Hypermobility and injury in dancers. A prospective cohort study

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Abstract

BACKGROUND: Joint hypermobility has a high prevalence in dancers and may be associated with injury and performance.

PURPOSE: To investigate the relationship between joint hypermobility and Joint Hypermobility Syndrome in university dancers.

METHODS: A prospective cohort injury study of 82 dancers (62 females, 20 males) who were assessed for joint hypermobility via the Beighton score ≥ 4 with lumbar flexion included and removed and for Joint Hypermobility Syndrome via the Brighton criteria.

RESULTS: Sixty-one dancers were classified as hypermobile which reduced to 50 dancers with lumbar flexion removed. A significant difference existed between pooled total days injured in hypermobile dancers and non-hypermobile dancers with lumbar flexion included ($p = 0.02$) and removed ($p = 0.03$). No significant differences existed for total Beighton score between injured and non-injured groups with lumbar flexion included ($p = 0.11$) and removed ($p = 0.13$). Total Beighton score was a weak predictor of total days injured ($r^2 = 0.06$, $p = 0.51$). Twelve dancers had Joint Hypermobility Syndrome. Forty-seven injuries occurred in 34 dancers and pooled injury rate was 1.03 injuries/1000 hours and lower limb injuries were most prevalent. Receiver operating characteristic curve analysis demonstrated an area under the curve of 0.83 for male dancers with lumbar flexion removed which was considered diagnostic for injury. **CONCLUSION:** The Beighton score can be utilised to identify dancers who may develop injury. Physiotherapists should consider the role of lumbar flexion in total Beighton score when identifying those dancers at risk of injury. Different injury thresholds in female and male dancers may aid injury management

Keywords: Beighton score, Brighton criteria, joint hypermobility, total days injured, lumbar flexion

INTRODUCTION

Dance is associated with short sets of explosive movements requiring balance, athleticism and artistry [1], indicative of the movement complexity and intensity. These movement demands require physical attributes including strength, speed, power, agility, cardiovascular endurance, flexibility, coordination and balance. The combined artistic and physical nature of dance places considerable stress on the body including vertical ground reaction forces which increase with dance routine intensity [2, 3] and mechanical loading augmented by movement difficulty [4]. Dancers are required to perform movements that may exceed normal anatomical range which may increase injury risk [5] and all of these factors may potentially contribute to injury.

Dance injury rates of between 0.57 and 5.6 injuries per 1000 hours dancing have been reported [6-9] and most injuries occur in the lower limb with overuse and foot and ankle injuries most prevalent [6-9]. Comparison of dance injury rates is limited by the different injury definition, lack of prospective design and over reliance on self-reporting of injury. Despite this previous systematic reviews have highlighted that dance has a high risk of injury regardless of genre and level [10, 11].

Joint hypermobility (JH) is characterised by excessive end of range joint motion [12] which exceeds normal limits and is assessed by the Beighton score [13]. Within dance, JH has been identified as having performance benefits [14] but may be associated with increased injury risk [9]. A recent review of JH classification proposed a new spectrum of JH related disorders which cluster the phenotypes presenting JH plus one or more of its secondary articular manifestations [15]. These manifestations include dislocations, subluxations, soft tissue injuries, chronic pain, disturbed proprioception and potential bone mass changes that do not fulfil the criteria for any of the Ehlers-Danlos syndrome (EDS) variant that compromise the hypermobility type [15]. Ethlers-Danlos syndromes are heterogeneous heritable connective tissue disorders characterised by JH, skin extensibility and tissue fragility which have been reclassified into 13 subtypes and include hypermobile EDS [16].

Four different hypermobility spectrum disorders are associated with one or more secondary musculoskeletal manifestations [15]. (1) Localised JH at < 5 joints. (2) Generalised joint hypermobility (GJH). (3) Peripheral JH: Present in the hands and/or feet. (4) Historical joint hypermobility in adults who have lost their GJH via the aging process and is associated with reduction in range of motion (ROM).

Joint Hypermobility Syndrome (JHS) is a connective tissue disorder associated with hypermobility in which musculoskeletal complaints are present in the absence of systematic rheumatological disease [17]. JHS is diagnosed by the Revised Brighton criteria (BC) (1998) [18] consisting of 2 major and 8 minor criteria which includes the presence of symptoms including arthralgia, dislocation, subluxation, spinal conditions, soft tissue rheumatism, marfanoid habitus, abnormal skin, eye signs, varicose veins and hernia. JHS has been associated with injury in dance as identified by the BC [19].

The classification of JH by the Beighton Score has been limited by the lack of consistency across the literature with cut-off points of ≥ 4 [13], ≥ 5 [20] and ≥ 6 [21] utilised. Recently JH classification have been investigated using three previously reported classification systems [22] namely Beighton et al [13] (≥ 4 hypermobile), Boyle et al [23] (0-2, not hypermobile); (3-4, moderately hypermobile); (5-9, distinctly hypermobile) and Stewart and Burden [24] (0-3, tight, not hypermobile); (4-6 , hypermobile) and (7-9 , distinctly hypermobile) with results highlighting the need to consider the categorisation of hypermobility in female dancers. A high prevalence of lumbar flexion (93%) has been reported in female dancers which impacted on JH classification and its inclusion in total Beighton score should be carefully considered [25]. The exclusion from the criteria of lumbar flexion in dancers has been utilised [26, 27] due to the large lumbar flexion ROM required for dance performance however this has not been applied consistently in future studies.

The current study was commenced prior to the publication of the new classification of JH [15, 16] and therefore utilised the BC [18] and associated symptom presentations some of which are contained within the new classification system. An enhanced understanding of injury is essential to reduce injury incidence and associated physical, psychological and financial cost and allow participation with reduced injury risk. The primary aim of this prospective cohort study of university dancers was to investigate whether total Beighton score can predict in injury and to determine the relationship between JH and injury. The secondary aim was to report the relationship between JHS and injury. The tertiary aim was to report injury demographics.

MATERIALS AND METHODS

Subjects

Eighty subjects volunteered to participate in this study. The subjects' demographics are reported in table 1 with associated means and standard deviations. All subjects were dancers enrolled on a University BSc (Hons) Dance programme and were 18 years of age or older. Recruitment was aimed at attaining dancers of similar age and previous dance experience which was aided by the use of two university year groups. By acceptance on the degree programme all dancers were deemed to be proficient dancers. The programme involves contemporary, ballet and jazz dancing. Prior to participation in the study the subjects were informed of what the study entailed and were provided with information sheets and completed informed consent forms. Subjects were screened with a medical questionnaire which determined general health including cardiovascular disease, diabetes and epilepsy. Exclusion criteria included no previous diagnosis of Ehlers-Danlos, Marfan Syndrome, osteogenesis imperfecta or injury within the previous 30 days. Three subjects were excluded from the study as they had suffered an injury in the previous 30 days and 2 subjects declined to participate. All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1975 Helsinki declaration as revised in 1983.

Insert table 1 here

PROCEDURES

Joint hypermobility

JH testing was performed at the start of the academic year and dancers were observed prospectively for injury over one academic year. Prior to testing the subjects height (cm) was measured using a stadiometer (Leicester Height Measure, Child Growth Foundation, Leicester, UK) and body mass (kg) were recorded using digital scales (Salter 9028, Kent, UK). Leg dominance was determined by asking dancers to state their preferred leg. The Beighton score [13] was used to measure JH which classifies JH as a score of ≥ 4 and has an Intraclass Correlation Coefficient (ICC) of 0.91 and a kappa 0.74 [28]. The same researcher performed all measurements, specifically a Chartered Physiotherapist with 17 years experience in JH classification. The Beighton score was quantified by measuring ROM of the 5th Metacarpophalangeal joints (1 point each joint for passive dorsiflexion beyond 90°), thumbs (1 point each joint for passive apposition to flexor aspect of the forearm), elbows (1 point each joint for hypextension beyond 10°), knees (1 point each joint for hyperextension beyond 10°) and lumbar spine (1 point for forward flexion so palms rest on the floor), providing a maximum score of 9. A goniometer (Vivomed, UK) was used to measure all joints except the lumbar spine for which JH was classified as yes/no based on the participants ability to put the palms of their palms flat on the floor. All tests were performed as described previously by [28]. Peripheral joint hypermobility was classified the presence of JH at the 5th metacarpophalangeal and/or thumb joints and absence of JH at other joints [15]. Test retest intra-rater reliability was determined using an $ICC_{3,1}$ [29] by the researcher measuring JH using the Beighton score of 18 subjects (9 male, 9 female) on 2 separate occasions 24 hours apart. These subjects were not part of the investigated population. Subjects were instructed not to participate in sport, dance activity or warm up during this 24 hour period. This timescale was selected to reduce the potential for ROM adaptations and intra-rater reliability for the total Beighton score had an $ICC_{3,1}$ of 0.98 (95% Confidence Intervals (CI) 0.97 to 0.99) indicating excellent reliability.

JHS screening

The BC [18] was used to determine JHS following a previously published protocol [28] and was diagnosed in the presence of two major criteria, one major and two minor criteria, or four major criteria [18] as is outlined in table 2. Skin hyperextensibility was measured by the pinching of the cutis on the volar surface of subjects non-dominant forearm midway between the lateral epicondyle of the humerus and the distal head of the radius with the forearm supinated [30]. The measurement was performed with skin callipers (Harpenden Skinfold Calliper, British Indicators, West Sussex, UK) and a positive diagnosis of skin hyperxtensibility was deemed as > 2cm [30]. Abnormal scarring was defined as contusion based broad scars with thin wrinkled surface located on the extensor aspect of the elbows, knee and lower legs and was defined as present or absent [31]. Participants completed an 8 item questionnaire (see appendix) which determined the prevalence of major and minor BC which was developed following consultation with other clinicians experienced in hypermobility assessment. A pilot study of the questionnaire with 10 participants determined face validity prior to the main study. The questions required simple yes/no responses and basic information regarding the subjects' condition such as the location and duration of symptoms. The main researcher was present during completion of the questionnaire to answer any queries.

Insert table 2 here

Injury recording

Injury was categorised using a '*time loss'* definition of injury that involved absence from dancing for one of more days and a *'medical attention injury'* which involved an injury that required the attention of the researcher but did not result in absence from dancing. Both definitions were adapted from Hamilton et al [32]. The time loss definition used Total Days Injured (TDI) as the dependent variable for statistical analysis. TDI was utilised due to the robustness of this data set and because *'medical attention injury'* can result in injury over reporting. Following injury, dancers were asked to attend the University Dance Injury Clinic which was available on a daily basis where they were reviewed by the Chartered Physiotherapist and injury data recorded. Injury was classified via differential diagnosis as either a sprain, strain, contusion, fracture, dislocation, disc pathology or tendinopathy. The following information was recorded: (1) Injury location. (2) Classification of injury type (overuse or trauma). Overuse injuries were defined as a result of repetitive micro-trauma and traumatic injuries resulted from a specific macro-traumatic event [33]. (3) Mechanism of injury: Jumping, travelling, turning, stretching, landing, collision, other. (4) Type of dance been performed at the time of injury: Contemporary, ballet, jazz. (5) When the injury occurred: Warm up, class, rehearsal, performance, other. (6) Injury severity: Slight (0-1 days), minimal (2-3 days), mild (4-7 days), moderate (8-28 days) and severe (greater than 28 days) [34]. (7) Lower limb dominant limb injury: Was recorded as yes/no.

Dancers were defined as having recovered from injury once they had been assessed by the researcher and recommenced dance classes, rehearsals or performance. Absence due to illness was not recorded to ensure only injury status was investigated. Reinjury was classified as injury of the same type occurring at the same location [35]. The term *'multiple injuries'* was used for those dancers who suffered more than one injury during the study and *'single injury'* for those who suffered one injury. Dance exposure (hours) was recorded by the using an attendance register that was completed by dancers on a weekly basis and verified verbally by the researcher with the dancers. Injury rates were calculated as injury/1000 hours dance exposure.

Statistical analysis

All statistical analysis was performed as a pooled analysis for both females and males and separately for gender. The following baseline demographics was analysed using an unpaired t-test: age, height, mass, years dancing, total Beighton score and total Beighton score with lumbar flexion removed which was performed in response to previous findings that dancers exhibit a positive lumbar flexion score as a performance adaptation [25-27]. For these baseline demographics, homogeneity of variances was assessed by Levene's test for equality of variances. Dance exposure was analysed between injured and non-injured groups for pooled, female and male groups using an unpaired t-test. A Shapiro-Wilk test determined normal distribution for these groups and homogeneity of variances was assessed using a Levene's test for equality of variance.

For all regression analysis a Durbin-Watson test was used to assess independence of observations and scatterplot was used to assess linearity between total Beighton score and TDI. Case wise diagnostics were used to check for outliers. The assumption of homoscedasticity was checked by inspection of a plot of the unstandardized values against predicted values [36]. Normal P-P plots were used to assess normal distribution and ensure that the variance in residuals were constant.

Linear regression was used to quantify the effect of total Beighton score as a predictor of TDI and all assumptions were met for all regression analysis.

An unpaired t-test was used to analyse total Beighton score between pooled injured and non-injured dancers and for TDI between hypermobile dancers (Beighton score ≥ 4) and non-hypermobile dancers with lumbar flexion included and removed. A Shapiro-Wilk test determined normal distribution for these groups and homogeneity of variances was assessed using a Levene's test for equality of variance. A one-way ANOVA was used to analyse total Beighton score between injured female dancers, non-injured female dancers, injured male dancers and non-injured male dancers. Normal distribution was determined by a Shaprio-Wilk test. Homogeneity of variance was assesses by the Levene's test for equality of variance

A one-way ANOVA was used to analyse total Beighton score between *'multiple injuries'* dancers, *'single injury'* dancers and '*non- injured'* dancers. Normal distribution was assessed by a Shapiro-Wilk test and heterogeneity of variance as assessed by Levene's test of homogeneity of variance. To allow meaningful analysis a pooled analysis was performed.

Total Beighton score was classified in to categories of 0-2, 3-4, 5-9 [23] and TDI for these categories was analysed using a one-way Welch ANOVA and a post-hoc Games-Howell test was performed. Pooled TDI normal distribution within the three classifications of 0-2, 3-4 5-9 was assessed by Shapiro-Wilk test and heterogeneity of variance was assessed by Levene's test of homogeneity of variance. A pooled analysis was used throughout to allow meaningful statistical analysis and was repeated with lumbar flexion removed using a one-way ANOVA and a post-hoc Tukey test applied.

Descriptive statistics were reported for the presence of JHS and peripheral joint hypermobility. Descriptive injury data was provided and injury rates calculated as injuries/1000 hours for dance exposure. Receiver operating characteristic (ROC) curves [37] were produced to assess the predictive ability of the total Beighton score as a predictor of injury (yes/no) and to determine the threshold score for sensitivity and specificity as a predictor of injury. Statistical analysis was performed using SPSS version 24 software (IBM Inc.) and significance was accepted at the $P < 0.05$ level.

RESULTS

Demographics

Baseline demographics of the dancers are reported in table 1. There was homogeneity of variances ($P > 0.05$) for age, years dancing, total Beighton score and total Beighton score with lumbar flexion removed. For height and weight the assumption of homogeneity of variance was violated ($P < 0.05$). Unpaired t-test analysis revealed significant differences between female and male dancers for height ($p = 0.001$, 95% CI -13.94 to -8.52), weight ($p = 0.001$, 95% CI -11.59 to -7.30). There was no significant difference between female and male dancers for age ($p = 0.68$, 95% CI -0.27 to 0.42), years dancing ($p = 0.71$, 95% CI -0.33 to 0.37), total Beighton score ($p = 0.09$, 95% CI 0.06 to 1.87) and total Beighton score with lumbar flexion removed ($p = 0.06$, 95% CI 0.11 to 1.89) at baseline. A total of 61 dancers (74.39%, 47 females, 14 males) were classified as hypermobile (Beighton score ≥ 4) and 50 dancers (61.73% 42 females, 8 males) with lumbar flexion removed. A total of 76 dancers (92.68%, 57 females, 19 males) were considered hypermobile for lumbar flexion.

Dance exposure

Pooled dance exposure was 39692 hours (575.25 ± 87.61), female dance exposure was 29717 hours (571.48 ± 97.77), male dance exposure was 9975 hours (586.76 ± 44.33). Dance exposure was normally distributed ($P > 0.05$) and there was homogeneity of variances, for all three dance exposure comparisons ($P > 0.05$). Unpaired t-test analysis of dance exposure for injured and non-injured dancers revealed no significant differences for pooled: ($p = 0.58$, 95% CI -30.20 to 53.91), females: ($p = 0.65$, 95% CI -39.89 to 63.79) and males: ($p = 0.88$, 95% CI -36.99 to 42.99.)

Regression analysis

Table 3 reports linear regression analysis for total Beighton score as a predictor of TDI for pooled, female and male analysis with lumbar flexion included and removed. No significant predictors were found for all analysis.

Insert table 3 here

Injury analysis

For analysis of total Beighton score between pooled injured and non-injured dancers data was normally distributed ($P > 0.05$) and homogeneity of variance existed for analysis with lumbar flexion ($p = 0.27$) and with lumbar flexion removed ($p = 0.25$). An unpaired test revealed no significant difference between pooled injured and non-injured dancers ($p = 0.94$, 95% CI -0.78 to 0.33). For injured dancers the mean total Beighton score was 4.70 ± 1.64 and for non-injured dancers 4.67 ± 2.03. With lumbar flexion removed there was no significant difference between pooled injured and non-injured dancers ($p = 0.86$, 95% CI -0.87 to 0.72). With lumbar flexion removed for injured dancers the mean total Beighton score was 3.76 ± 1.59 and for non-injured dancers was 3.83 ± 2.02.

For unpaired t-test analysis of TDI between hypermobile dancers (Beighton score ≥ 4) and non-hypermobile dancers with lumbar flexion included and removed a separate gender analysis was not possible due to limited sample size. Data was normally distributed however there was heterogeneity of variance as assessed by Levene's test of homogeneity of variance with lumbar flexion included and removed ($p = 0.01$). There was a significant difference between pooled TDI in hypermobile dancers and non-hypermobile dancers with lumbar flexion included ($p = 0.02$, 95% CI -8.70 to 0.35) and with lumbar flexion removed ($p = 0.03$, 95% CI -7.98 to 0.43). For those dancers classified as hypermobile (Beighton score ≥ 4) mean TDI was 7.38 ± 11.13 and 7.14 ± 10.97 with lumbar flexion removed and for non-hypermobile dancers was 2.85 ± 5.99 and 2.94 ± 6.16 with lumbar flexion removed.

For analysis of total Beighton Score between groups (female injured, female non-injured, male injured, male non-injured) data was normal distributed for all groups ($P > 0.05$) and homogeneity of variances existed in all groups for analysis with lumbar flexion ($p = 0.29$) and with lumbar flexion removed ($p = 0.23$). A one-way ANOVA with lumbar flexion included revealed no significant differences for total Beighton score between groups (female injured, female non-injured, male injured, male non-injured) F (3, 78) = 2.11, ($p = 0.11$). Mean total Beighton scores were: female injured 4.78 ± 1.76, (95% CI 4.18-5.37), female non-injured 5.12 ± 2.07, (95% CI 4.28-5.95), male injured 4.40 ± 1.17, (95% CI 3.56-5.24), male non-injured 3.50 ± 1.43, (95% CI 2-47-4.53). The mean pooled total Beighton score was 4.68 ± 1.81 (95% CI 4.28-5.08).

A one-way ANOVA revealed no significant differences for total Beighton score with lumbar flexion removed between groups (female injured, female non-injured, male injured, male non-injured) F (3, 78) = 2.34 ($p = 0.13$). Mean total Beighton scores were: female injured 3.86 ± 1.69, (95% CI 3.29 to 4.43), female non-injured 4.19 ± 2.09, (95% CI 3.34 to 5.04), male injured 3.40

± 1.17, (95% CI 2.56 to 4.24), male non-injured 2.70 ± 1.41, (95% CI 1.68 to 3.71). The mean pooled Beighton score with flexion removed was 3.79 ± 1.78, (95% CI 3.38 to 4.16).

Multiple injury analysis

For total Beighton score there was normal distribution for *'multiple injuries'*, '*single injury'* and '*non-injured'* groups and homogeneity of variances (P > 0.05). One-way ANOVA analysis revealed no significant difference in total Beighton score between pooled *'multiple injuries'* dancers, *'single injury'* dancers and '*non-injured'*, F (2, 80) = 0.38, (p = 0.69) Analysis was repeated with lumbar flexion removed and the findings remained non-significant F (2, 80) = 0.56, (p = 0.57). These findings are reported in table 4.

Insert table 4 here

Total Beighton score categorised for the Boyle et al [23] classification

Table 5 reports the distribution of total Beighton score classified in to groups 0-2, 3-4, 5-9 [23]. Pooled TDI within the three classifications of 0-2, 3-4, 5-9 was normally distributed for each classification (P > 0.05); but there was heterogeneity of variance as assessed by Levene's test of homogeneity of variance (p = 0.01). A one-way Welch ANOVA demonstrated a significant difference between groups (p = 0.04) and a post-hoc Games-Howell test identified a significant difference between the 3-4 and the 5-9 classification F (2, 42.164) = 3.644, (p = 0.03). Pooled TDI with lumbar flexion removed revealed normal distribution of pooled TDI analysis within the three classifications (P > 0.05) and there was homogeneity of variance (p = 0.46). A one-way ANOVA demonstrated a significant difference between groups F (2, 80) = 193.15 (p = 0.01) and a post-hoc Tukey test identified a significant difference between the 0-2 and the 3-4 classification (p = 0.01, 95% CI -2.80 to -1.77) and 0-2 and 5-9 classification (p = 0.01, 95% CI -5.28 to -4.13).

Insert table 5 here

Brighton criteria

Table 6 reports those dancers who were positive for JHS as defined by the BC. A total of 12 dancers (11 females, 1 male) were identified as having JHS. The removal of lumbar flexion from TBS removed one female dancer from the JHS total (female dancer injured category). Dancers that were positive for *'soft tissue rheumatism'* all suffered from tendinopathy. Those dancers who were positive for *'abnormal skin'* suffered for skin hyperextensibility and those who were positive for *'eye signs'* suffered from myopia.

Insert table 6 here

Peripheral Joint Hypermobility

Joint hypermobility analysis revealed that only one dancer (male non-injured) was classified as having peripheral joint hypermobility. However when lumbar flexion was excluded from the total Beighton score 15 female dancers (9 injured, 6 non-injured) and 7 male dancers (1 injured, 6 non-injured) demonstrated peripheral joint hypermobility.

Injury type

Injury type is reported in table 7 (number of injuries, percentage and TDI). The most common injury in female dancers was latissimus dorsi muscle strain (n = 7, 18.9%) and in male dancers was hamstring strain (n = 3, 30%).

Insert table 7 here

Injury rate and mechanism of injury

Forty-seven injuries occurred in 34 dancers (27 females, 7 males) and TDI was 451 days (females 371 days, males 80 days). Forty-one injuries were "*time loss"* injuries. Of the six *"medical attention"* injuries 5 were overuse injuries (5 females) and 1 traumatic (1 female). Table 8 reports injury rates for pooled, female dancers and male dancers using *"time loss"* and *"medical attention"* methods of injury definition. Traumatic injuries occurred during the following: class (12 injuries, 10 females, 2 males), warm up (7 injuries, 5 females, 2 males), rehearsal (6 injuries, 4 females, 2 males). With regard to the mechanism of injury for traumatic injuries the following was reported: jumping (4 injuries, 3 females, 1 male), travelling (3 injuries, 3 females), turning (1 injury, 1 female), stretching (13 injuries, 10 females, 3 males), landing (3 injuries, 2 females, 1 male), collision (1 injury, 1 male). Overuse injuries occurred during the following: class (13 injuries, 10 females, 3 males), warm up (2 injuries, 1 female, 1 male), rehearsal (4 injuries, 4 females), performance (3 injuries, 3 females). Thirty-nine of the injuries occurred during contemporary dance, 7 occurred during ballet and 1 during jazz. Table 9 reports injury rates for traumatic and overuse injuries for pooled, female and male dancers.

Insert table 8 and table 9 here

Two female dancers suffered 3 injuries one of these dancers suffered 3 *"time loss"* injuries. The other dancer suffered two *"time loss"* injuries which were classified as a reinjury and one *"medical attention"* injury. Six female dancers suffered 2 injuries and six of these 10 injuries were *"time loss"* injuries. Overall 2 female dancers suffered a reinjury. One male dancer suffered 3 injuries (all *"time loss"* injuries) and one male dancer suffered two injuries (both *"time loss"* injuries). Neither male dancer suffered a reinjury. At the lower limb there were 33 injuries of which 14 (44%) occurred in the dominant limb (11 females, 3 males).

Injury severity

For TDI the following injury severity was recorded: 28 days+ (4, 4 females), 8-28 days (16, 13 females, 3 males), 4-7 days (7, 6 females, 1 male), 2-3 days (14, 8 females, 6 males), 1 day (0).

ROC curve analysis

ROC curve analysis of total Beighton score demonstrated an area under the curve for differentiating between injured and non-injured dancers for pooled analysis of: (0.51, standard error 0.07, asymptomatic 0.90, 95% CI 0.37-0.65) and for pooled analysis lumbar flexion removed: (0.57, standard error 0.08, asymptomatic 0.30, 95% CI 0.43-0.71). ROC curve analysis of total Beighton score demonstrated an area under the curve for differentiating between injured and non-injured dancers for female dancers of: (0.49, standard error 0.08, asymptomatic 0.87, 95% CI 0.32-0.65) and for female dancers lumbar flexion removed: (0.47, standard error 0.08, asymptomatic 0.69, 95% CI 0.31-0.63). ROC curve analysis of total Beighton score demonstrated an area under the curve for differentiating between injured and non-injured dancers for male dancers of: (0.55, standard error 0.15, asymptomatic 0.77, 95% CI 0.25-0.84) and for male dancers flexion removed: (0.83, standard error 0.10, asymptomatic 0.03, 95% CI 0.63-1.00). Figures 1, 2 and 3 report ROC curve analysis of total Beighton score with lumbar flexion included and removed for pooled, female and male dancers.

Insert figures 1, 2 and 3 here

Table 10 reports ROC curve sensitivity and specificity for the Beighton score with lumbar flexion and with lumbar flexion removed as a predictor of injury threshold. The following threshold points were identified: For pooled dancers a score of 1.5 provided a sensitivity and specificity of 0.97 and with lumbar flexion removed a score of 0.5 provided a sensitivity and specificity of 0.97. For female dancers a score 1.5 provided a sensitivity of 0.96 and a specificity of 1.00 and with lumbar flexion removed a sensitivity of 0.85 and a specificity of 0.96. For male dancers a score of 1.5 provided a sensitivity of 1.00 and a specificity of 0.9 and with lumbar flexion removed a score of 0.5 provided a sensitivity of 1.0 and a specificity of 0.9.

Insert table 10 here

DISCUSSION

The primary aim of the study were to determine whether total Beighton can predict injury in university dancers and the relationship between total Beighton score and injury. A total of 61 dancers (74.39%, 47 females, 14 males) were classified as hypermobile (Beighton score ≥ 4) and 50 dancers (61.73% 42 females, 8 males) when lumbar flexion was removed. Our findings were higher than previously reported 44% [9] and similar to the rates of 70% in adolescent ballet dancers [38] and 69% in college age contemporary dance students [19] all of which utilised a Beighton score ≥ 4. Total Beighton score was a weak predictor of TDI for pooled and separate gender analysis. The greatest r^2 values (table 3) were found for male dancers with lumbar flexion included (.137) and with lumbar flexion removed (.142) however no linear regression findings were statistically significant. Caution should be taken when interpreting these male dancer findings due to the limited sample size. Analysis of baseline data revealed no significant differences between female and male dancers for age, years dancing, total

Beighton score and total Beighton score with flexion removed ($P > 0.05$). This meant that pooled analysis appropriate for linear regression. Dance exposure can potentially influence injury risk however statistical analysis revealed no significant difference between injured and non-injured dancers dance exposure for pooled, female and male analysis ($P < 0.05$) and mean dance exposure was similar for female (571.48 hours ± 97.77) and male dancers (586.76 hours ± 44.33).

Analysis of total Beighton score between pooled injured and non-injured dancers data revealed no significant difference between pooled injured and non-injured dancers ($p = 0.94$) and with lumbar flexion removed ($p = 0.86$). No significant findings existed for analysis of total Beighton score for a pooled injured and non-injured dancers ($p = 0.94$) and female injured, female non-injured, male injured, male non-injured groups ($p = 0.11$). Non-significant findings remained for pooled analysis ($p = 0.86$) with the removal of lumbar flexion from analysis between groups ($p = 0.13$). Previous research [19] suggested that total number of injuries, physical complaint injuries and time loss injuries were significantly correlated with the Brighton criteria and Joint Hypermobility Syndrome but no relationship existed between injury and General Joint Hypermobility assesses via the Beighton Score. While McCormack et al [39] reported increased arthralgia in dancers with Benign Joint Hypermobility syndrome in comparison to those without the syndrome however the methodology of this study was limited with information regarding the diagnosis and definition of injury not provided. There was a significant difference between pooled TDI in hypermobile dancers (Beighton score ≥ 4) and non-hypermobile dancers with lumbar flexion included ($p = 0.02$) and with lumbar flexion removed ($p = 0.03$). This supports previous findings of increased injury risk in hypermobile dancers [9] and suggests that physiotherapists should consider total Beighton score with and without lumbar flexion to determine potential injury risk.

The finding of two reinjuries suggests that the presence of *'injury prone'* individuals was not a problem within the study. Previous injury has been identified as a risk factor for injury [40-42]. The author acknowledges this may require consideration in future studies however this would have required self-reporting of injury and is prone to recall bias. The author preferred to use a prospective method of data collection and a Chartered Physiotherapist to provide a clinical diagnosis. In attempt to consider previous injury within the study analysis was performed of the total Beighton score of '*multiple injuries*', '*single injury*' and '*non-injured*' dancers (table 4) however these findings were non-significant with lumbar flexion ($p = 0.38$) and with lumbar flexion removed ($p = 0.57$). Total Beighton score may not be a factor in the development of multiple injuries however analysis is limited by the small sample of subjects who met this criteria ($n = 10$) which prevented separate gender analysis. Previous research has reported that dancers who had suffered two or more previous injuries within the previous year were more likely to sustain injury [9].

One of the strengths of this study was the consideration of role of lumbar flexion in total Beighton score. A total of 76 (92.68%, 57 females, 19 males) were considered positive for joint hypermobility on lumbar flexion in support of previous findings [25, 26, 27]. There may be a need for interpretation of lumbar flexion to be combined with performance of a Schöbers or Schöbers modified test [43] as the current lumbar flexion measurement is also influenced by hamstring flexibility to determine the contribution of the lumbar spine. The classification of total Beighton score with categories of 0-2, 3-4, 5-9 [23] demonstrated a significant difference between pooled TDI of those dancers in the 3-4 and 5-9 classification ($p = 0.03$) and between the 0-2 and 3-4 classification with lumbar flexion removed ($p = 0.01$) (table 5) which highlights the need to consider alternative groupings to the traditional Beighton score classification of JH of ≥ 4 [13]. These findings did not support the suggestion that dancers with high or low scores were more likely to develop injury than medium score dancers [44] however this hypothesis was not based on dance specific data. Dancers with a Beighton score of 0-2 and 5-9 had an increased injury risk in comparison to those with a Beighton score of 3-4 [9] and therefore in combination with our findings suggest a need to consider the degree of JH in dancers.

With regard to the secondary aim of the study, 12 dancers (11 females, 17.7%, 1 male, 5%) were positive for JHS. The removal of lumbar flexion from total Beighton score removed one female dancer from the JHS total. Previous values of 30% in student and professional ballet dancers [39], 31% in pre-professional degree level students [45] and 16% in ballet students have been reported [46]. Arthralgia was the most common musculoskeletal symptom observed in JHS and it has previously been reported that arthralgia was a major component of hypermobility related problems [47]. Peripheral joint hypermobility [15] was only present in one male non-injured dancer however with the removal of lumbar flexion from the total Beighton score, 22 dancers had peripheral joint hypermobility (10 injured, 12 non-injured). This may require further consideration in future studies with a larger sample size to determine any potential role in injury development.

The tertiary aim was to report injury demographics and the study utilised both a *"time loss"* definition and a *"medical attention"* definition of injury. Pooled analysis injury rates of 1.03 injuries/1000 hours *("time loss"* injury) were higher than previously reported in two professional modern dance companies (0.16 injuries/1000 hours) [48] and 0.20 injuries/1000 hours [49] and for students enrolled on a pre-professional modern dance programme of 0.57 injuries/1000 hours [9]. Injury rate was lower than 4.00 injuries/1000 hours in students performing modern dance [50]. Our pooled *"medical attention"* injury rates of 1.18

injuries/1000 hours were higher than *"medical attention"* injuries reported in pre-professional ballet dancers of 0.77 injuries/1000 hours [6] and 0.80 injuries/1000 hours [51]. Gender specific injury comparison is limited due the tendency for studies to report pooled analysis. Our female dancer injury rates of injuries 1.04 injuries/1000 hours (*"time loss"* injury), 1.25 injuries/1000 hours (*"medical attention"* injury) and male dancer injury rates of injuries 1.00/1000 hours (*"time loss"* and *"medical attention"* injury) were higher than the rate of 0.80 injuries/1000 hours [51] reported in in both female and male dancers using a *"medical attention"* definition. Our findings for both *"time loss"* and *"medical attention"* injury rates are within the boundaries of previously reported findings and differences may be due to the different ability levels and genres of dance and injury surveillance systems utilised.

In agreement with previous dance injury audits [6, 7, 8, 9, 52] lower limb injuries were most prevalent (33, 70%). In ballet, injury may be influenced by the time spent '*en pointe*' or in turnout positions. The most common injury was in female dancers was latissimus dorsi muscle strain however this category did include one reinjury. The use of both *"time loss"* and *"medical attention"* injury definitions of injury recording was a strength of the study however only 6 *"medical attention"* injuries which reduces the risk of over reporting of injury. For traumatic injuries a stretching mechanism (n = 13) was most common and was associated with the development of muscle strains and occurred most frequently during class (n = 12). The frequency of traumatic injuries during warm up (n = 7) may provide a potential area for injury prevention and contrasts to the development of overuse injuries during warm up (n = 2). Dance class was also the most frequent location for overuse injuries (n = 13) however this may merely reflect that dance class provided the greatest proportion of dance exposure. Contemporary dance was performed most frequently and was associated with the greatest number of injuries (n = 39) in comparison to ballet (n = 7) and jazz (n = 1). The holistic nature of the dancers' degree prevented comparison of injury rates for different genres and future studies may wish to consider monitoring this factor. With regard to injury severity the most common duration of injury was 8-28 days (pooled, n = 16, 34%) which reflects the normal healing duration of Grade 1 muscle strains which were the most common injury (n = 25, 53%).

For ROC curve analysis for the area under the curve values of greater than 0.5 can be considered diagnostic as ≤ 0.50 and below can be considered a chance level [37]. ROC curve analysis demonstrated an area under the curve for total Beighton score for differentiating between injured and non-injured dancers for pooled analysis of 0.51 and with lumbar flexion removed of 0.57 (figure 1). Female values were not diagnostic. Values for male dancers were 0.55 and with lumbar flexion removed 0.83 (figure 3). For a male dancers the area under the curve of 0.83 with lumbar flexion removed is worthy of further investigation and is suggestive that it may be possible to use a total Beighton score cut off in male dancers to predict increased injury risk. The increase in predictability with the removal of lumbar flexion highlights the importance of considering this potential performance adaptation within dancers.

ROC curve analysis allowed calculation of a score that provided sensitivity and specificity for the identification of injured participants (table 10). Analysis indicated that for the pooled dancers a score of 1.5 provided a sensitivity and specificity of 0.97 and with lumbar flexion removed a score of 0.5 provided a sensitivity and specificity of 0.97. For female dancers a score 1.5 provided a sensitivity of 0.96 and a specificity of 1.00 and with lumbar flexion removed a sensitivity of 0.85 and a specificity of 0.96. For male dancers a score of 1.5 provided a sensitivity of 1.00 and a specificity of 0.9 and with lumbar flexion removed a score of 0.5 provided a sensitivity of 1.0 and a specificity of 0.9. These values may aid injury management and training load monitoring by allowing physiotherapists to monitor dancers within this the sensitivity and specificity continuum for specific total Beighton scores. Although the author recognises that Beighton score values of 0.5 are not possible and that these proposed injury thresholds are low it is possible for physiotherapists to select a specific sensitivity and specificity based on these values to aid monitoring of total Beighton score. These findings demonstrate the potential benefits of using quantifiable objective measures such as the Beighton score and future research may wish to quantify how JH may interact at specific joints in relation to potential injury development.

The author acknowledges that some limitations exist within the study. The statistical power of regression analysis is influenced by the number of participants and therefore future research may wish to use a larger sample size. The results of the study are limited to the populations investigated and such a homogenous sample may be influenced by growth and maturity factors. Females have been reported to demonstrate significantly greater joint laxity than males post puberty [53]. Furthermore ethnicity is associated with joint hypermobility with a higher prevalence reported in Asians and Africans followed by white Caucasians [54] and in the current study the majority of the dancers were white Caucasian (n = 79, 96.34%). The authors acknowledge the multifactorial nature of injury [55, 56] and that injury etiology occurs in a dynamic recursive fashion [56] as risk factors can alter during exposure. Although the use of the Beighton score is advocated in the identification of injury in dance it is one potential tool in injury prevention. For example if pain is the main problem it must be determined if the cause of pain is due to abnormal tissue loading related to JH and whether a stability, strengthening or stretching programme would be most appropriate or whether specific movements are the source of pain. It is important that the interaction of risk factors is considered. Low impact, isometric and eccentric strengthening exercises can be useful however programmes that focus on range of motion exercises or repetitive forceful movements can potentially worsen joint symptoms [57].

CONCLUSION

Total Beighton score was a weak predictor of TDI however analysis of TDI between injured and non-injured dancers and the categorisation of total Beighton score highlighted significant findings. Due to the high prevalence of JH lumbar flexion in dancers it is important that physiotherapists consider this factor when determining JH. Lower limb injuries were the most common location of injury and trauma the most frequent mechanism of injury. The Beighton score can be used to identify those dancers with the potential to develop injury and the different injury thresholds in female and male dancers may aid injury management.

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Table 1 Subject demographics

Group	Age (years)	Height (cm)	Mass (kg)	Ethnicity	Years dancing	TBS	TBSLFR
Pooled N = 82	20.33 +/- 0.68	164.26 +/- 8.08	62.52 +/- 6.54	79 white Caucasian 2 black Caribbean 1 Asian	11.51 +/- 1.11	4.68 +/- 1.81	3.79 +/- 1.78
FD N = 62	20.35 +/- 0.67	161.52 +/- 7.00*	60.22 +/- 5.44*	60 white Caucasian 2 black Caribbean	11.44 +/- 1.11	4.92 +/- 1.88**	4.00 +/- 1.86**
MD N = 20	20.28 +/- 0.72	172.75 +/- 4.54*	69.67 +/- 3.60*	19 white Caucasian 1 Asian	11.75 +/- 1.12	3.80 +/- 1.40**	3.00 +/- 1.30**

*P < 0.001

**P < 0.05

Abbreviations: FD; Female Dancers; MD; Male Dancers; TBS; Total Beighton Score; TBSLFR; Total Beighton Score Lumbar Flexion Removed

Table 2 Brighton criteria [18]

Major criteria
BS of ≥ 4/9
Arthralgia for > 3 months in 4 or more joints
Minor criteria
BS of ≥ 4/9
Arthralgia for > 3 months in 4 or more joints
Minor criteria
BS of 1, 2, 3/9
Arthralgia > 3 months in one to three joints or back pain > 3 months, spondylosis, spondylolysis/spondylolisthesis.
Dislocation/subluxation in more than one joint, or in one joint on more than one occasion.
Soft tissue rheumatism > 3 lesions (e.g. epicondylitis, tenosynovitis, bursitis)
Marfanoid habitus (tall, slim, span/eight ratio > 1.03: lower segment ratio less than 0.89, arachnodactyly (positive Steinberg/wrist signs).
Abnormal skin: striae, hyperextensibility, thin skin, papyraceous scarring.
Eye signs: drooping eyelids or myopia or antimongoloid slant.
Varicose veins or hernia or uterine/rectal prolapse.

Abbreviations: BS; Beighton Score

Table 3 Total Beighton Score as a predictor of TDI

Group	r^2	F value	P value
Pooled MBS 4.68 ± 1.81	.006	0.45	0.51
Pooled MBS LFR 3.79 ± 1.78	.006	0.48	0.49
MTDI 6.54 ± 12.64			
FD MBS 4.92 ± 1.88	.001	0.006	0.94
MBS LFR 4.00 ± 1.86	.001	0.13	0.91
MTDI 7.13 ± 13.88			
MD MBS 3.80 ± 1.40	.137	2.86	0.11
MBS LFR 3.00 ± 1.30	.142	3.14	0.09
MTDI 4.71 ± 7.77			

Abbreviations: MBS; Mean Beighton Score; MTDI; Mean Total Days Injured; FD; Female Dancers; MD Male Dancers; LFR; Lumbar Flexion Removed; LFR; Lumbar Flexion Removed

Table 4 Total Beighton score in "multiple injuries", "single injury" and "non-injured" dancers

Group	Mean BS	P value	95% CI
Non-injured (n = 35)	4.67 ± 2.03	0.69	4.05 - 5.43
Single injury (n = 24)	4.92 ± 1.77	0.69	4.17 - 5.66
Multiple injuries (n = 10)	4.30 ± 1.70	0.69	3.08 - 5.52
Non-injured LFR (n = 35)	3.83 ± 2.02	0.57	3.14 - 4.52
Single injury LFR (n = 24)	4.04 ± 1.65	0.57	3.34 - 4.52
Multiple injuries LFR (n = 10)	3.30 ± 1.70	0.57	2.08 - 4.52

Abbreviations: BS; Beighton Score; BSLFR; Beighton Score Lumbar Flexion Removed; CI; Confidence Intervals

Table 5 Distribution of dancers using Boyle et al [23] classification of the Beighton score

BS	Total	Total LFR
0-2	n = 12 (9 FD, 3 MD)	n = 17 (10 FD, 7 MD)
3-4	n = 25 (13 FD, 12 MD)	n = 43 (30 FD, 13 MD)
5-9	n = 45 (40 FD, 5 MD)	n = 22 (21 FD, 1 MD)

Abbreviations: BS; Beighton Score; FD; Female Dancers; MD; Male Dancers; LFR: Lumbar Flexion Removed

Table 6 Brighton criteria positive components for injured and non-injured dancers

Group	JHS positive (n)	Positive Brighton criteria component
FD injured	7	BS ≥ 4 (n = 7) Arthralgia > 3 months ≥ 4 more joints (n = 7) Abnormal skin (n = 2) Eye signs (n = 2) Soft tissue rheumatism > 3 lesions (n = 1) Dislocation (n = 1)
FD non-injured	4	BS ≥ 4 (n = 4) Arthralgia > 3 months ≥ 4 more joints (n = 3) Eye signs (n = 2) Varicose veins (n = 1) Dislocation (n = 1)
MD injured	1	BS ≥ 4 (n = 1) Arthralgia > 3 months ≥ 4 more joints (n = 1) Abnormal skin (n = 1)
MD non-injured	-	-

Abbreviations: FD; Female Dancer; MD; Male Dancer; JHS; Joint Hypermobility Syndrome; N; Number; BS; Beighton Score

Table 7 Injury type

Injury type	FD Number of injuries/TDI	MD Number of injuries/TDI
Ankle ligament sprain	3 (8%, 28 days)	0 (0%, 0 days)
Knee ligament sprain	1 (2.7%, 10 days)	0 (0%, 0 days)
Achilles tendinopathy	3 (8%, 3 days)	0 (0%, 0 days)
Patella tendinopathy	4 (11%, 6 days)	0 (0%, 0 days)
Plantar fasciitis	3 (8%, 33 days)	0 (0%, 0 days)
Supraspinatus tendinopathy	2 (5.4%, 28 days)	1 (10%, 3 days)
Iliotibial band strain	1 (2.7%, 3 days)	0 (0%, 0 days)
Adductor strain	4 (11%, 17 days)	1 (10%, 3 days)
Hamstring strain	3 (8%, 24 days)	3 (30%, 30 days)
Quadriceps strain	0 (0%, 0 days)	1 (10%, 21 days)
Gastrocnemius strain	2 (5.4%, 14 days)	0 (0%, 0 days)
Tibialis anterior strain	0 (0%, 0 days)	2 (20%, 17 days)
Latissimus dorsi muscle strain	7 (18.9%, 122 days)	1 (10%, 3 days)
Lumbar disc prolapse	1 (2.7%, 14 days)	0 (0%, 0 days
Thoracic spine dysfunction	1 (2.7%, 7 days)	0 (0%, 0 days)
Finger contusion	1 (2 days)	0 (0%, 0 days)
Gastrocnemius contusion	0 (0 days)	1 (10%, 3 days)
Metatarsal fracture	1 (2.7%, 60 days)	0 (0%, 0 days)
Total	37 (371 days)	10 (80 days)

Abbreviations: FD: Female Dancers; MD: Male Dancers; TDI; Total Days Injured

Table 8 Injury rates, TDI and traumatic and overuse injuries

Group	Inj/1000 hrs TLI	Inj/1000 hrs MAI	TI (n)	OI (n)	TDI (Mean/SD)
Pooled	1.03	1.18	25	22	451 (6.54 ± 12.64)
FD	1.04	1.25	19	18	371 (7.13 ± 13.88)
MD	1.00	1.00	6	4	80 (4.71 ± 7.77)

Abbreviations: FD; Female Dancers; MD; Male Dancers; TLI; Time Loss Injuries; MAI; Medical Attention Injuries; INJ; Injuries; HRS; Hours; TI; Traumatic Injuries; OI: Overuse Injuries; N; Number; TDI; Total Days Injured

Table 9 Traumatic and overuse injury rate

Group	TI/1000 hrs MAI	TI/1000 hrs TLI	OI/1000 hrs MAI	OI/1000 hrs TLI
Pooled	0.63	0.60	0.55	0.43
FD	0.64	0.61	0.61	0.44
MD	0.60	0.60	0.40	0.40

Abbreviations: FD; Female Dancers; MD; Male Dancers; TLI; Time Loss Injuries; MAI; Medical Attention Injuries; INJ; Injuries; HRS; Hours; TI; Traumatic Injuries; OI: Overuse Injuries

Table 10 ROC curve analysis of sensitivity and specificity values of total Beighton score

Group Variable	Positive if ≥ to	Sensitivity	Specificity
Pooled BS	1.5	0.97	0.97
	2.5	0.79	0.87
	3.5	0.68	0.71
	4.5	0.61	0.54
Pooled BSLFR	0.5	0.97	0.97
	1.5	0.88	0.91
	2.5	0.82	0.71
	3.5	0.71	0.54
	4.5	0.44	0.23
FD BS	1.5	0.96	1.00
	2.5	0.82	0.96
	3.5	0.74	0.76
	4.5	0.67	0.64
FD BSLFR	1.5	0.85	0.96
	2.5	0.78	0.76
	3.5	0.70	0.64
	4.5	0.44	0.32
MD BS	1.5	1.0	0.90
	2.5	0.71	0.70
	3.5	0.43	0.60
	4.5	0.43	0.30
MD BSLFR	0.5	1.0	0.9
	1.5	1.0	0.8
	2.5	1.0	0.6

Abbreviations: FD: Female dancers, MD: Male dancers; BS: Beighton Score, BSLFR: Beighton Score Lumbar Flexion Removed

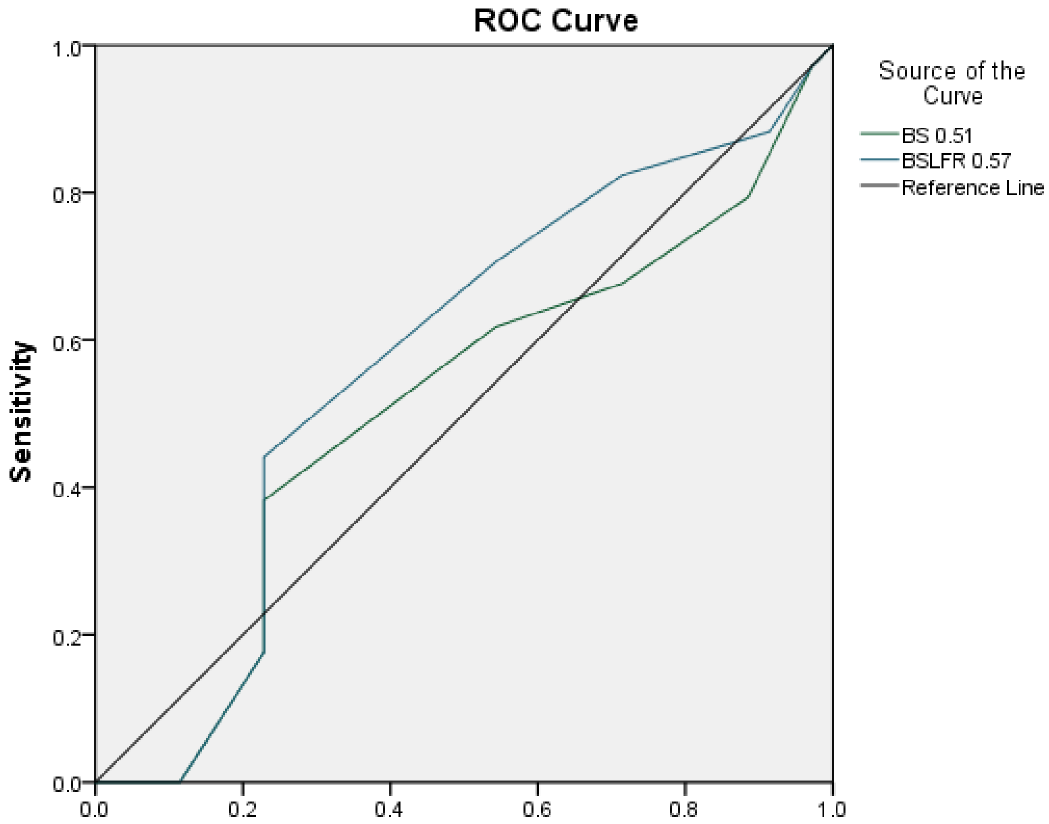

Figure 1 ROC curve pooled analysis of total Beighton score

BSLFR: Beighton Score Lumbar Flexion Removed; BS: Beighton Score

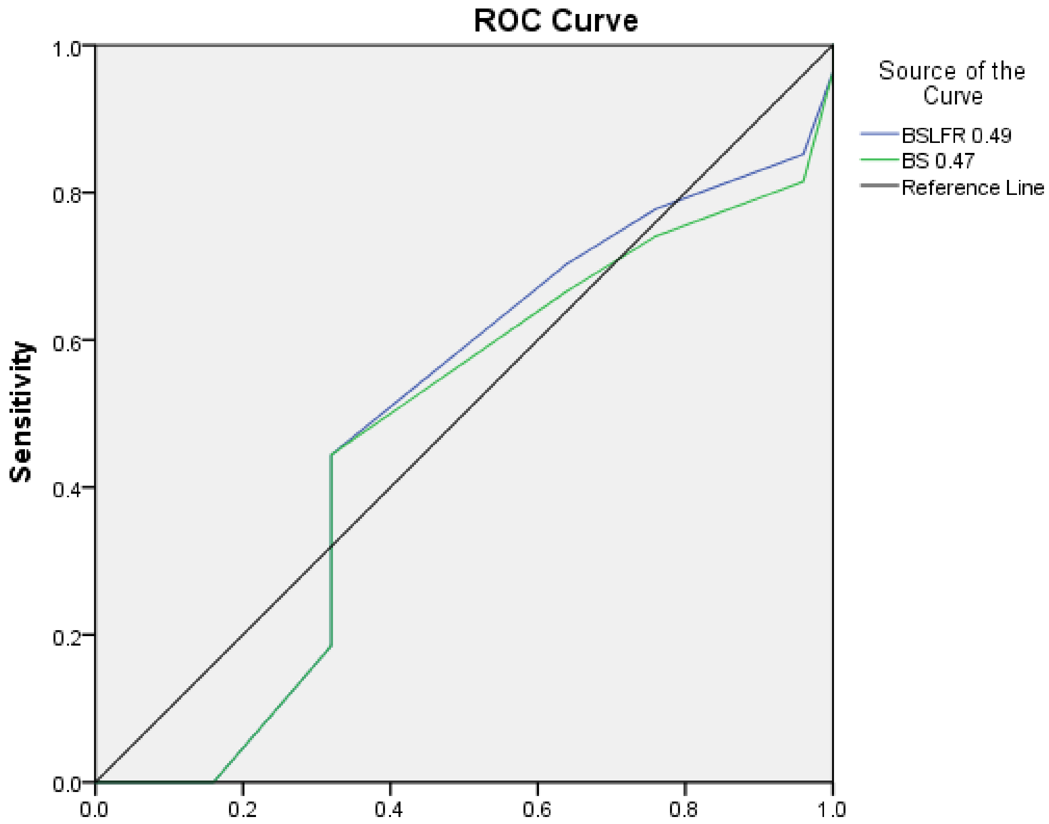

Figure 2 ROC curve female dancer analysis of total Beighton score

BSLFR: Beighton Score Lumbar Flexion Removed; BS: Beighton Score

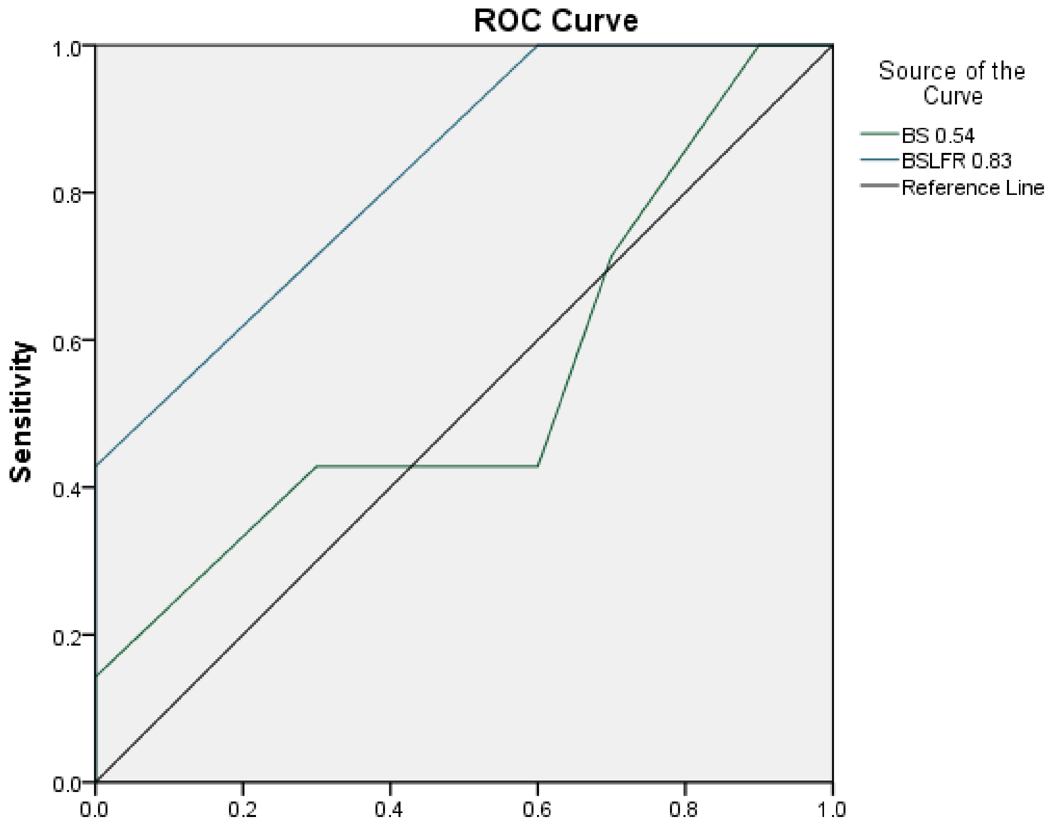

Figure 3 ROC curve male dancer analysis of total Beighton score

BSLFR: Beighton Score Lumbar Flexion Removed; BS: Beighton Score

APPENDIX

Brighton criteria 8 item questionnaire

Please answer the following questions and circle the appropriate answer.

(1) Have you ever had pain in any joint including your back at any time that lasted more than 3 months?

Yes/No. If yes please write which joint(s):

(2) Do you suffer from spondylosis, spondylolysis or spondylolisthesis of the spine (slipping of the vertebrae in the spine/arthritis in the spine).

Yes/No

(3) Have you ever suffered dislocation or subluxation of a joint?

Yes/No. If yes please write which joint(s) and how many times.

(4) Have you ever suffered from soft tissue rheumatism (epicondylitis, tenosynovitis and bursitis)?

Yes/No. If yes please write which joint(s).

(5) Are you short sighted or suffer from drooping eyelids or an antimongoloid slant?

Yes/No If yes please write which:

(6) Have you suffered from varicose veins?

Yes/No

(7) Have you suffered from a hernia or uterine or rectal prolapse?

Yes/No If yes please write which:

(8) Have you ever been diagnosed with hyperextensibilty (stretchy) skin, striae, thin skin or papyraceous scarring?

Yes/No If yes please write which: