles. The knee angle was kept at 90° throughout the measurements, and the hip ROM was fixed at 115° of flexion from full extension.

Functional Movement Screen

In a previous study, the FMS demonstrated moderate value as an indicator of injuries.³ The FMS is an objective screening tool consisting of 7 movement tests (deep squat, hurdle step, in-line lunge, shoulder mobility, active SLR, stability push-up, and rotary stability) and 3 clearing tests (impingement, press-up, and posterior rocking). Scores range from 0 to 3 for each test, with the highest total score being 21. If pain occurred during the movement or clearing tests, the score of the relevant test was considered to be 0.

For the FMS, participants were divided into 2 groups using an FMS composite score of 14 as the dividing point ($FMS \leq 14$ and $FMS \geq 15$). This score was selected for grouping, as previous studies have reported that injuries tended to occur at FMS composite scores ≤ 14 .³ A composite score of 14 on the FMS indicates that 7 of the disciplines averaged ≤ 2 points.

A low FMS score was expected from the study participants because we included athletes with chronic LBP. Therefore, the FMS composite score groups were compared both with and without the results of the clearing tests. None of the participants experienced any pain during the movement tests.

Statistical Analysis

The time to the occurrence of LBP was analyzed using the Kaplan-Meier method for descriptively presenting data, and the log-rank test was performed as a univariate test for determining differences between the low and high groups.^{5,10} Multivariate regression analysis was thereafter applied using the Cox proportional hazards regression on the measurements that showed significant differences in the log-rank test. All tests were 2-sided, and $P < .05$ was

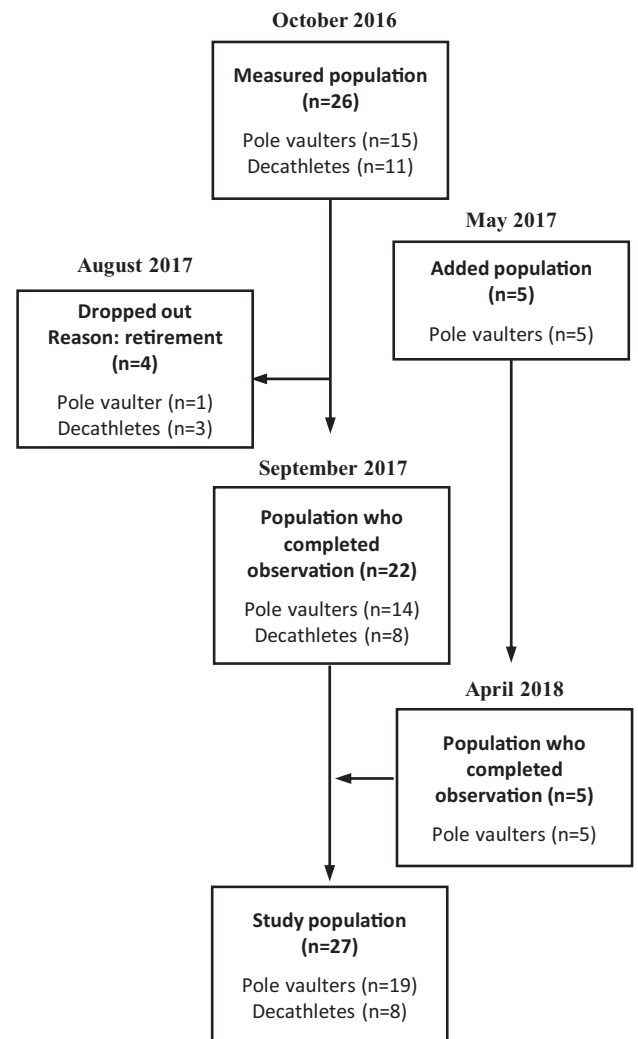


Figure 1. Flow chart of participant enrollment in the study.

considered statistically significant. The results of the study also allowed for the calculation of statistical power. EZR (Easy R; The R Foundation for Statistical Computing) software (Version 1.35) was used for data analysis.¹¹

RESULTS

Of the 31 study participants, 4 (12.9%) retired from sport and dropped out of the study during the 1-year observation period. None of these 4 athletes had chronic LBP. These 4 athletes were not included in the injury incidence analysis but were included in the analysis of LBP risk factors. Of the 27 remaining participants, 21 (77.8%) had a history of LBP, and 11 had chronic LBP. The inclusion of study participants is shown in Figure 1.

All Participants

Injury Incidence. During the 1-year observation period, LBP occurred in 15 participants (48.4%). In addition, 11

participants experienced TLIs, while only 4 experienced NTLIs. The occurrence of LBP is shown in Table 1.

Risk Factors. The median values of each measurement included in the analysis of LBP risk factors are shown in Tables 2 to 5.

Log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the participants with chronic LBP versus those without chronic LBP ($P = .037$) (Figure 2). No other statistically significant differences were observed between the groups.

Active and Passive ROM, Muscle Tightness, and Spinal Column Alignment. Log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the low group for passive hip flexion angle on both legs (takeoff leg: $P = .034$; non-takeoff leg: $P = .023$) (Figure 3). No other significant differences were observed between the 2 groups.

TABLE 1
Occurrence of LBP in All Participants^a

	LBP Occurrence		Type of LBP ^b		
	TLI	NTLI	Flexed	Extended	Combined
	Male pole vaulters (n = 12)	5	2	2	2
Female pole vaulters (n = 7)	3	1	4	0	0
Decathletes (all male; n = 8)	3	1	3	0	1
Total (N = 27)	11	4	9	2	4

^aData are presented as No. LBP, low back pain; NTLI, non-time loss injury; TLI, time-loss injury.

^bFlexed = pain during lumbar flexion; extended = pain during lumbar extension.

Hip Flexion, Knee Flexion, and Isokinetic Extension Strength. Log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the low group for hip flexion peak torque per BW on the non-takeoff leg ($P = .047$) (Figure 4). No other significant differences were observed between the 2 groups.

Functional Movement Screen. There were no significant differences found between the participants when divided according to FMS composite score ≤ 14 versus ≥ 15 .

Multivariate Analysis. The results of Cox multivariate regression analysis demonstrated a relationship between the occurrence of LBP and low hip flexion peak torque per BW on the non-takeoff leg (hazard ratio [HR], 3.805; $P = .026$) (Table 6).

Athletes Without Chronic LBP

Because LBP occurrence in athletes was associated with chronic LBP, we performed a subanalysis of LBP factors on athletes without chronic LBP. This included the 4 participants without chronic LBP who dropped out of the study as well as the 16 participants without chronic LBP.

Injury Incidence. This analysis included 16 participants who were observed for 1 year. LBP occurred in 7 participants without chronic LBP during the observation period: 4 participants experienced TLIs, and 3 experienced NTLIs (Table 7).

Risk Factors. A total of 20 participants without chronic LBP, including the 4 who dropped out, were included in this analysis to examine LBP risk factors. No significant differences in age, height, BW, and personal best record were observed between the low and high groups.

Active and Passive ROM, Muscle Tightness, and Spinal Column Alignment. Log-rank tests revealed a statistically significant change in the survival curve for the occurrence

TABLE 2
Participant Characteristics^a

	All (n = 31)	Without Chronic LBP (n = 20)	With Chronic LBP (n = 11)
Age, y	20.0 [19.0 to 20.5] (18.0 to 21.0)	20.0 [18.8 to 20.3] (18.0 to 21.0)	19.0 [19.0 to 20.5] (18.0 to 21.0)
Height, cm	175.0 [165.5 to 180.0] (155.0 to 188.0)	175.5 [171.5 to 180.0] (155.0 to 187.0)	170.0 [164.5 to 180.5] (157.0 to 188.0)
Body weight, kg	67.8 [59.7 to 71.4] (48.7 to 81.1)	71.0 [63.9 to 71.5] (49.4 to 77.1)	59.7 [55.3 to 69.6] (48.7 to 81.1)
Personal best record, m	4.0 [3.5 to 4.6] (3.0 to 5.5)	4.2 [3.4 to 4.6] (3.0 to 5.5)	3.7 [3.6 to 4.4] (3.4 to 5.1)
Spinal column alignment, ^b deg			
Thoracic kyphosis			
Erect	31.0 [26.5 to 37.5] (–14.0 to 50.0)	31.5 [27.0 to 37.3] (–14.0 to 46.0)	31.0 [24.5 to 37.0] (15.0 to 50.0)
Extended	9.0 [3.5 to 17.0] (–6.0 to 65.0)	10.5 [8.0 to 40.3] (–6.0 to 65.0)	5.0 [1.5 to 12.5] (–6.0 to 17.0)
Flexed	48.0 [35.5 to 57.5] (–38.0 to 69.0)	45.0 [33.3 to 58.5] (0.0 to 69.0)	50.0 [44.0 to 55.0] (–38.0 to 63.0)
Lumbar lordosis			
Erect	–23.0 [–27.5 to –18.0] (–34.0 to –5.0)	–23.5 [–27.8 to –21.5] (–34.0 to –10.0)	–20.0 [–26.5 to –13.5] (–33.0 to –5.0)
Extended	–29.0 [–32.0 to –20.0] (–50.0 to 32.0)	–25.5 [–33.5 to –8.5] (–41.0 to 32.0)	–30.0 [–32.0 to –27.5] (–50.0 to 17.0)
Flexed	17.0 [4.0 to 29.5] (–38.0 to 46.0)	15.0 [1.8 to 23.3] (–38.0 to 46.0)	23.0 [15.5 to 38.0] (2.0 to 41.0)

^aData are presented as median [interquartile range] (range). LBP, low back pain.

^bPositive values indicate kyphosis, and negative values indicate lordosis.

TABLE 3
ROM and Isokinetic Muscle Strength Measurements in All Participants (n = 31)^a

	Takeoff Leg	Non-Takeoff Leg
Passive shoulder flexion, deg	141.7 [136.4 to 146.2] (122.4 to 164.7)	137.0 [131.8 to 148.5] (116.0 to 165.5)
Passive ankle flexion, deg	11.0 [8.0 to 18.8] (1.7 to 27.1)	14.3 [11.1 to 17.2] (-1.0 to 32.0)
SLR, deg		
Passive	78.1 [72.2 to 86.5] (64.6 to 98.6)	78.8 [72.6 to 85.5] (62.8 to 109.5)
Active	69.5 [61.1 to 74.0] (49.4 to 102.1)	71.4 [66.7 to 78.5] (53.4 to 96.2)
Δ SLR	12.2 [4.8 to 14.5] (-14.9 to 28.8)	5.9 [3.1 to 12.1] (-8.0 to 26.8)
Passive knee extension, deg	67.2 [63.3 to 76.3] (51.5 to 86.1)	66.0 [59.4 to 76.2] (45.2 to 87.8)
Knee flexion, deg		
Passive	159.8 [158.5 to 165.2] (149.3 to 168.3)	161.9 [158.3 to 165.2] (148.1 to 169.7)
Active	142.8 [137.5 to 146.2] (127.3 to 155.8)	144.1 [137.6 to 146.7] (120.6 to 155.3)
Δ Flexion	17.9 [14.9 to 21.6] (10.9 to 26.1)	18.3 [16.1 to 20.3] (11.2 to 30.6)
Hip extension, deg		
Passive	16.1 [14.8 to 21.0] (11.1 to 26.0)	17.8 [15.3 to 21.0] (11.1 to 26.7)
Active	10.4 [7.4 to 13.8] (1.6 to 17.3)	10.6 [8.2 to 13.3] (2.3 to 21.2)
Δ Extension	6.7 [4.0 to 9.4] (-2.1 to 19.4)	8.2 [2.9 to 10.3] (-3.3 to 20.3)
Hip flexion, deg		
Passive	129.8 [125.7 to 135.2] (109.5 to 141.6)	132.7 [127.8 to 135.2] (114.5 to 142.3)
Active	116.0 [108.4 to 120.4] (95.8 to 129.9)	119.0 [112.4 to 121.5] (104.8 to 142.6)
Δ Flexion	14.7 [11.5 to 19.5] (4.1 to 32.3)	13.9 [8.3 to 17.0] (-1.8 to 21.7)
Isokinetic muscle strength, %		
Knee extension	254.7 [233.2 to 290.8] (171.8 to 372.3)	264.8 [237.4 to 282.8] (143.6 to 360.8)
Knee flexion	139.5 [123.3 to 160.3] (86.8 to 189.2)	138.8 [118.3 to 155.3] (91.4 to 186.4)
Hip extension	232.1 [200.9 to 251.9] (127.9 to 328.4)	237.2 [207.4 to 267.3] (150.8 to 351.8)
Hip flexion	201.8 [181.3 to 211.5] (143.4 to 266.4)	205.7 [174.9 to 222.7] (144.8 to 266.4)

^aData are presented as median [interquartile range] (range). ROM, range of motion; SLR, straight-leg raise.

TABLE 4
ROM and Isokinetic Muscle Strength Measurements in Participants Without Chronic LBP (n = 20)^a

	Takeoff Leg	Non-Takeoff Leg
Passive shoulder flexion, deg	140.6 [135.3 to 144.5] (122.4 to 162.1)	138.8 [132.4 to 148.2] (116.0 to 165.5)
Passive ankle flexion, deg	9.9 [7.7 to 20.1] (1.7 to 27.1)	15.5 [11.1 to 17.2] (-1.0 to 32.0)
SLR, deg		
Passive	78.5 [72.3 to 86.9] (67.4 to 98.6)	77.5 [73.4 to 85.6] (62.8 to 109.5)
Active	70.4 [64.7 to 77.0] (49.5 to 92.1)	73.8 [67.7 to 83.0] (55.7 to 96.2)
Δ SLR	10.9 [3.2 to 13.3] (-1.3 to 17.9)	5.7 [3.5 to 11.3] (-7.9 to 19.5)
Passive knee extension, deg	67.0 [61.7 to 73.8] (51.5 to 85.2)	65.4 [60.1 to 72.4] (47.7 to 83.6)
Knee flexion, deg		
Passive	159.4 [158.3 to 166.0] (149.3 to 168.3)	162.2 [159.1 to 165.6] (151.0 to 169.7)
Active	143.5 [139.1 to 146.2] (127.3 to 155.8)	143.1 [138.3 to 148.0] (120.6 to 155.3)
Δ Flexion	16.9 [14.0 to 22.0] (10.9 to 26.1)	18.2 [16.0 to 20.1] (11.2 to 30.4)
Hip extension, deg		
Passive	16.0 [14.8 to 18.7] (11.1 to 25.3)	18.1 [16.3 to 20.1] (11.1 to 26.7)
Active	10.4 [7.4 to 14.1] (1.6 to 17.3)	10.7 [8.3 to 13.2] (2.3 to 21.2)
Δ Extension	6.8 [4.5 to 9.7] (-1.7 to 15.7)	8.2 [1.9 to 10.5] (-0.8 to 20.3)
Hip flexion, deg		
Passive	131.5 [125.6 to 136.8] (109.5 to 141.6)	132.9 [128.2 to 136.4] (120.2 to 142.3)
Active	116.2 [107.8 to 122.0] (96.1 to 129.9)	120.4 [112.4 to 124.0] (106.7 to 142.6)
Δ Flexion	15.0 [12.8 to 19.1] (4.1 to 32.3)	13.9 [7.3 to 16.9] (-1.8 to 21.7)
Isokinetic muscle strength, %		
Knee extension	251.1 [233.9 to 285.3] (171.8 to 372.3)	263.8 [237.3 to 279.9] (143.6 to 318.3)
Knee flexion	141.9 [129.2 to 157.0] (101.1 to 181.6)	136.2 [118.8 to 155.5] (91.4 to 184.3)
Hip extension	229.1 [201.4 to 251.3] (127.9 to 328.4)	232.2 [202.2 to 226.9] (150.8 to 266.4)
Hip flexion	202.4 [191.3 to 226.9] (143.4 to 266.4)	210.2 [176.4 to 223.3] (147.2 to 256.2)

^aData are presented as median [interquartile range] (range). LBP, low back pain; ROM, range of motion; SLR, straight-leg raise.

TABLE 5
ROM and Isokinetic Muscle Strength Measurements in Participants With Chronic LBP (n = 11)^a

	Takeoff Leg	Non-Takeoff Leg
Passive shoulder flexion, deg	145.0 [141.3 to 148.9] (131.8 to 164.7)	137.0 [131.6 to 145.9] (119.9 to 164.1)
Passive ankle flexion, deg	12.9 [10.1 to 17.0] (5.4 to 19.4)	13.4 [10.8 to 16.6] (7.5 to 19.7)
SLR, deg		
Passive	74.8 [72.6 to 83.5] (64.6 to 90.7)	80.2 [70.9 to 85.4] (66.7 to 92.0)
Active	61.9 [60.0 to 70.8] (49.4 to 102.1)	69.9 [63.8 to 75.1] (53.4 to 90.8)
Δ SLR	13.1 [7.9 to 15.7] (-14.9 to 28.8)	6.9 [2.8 to 16.1] (-8.0 to 26.8)
Passive knee extension, deg	72.0 [63.8 to 77.8] (53.4 to 86.1)	71.0 [59.0 to 80.4] (45.2 to 87.8)
Knee flexion, deg		
Passive	160.2 [159.4 to 164.4] (149.9 to 165.7)	161.4 [158.3 to 164.5] (148.1 to 167.4)
Active	142.8 [137.3 to 146.2] (131.2 to 151.4)	144.1 [136.4 to 145.4] (134.3 to 147.8)
Δ Flexion	18.0 [16.8 to 20.0] (14.3 to 24.3)	18.3 [16.1 to 20.3] (12.2 to 30.6)
Hip extension, deg		
Passive	16.3 [13.9 to 22.4] (12.0 to 26.0)	16.0 [14.2 to 22.0] (11.7 to 24.4)
Active	10.1 [8.1 to 13.3] (5.1 to 14.9)	9.3 [8.4 to 13.4] (3.2 to 19.9)
Δ Extension	6.2 [4.0 to 9.1] (-2.1 to 19.4)	9.1 [3.1 to 10.3] (-3.3 to 13.1)
Hip flexion, deg		
Passive	129.8 [126.5 to 131.3] (111.7 to 135.5)	131.9 [124.0 to 133.9] (114.5 to 139.0)
Active	111.8 [110.7 to 118.4] (95.8 to 123.2)	117.7 [113.0 to 120.8] (104.8 to 122.9)
Δ Flexion	13.3 [9.7 to 21.0] (8.2 to 25.2)	13.9 [9.5 to 17.1] (2.3 to 21.2)
Isokinetic muscle strength, %		
Knee extension	255.5 [232.0 to 298.8] (213.2 to 357.2)	267.8 [237.4 to 282.8] (215.4 to 360.8)
Knee flexion	127.5 [110.6 to 160.4] (86.8 to 189.2)	147.2 [114.6 to 155.2] (100.7 to 186.4)
Hip extension	233.9 [203.5 to 253.9] (148.8 to 273.5)	237.2 [221.4 to 270.6] (151.6 to 351.8)
Hip flexion	185.6 [167.2 to 203.5] (153.7 to 207.8)	196.9 [169.6 to 216.1] (144.8 to 266.4)

^aData are presented as median [interquartile range] (range). LBP, low back pain; ROM, range of motion; SLR, straight-leg raise.

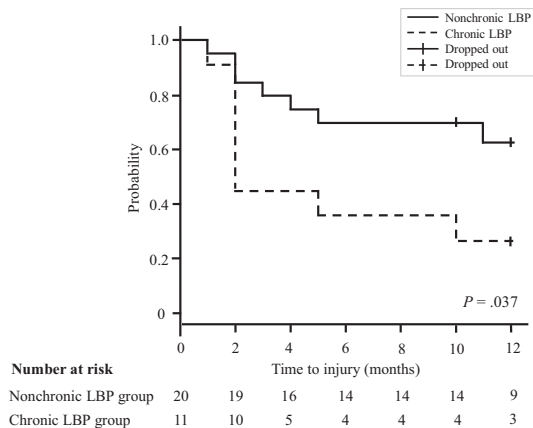


Figure 2. Kaplan-Meier curve for time to injury between the participants without chronic low back pain (LBP) and those with chronic LBP during the 1-year observation period.

of LBP in the low group for passive hip extension angle on the takeoff leg (HR, 9.008 [95% CI, 1.071-75.730]; $P = .014$) (Figure 5). No significant differences in other factors were observed between the high and low groups.

Hip Flexion, Knee Flexion, and Isokinetic Extension Strength. No significant differences in any factors were observed between the high and low groups.

Functional Movement Screen. There were no significant differences found between the groups when divided according to FMS composite score ≤ 14 versus ≥ 15 .

DISCUSSION

This prospective cohort study was the first to determine the risk of LBP occurrence in collegiate pole vaulters and decathletes. The purpose of this study was to clarify the physical factors associated with LBP occurrence in collegiate pole vaulters and decathletes. Log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the participants with chronic LBP, the low group for hip flexion peak torque per BW on the non-takeoff leg, and the low group for passive hip flexion angle on both legs. In only the participants without chronic LBP, log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the low group for passive hip extension angle on the takeoff leg.

During the 1-year observation period, 15 of 31 athletes experienced LBP. Clarsen et al⁴ reported that a new method of injury surveillance that uses questionnaire data captures a more nuanced and complete picture of the burden of overuse injuries. Thus, this study's use of questionnaire data made it possible to record LBP with greater accuracy. In addition, the most frequent categorization of LBP was the flexed type, which occurred in 9 athletes. In a previous study,⁹ LBP and spondylolysis fractures were attributed to forced hyperextension of the spine at plant and takeoff as the pole vaulter drives forward and upward. This study suggests the possibility of focusing on flexed-type LBP in future research on pole vaulters. Considering the vaulting motion, it is possible to consider the relationship between flexed-type LBP in the run-up and swing

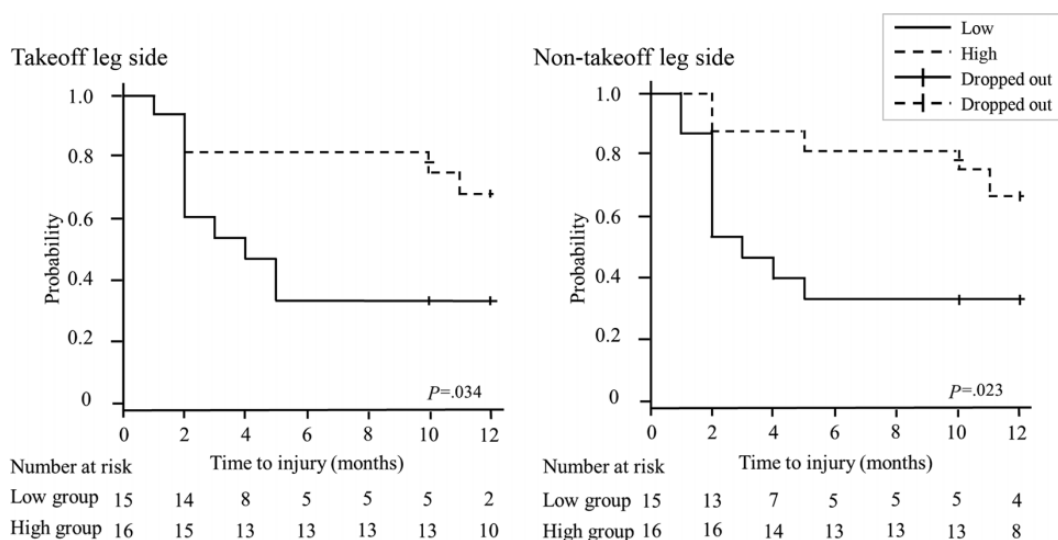


Figure 3. Kaplan-Meier curves for time to injury during the 1-year observation period display passive hip flexion angle by low and high groups for all participants.

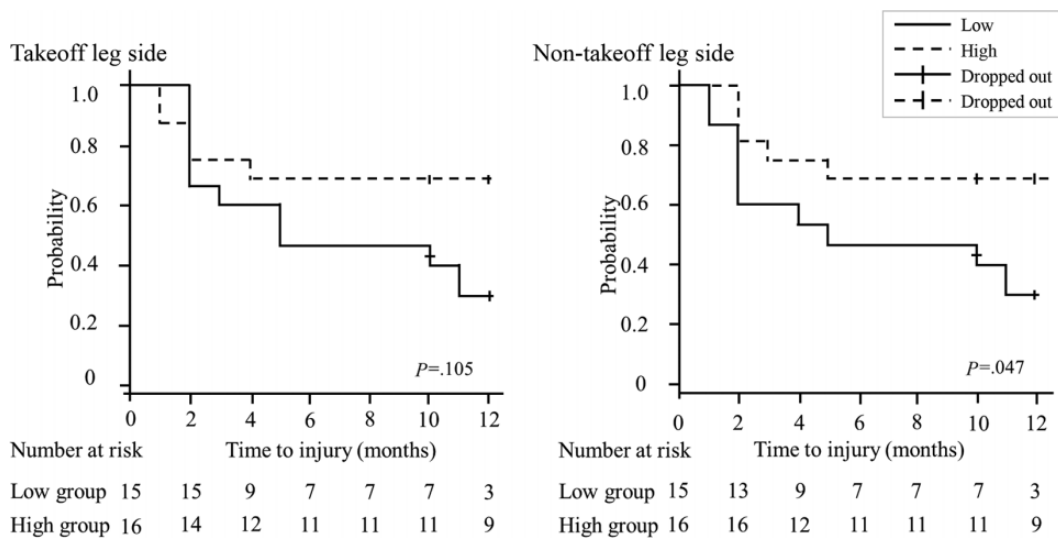


Figure 4. Kaplan-Meier curves for time to injury during the 1-year observation period display hip flexion peak torque per body weight by low and high groups for all participants.

phases of pole vaulting. The relationship between flexed-type LBP and the vaulting motion should also be clarified in future studies.

A comparison was made between the groups regarding the maximum torque per BW of the knee and hip joints in which the log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the low group for hip flexion peak torque per BW on the non-takeoff leg. In addition, the results of Cox multivariate regression analysis statistically demonstrated a relationship between the occurrence of LBP and low hip flexion peak torque per BW on the non-takeoff leg (HR, 3.805). Unlike other runners, pole vaulters run with a pole. Frère et al⁸ compared normal runs to running with a pole and

reported that force and speed in the horizontal direction are significantly reduced while running with a pole and that power decreases accordingly. Running with a pole restricts arm pretension, making it impossible to apply force to the ground. Unlike with other runners, we suggest that a pole vaulter who needs to run with a pole to apply a ground-reaction force may experience less strain on his or her lower back by using the strategy of raising the knees higher.

Log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the low group for passive hip flexion angle on both legs. The normal angle of hip joint flexion^{15,18} is 120° in healthy people, but the median hip flexion angle used for grouping in this study

TABLE 6
Results of Cox Proportional Hazards Multivariate Regression Analysis for Time to Injury^a

	P Value	HR (95% CI)
Nonchronic LBP (reference)		1.000
Chronic LBP	.064	2.743 (0.944-7.970)
Hip flexion		
High group (reference)		1.000
Takeoff leg	.058	3.328 (0.962-11.510)
Non-takeoff leg	.064	3.144 (0.936-10.560)
Hip flexion peak torque/BW		
High group (reference)		1.000
Non-takeoff leg	.026	3.805 (1.173-12.340)

^aBW, body weight; HR, hazard ratio; LBP, low back pain.

TABLE 7
Occurrence of LBP in Participants Without Chronic LBP^a

	LBP Occurrence		Type of LBP ^b		
	TLI	NTLI	Flexed	Extended	Combined
Female pole vaulters (n = 2)	1	0	1	0	0
Decathletes (all male; n = 6)	1	2	2	0	1
Total (n = 16)	4	3	5	1	1

^aData are presented as No. LBP, low back pain; NTLI, non-time loss injury; TLI, time-loss injury.

^bFlexed = pain during lumbar flexion; extended = pain during lumbar extension.

was 129.8° for the takeoff leg and 132.7° for the non-takeoff leg. However, there was a significant difference in the occurrence of LBP between the low group and high group for hip flexion, so it may be necessary for pole vaulters to increase their hip flexion angle to prevent LBP.

An analysis of the questionnaire responses showed that log-rank tests revealed a statistically significant change in the survival curve for the occurrence of LBP in the participants with chronic LBP. In other words, LBP is likely to recur within a year when the athlete is aware of his or her vulnerability to LBP. Therefore, an intervention to prevent LBP is necessary for athletes who are aware of their chronic LBP, even if they are not currently experiencing pain.

The subanalysis of athletes without chronic LBP indicated that LBP occurrence was associated with a low passive hip extension angle on the takeoff leg. Kitamura et al¹² reported that for swimmers, the LBP group had less hip extension ROM and a high elastic modulus of the psoas major than did the control group. In addition, that study reported that the LBP group showed a larger lumbar extension angle when performing a dolphin kick than did the control group. The lesser hip extension ROM was associated with a high psoas elastic modulus and large lumbar extension angle during the dolphin kick. Rebella¹⁶ reported that 30% of injuries, including 83% of low back injuries, occur during the plant and takeoff phase of the vault. It is possible that the lumbar spine extension in takeoff and the lesser hip extension ROM are associated with the occurrence of LBP in pole vaulters. Future studies need to be done to clarify the relationship between LBP and the lumbar extension angle in takeoff.

This study has several limitations. The participants might have had a history of LBP or chronic LBP, resulting in overreporting of the occurrence of LBP. For this reason, data from athletes without chronic LBP were also

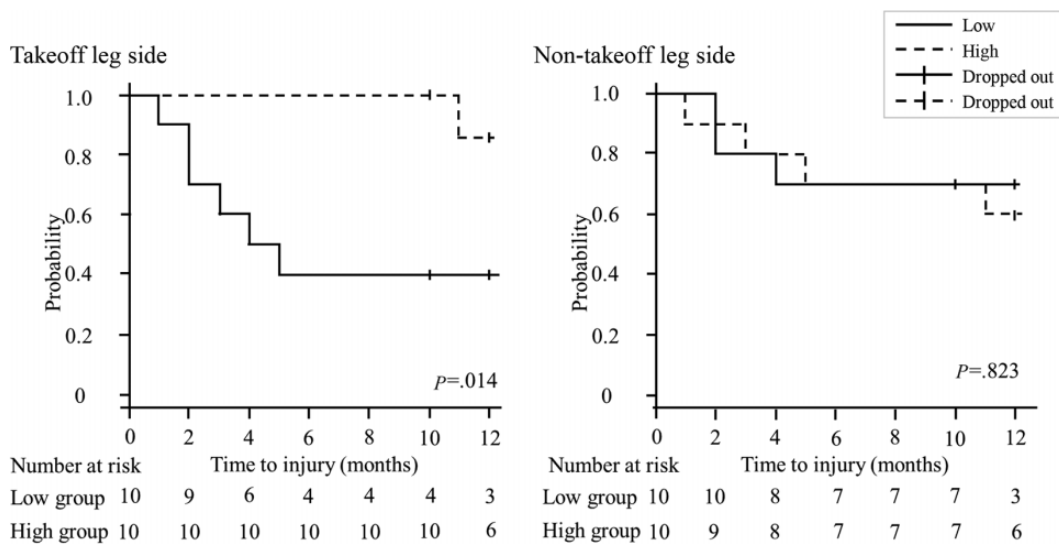


Figure 5. Kaplan-Meier curves for time to injury during the 1-year observation period display passive hip extension angle by low and high groups for participants without chronic low back pain.

separately analyzed. We also did not consider degenerative changes to the lumbar spine, which could influence LBP occurrence. If participants have degenerative changes, the lumbar spine is unstable and is likely to cause LBP. Radiography or computed tomography was not performed because of the risk of high radiation exposure. Additionally, the physical factors in this study were measured only once, at the beginning of the observation period. Therefore, it is possible that the numerical values of the physical factors changed during the observation period. Active ROM was measured by analyzing reference points attached to compression garments worn by the participants; however, it is possible that the reference points were misaligned during measurements. Many factors were measured in this study, and the alpha error in the statistical results was large.

Because this study focused on a small sample of collegiate pole vaulters and decathletes from a single institution, it is unknown whether the results can be generalized to all such athletes. Also, all the participants were Japanese, so it is not clear if the results would be the same in other ethnicities. We added a separate study population in April 2017 (5 pole vaulters) to ensure the largest number of participants. It is possible that the corresponding difference in the observation start time affected the occurrence of LBP. Participants in this study included not only pole vaulters but also decathletes. Because decathletes participate in 10 events, it is possible that the factors related to LBP in them differ from those specific to LBP in pole vaulters. The statistical power was calculated with the following protocol (registration period, 6 months; follow-up period, 12 months; total research period, 12 months; survival rate of group 1, 0.2%; survival rate of group 2, 0.6%; alpha error, 0.05; sample size of group 1, 15; sample size of group 2, 16). The statistical power was 0.562, which was reduced by the small sample size. Thus, there may be factors that were not detected. In future studies, it is necessary to include a greater number of participants from multiple institutions.

Despite the limitations, the present study represents a valuable starting point. Future research should clarify the relationships among factors by increasing the number of participants with longitudinal observations and multivariate analyses and should perform an analysis that relates pole vaulters with these factors. Intervention studies are needed to confirm that the factors resulting from this study are responsible for the occurrence of LBP.

CONCLUSION

This study showed a statistically significant change in the survival curve for the occurrence of LBP in the low group for hip flexion peak torque per BW, in the low group for passive hip flexion angle, and in the participants with chronic LBP. Therefore, it may be necessary to acquire sufficient ROM and hip flexion to prevent LBP occurrence in pole vaulters and decathletes.

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