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Joint hypermobility in young gymnasts: Implications for injury and performance

Ross Armstrong

Ross Armstrong, BSc (Hons), MSc, MSc (Sports and Exercise Medicine)[a]
a. Department of Sport and Physical Activity, Sports Injuries Research Group, Edge Hill University, Ormskirk, Lancashire, L39 4QP, England.

Corresponding author: Ross Armstrong
Address: Department of Sport and Physical Activity, Sports Injuries Research Group, Edge Hill University, Ormskirk, Lancashire, L39 4QP, England. Telephone: (0044) 01695 584246 Fax: (0044) 01695 579997 Email: armsross@edgehill.ac.uk
https://orcid.org/0000-0002-8424-6854

Abstract
Objectives: Hypermobility in gymnastics has both performance and injury implications. There is a paucity of studies that have reported joint hypermobility scores in young gymnasts and there is a need to consider joint hypermobility across different gender, age and performance levels. This study aimed to report the prevalence of joint hypermobility and range of motion values for the hip, shoulder, ankle and spine in male and female gymnasts.
Methods: This study determined joint hypermobility via the Beighton score and range of motion for hip flexion, extension, abduction, shoulder flexion, ankle plantarflexion and lumbar extension in 25 male gymnasts (age:10.44±2.89 years, height:142.16±20.00cm, mass: 28.00±7.43kg and 25 female gymnasts (age:11.16±2.70 years,height: 141.55±22.34cm,mass: 32.33±7.99kg).

Results: Joint hypermobility ranged from 56% (male gymnasts) to 68% (female gymnasts). The highest Beighton score was observed in female gymnasts (4.76±2.05), female gymnasts ≤13 years (4.93±1.87) and male national level gymnasts (5.67±1.15). No significant differences existed for Beighton scores between male and female gymnasts for gender (p=0.26) and age (p=0.095). Significant differences existed between male and female gymnasts for left hip extension (p=0.001), right hip extension (p=0.001), left hip abduction (p=0.001), right hip abduction (p=0.001) and lumbar extension (p=0.001) with all range of motion greater in females. For age and gender groups, significant differences existed between female gymnasts <13 and male gymnasts ≥13 for hip flexion, hip extension and hip abduction movements bilaterally and between female gymnasts <13 and male gymnasts <13 significant differences existed for all hip extension and hip abduction bilaterally. Between female gymnasts <13 and ≥13 significant differences existed for shoulder flexion bilaterally. Between female gymnasts ≥13 and male gymnasts <13 significant differences existed for all shoulder flexion bilaterally and for lumbar extension which was significantly greater in the <13 female gymnasts than ≥13 male gymnasts. A significant difference existed between male and female gymnasts for left hip extension (p=0.01), right hip extension (p=0.01) and left hip abduction (p=0.001) and right hip abduction (p=0.001)
Conclusion: No significant differences were observed for the BS between gender, age and performance level groups however significant differences did exist for several range of motion values particularly at the hip in relation to gender, age and level and therefore this joint may be an important focus for performance enhancement and injury prevention. These differences highlight the importance of range of motion measurement in addition to BS measurement and the need to consider gender age and gymnastic level when working with child gymnasts.

Keywords: Age, Beighton score, gender, gymnastic level, joint hypermobility, flexibility

Introduction

Gymnastics requires high levels of strength, flexibility[1] proprioception, endurance and the performance of complex movement tasks combined with aesthetic demands. Participation often commences in early childhood with young gymnasts commencing training at a minimum age of 5 years old, continuing throughout childhood and adolescence[2] when the they tend to specialise in a specific discipline.[3,4] Gymnasts often commit to a maximum of 30 hours a week training[2] which may have implications for injury as adolescents experience an increased injury rate due to growth changes associated with puberty[5] which may alter soft tissue structures that contribute to joint stability and result in injury.[6,7] International level gymnasts often compete during adolescence with a mean age of 15.3 years reported[8] and peak performance is usually reached 10 years after training commnences.[9,10] During this 10-year period, skills complexity, training volume and intensity increases dramatically[9] and the career of a gymnast can be short with many retired by 15 years old.[10]

Spine mobility and stretching programmes often commence at the age of 5 years and these movements may exceed normal anatomical range to obtain aesthetically appealing positions.[11] Stretching is the elongation of a force or torque that places the muscle and tendon complex at its maximum length[11] and flexibility is pain free range of motion (ROM) at a joint.[11]Joint hypermobility (JH) is the capability of a joint to move passively and/or actively beyond normal limits along physiological axes[12] and is considered a descriptive rather than diagnostic term.[12] The fitness profiles of gymnasts are linked to the demands of the sport and changes in these profiles has being synchronised with progressive rule changes established by the gymnastics Code of Points[13] which influences gymnastics training with an emphasis on flexibility more prominent in earlier codes.[14]

JH is assessed by the Beighton score (BS)[15] which assesses five joints that provide a maximum score of 9 with scores of ≥4 classified as hypermobile[16] however values of 4, 5 and 6 have been utilised.[17] In dancers, the prevalence of lumbar flexion has been reported to be as high as 93%[18] and is recognised a performance adaptation. Due to the performance demands of gymnastics it is likely that a similar prevalence will exist. Joint ROM can be increased by repetitive physical activity in athletes who participate in gymnastics and dance.[19] The BS has not been applied to young gymnasts[20] and there is a paucity of research regarding the influence of JH on injury and performance in gymnasts and therefore the current study at times will consider dance research. In schoolchildren, declining flexibility has been observed from 6 to 12 years followed by an increase to 18 years[21] while a 'pulse' of flexibility was reported in 4500 children and occurred between 14 to 17 years.[22] In US female gymnasts shoulder hyperflexion and greater spinal ROM was reported from the age of 9 through to the senior national team aged >15 years.[23] Peak height velocity is associated with a reduction or plateau of flexibility[24,25] and flexibility may reduce during this stage as bone growth is greater than muscle lengthening.[26] The critical stage for the development of flexibility is between 6 and 11 years.[27]

JH is influenced by gender, age and specific changes to the body because of injury or other musculoskeletal disorders[28,29] and is more prevalent in females.[19] JH may have performance benefits in gymnastics and dance[30] and the prevalence of JH is greater in gymnasts and dancers than the general population.[28] To obtain the required body shapes gymnasts must be able to move their joint through maximal ROM[31] and those gymnasts with reduced JH are less likely to compete at a professional standard and may increase the risk of a muscular injury.[32] Although performance benefits may be associated with JH, specific gymnastic movements can result in the adoption of unstable joint positions which can result in injury.[33] One such movement is split leap which requires extreme hip flexion and can result in impingement between the distal femoral neck and the anterior inferior iliac spine.[34] Compensatory injury may also be developed due to the high levels of hip flexibility[33] and the lumbar spine, sacroiliac joints and hip flexors may become injured due to compensatory stress.[35,36] The stability of joints is provided by active and passive mechanisms which provide protection against joint injury and include ligaments, joint capsules, passive or reflexive muscle tension and soft tissue.[6]

The identification of JH levels and ROM values may allow intervention which can potentially improve performance and reduce injury risk. The primary aim of this study was to report JH values as determined by the BS in young gymnasts with consideration of gender, age and gymnastic competition level. The secondary aim was to report the ROM values at the hip, shoulder, ankle and spine with consideration of gender, age and gymnastic competition level.

Materials and methods

Participants

Fifty participants volunteered to participate in this study and was composed of 25 male gymnasts and 25 female gymnasts recruited from a gymnastics club. The participants demographics are outlined in table 1. Regional level gymnasts were classified as those gymnasts who had competed for their region on at least one occasion and national level gymnasts were classified as those who had competed for their country on at least one occasion. Recruitment was aimed at attaining age-matched groups standardised for weekly training volume of 15 hours per week. Subjects were excluded from the study if they had suffered an injury in the previous 30 days[37] which prevented them participating in or completing a training session or competition. Participants were verbally briefed on the study and consent forms were completed by the participant and parent/guardian as all participants were aged under 16 years and the gymnastics coach. All procedures performed involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1975 Helsinki declaration as revised in 1983.

Table 1 Participants demographics

Gender	Age (years)	Height (cm)	Mass (kg)	Ethnicity	Level
Male	10.44±2.89	142.16±20.0	28.00±7.43	23 white Caucasian 2 Asian	22 Regional 3 National
Female	11.16±2.70	141.55±22.34	32.33±7.99	24 white Caucasian 1 Asian	17 Regional 8 National

Procedures

Joint hypermobility screening

The BS[15] was used to measure JH which classifies JH as a score of ≥4 The same clinician performed all measurements, specifically a Chartered Physiotherapist with 16 years experience in BS classification. The BS was quantified by measuring ROM of the 5th Metacarpophalangeal joints (1 point each joint), thumbs (1 point each joint), elbows (1 point each joint), knees (1 point each joint) and lumbar spine (1 point), 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 hands flat on the floor. All tests were performed as described previously by Juul-Kristensen et al (2007).[38] The BS has an Intraclass Correlation Coefficient (ICC) of 0.91 and a kappa 0.74.[38] Intra-rater reliability of the BS was assessed by the Chartered Physiotherapist by measuring JH using the BS of 20 subjects (10 male, 10 female) on 2 separate occasions 24 hours apart. These subjects were not part of the investigated population. The Chartered Physiotherapist was blinded to previous results to allow determination of ICC's. Subjects were instructed not to participate in sport, dance activity or warm up during this 24 hour period to reduce the potential for ROM adaptations.

Range of movement

Active joint ROM measurements were measured bilaterally with a goniometer (Vivomed, UK) for hip flexion, hip extension, hip abduction, shoulder flexion and ankle plantarflexion by the Chartered Physiotherapist who had 16 years experience of performing these measurements. The procedure of measurement[39,40]is outlined in table 2. Ankle plantarflexion was measured from dorsiflexion through to plantarflexion. Lumbar extension ROM was measured using a tape measure to measure the distance between the participant's middle finger tip and the floor (Hahne, Keating and Wilson 2004). Each participant stood with their feet hip width apart and the front of their thighs against a massage plinth to limit hip movement and then placed the backs of their hands onto the back of their legs and they then extended backwards[41] and the measurement was performed. This method has an ICC of 0.96 for which represents good reliability.[41]

Table 2 Joint Range of Motion measurement procedure

Measurement	Patient position	Goniometer alignment
Hip flexion	Supine	Centre of fulcrum over lateral greater trochanter Proximal arm over later midline of pelvis Distal arm in line with lateral epicondyle of femur
Hip extension	Prone	Centre of fulcrum over lateral greater trochanter Proximal arm over lateral midline of pelvis Distal arm in line with later epicondyle of femur
Hip abduction	Supine	Centre of fulcrum over anterior superior iliac spine (ASIS).Proximal arm in line with opposite ASIS Distal arm in line with anterior midline of the femur
Shoulder flexion	Sitting	Centre of fulcrum over lateral aspect of greater tubercle of humerus Proximal arm parallel to midline of thorax Distal arm in line with midline of humerus
Ankle plantarflexion	Supine	Centre of fulcrum over lateral malleolus Proximal arm in line with fibula head Distal arm in line with fifth metatarsal

Statistical analysis

The data satisfied the criteria for normal distribution as determined by a Shapiro-Wilk test. An unpaired t-test was used to analyse differences in total BS and ROM values between male and female gymnasts and regional and national level gymnasts. Total BS and joint ROM were analysed using a one-way Anova to determine significance between female gymnasts <13, female gymnasts ≥13, male gymnasts <13 and male gymnasts ≥13. The assumptions of homogeneity of variance were determined using a Levene's test and a post-hoc Tukey test was applied when appropriate to identify significance differences between groups. All results were reported as means and standard deviations and significance was accepted as P<0.05 and 95% confidence intervals (CI) reported. Statistical analysis was performed using SPSS version 24 software (IBM Inc.)

Results

Beighton Score

Male and female gymnasts

Table 3 reports the mean BS for male and female gymnasts with consideration of gender, age and performance level and the number of gymnasts classified as hypermobile using as classification of BS≥4 and BS≥5 (percentage). The highest BS occurred in female gymnasts (4.76±2.05), female gymnasts ≤13 years (4.93±1.87) and male national level gymnasts (5.67±1.15). For male and female gymnasts there was homogeneity of variance as assessed by Levens's test for equality of variances (p=0.62). An unpaired t-test revealed no statistical significant difference between male and female gymnasts for BS (F=0.246), p=0.26, 95% CI =-0.51 to 1.87. There was a prevalence of 62% (BS≤4) in male and female gymnasts with a gender specific prevalence of 56% in males and 68% in females.

Table 3 Beighton scores

Group	Mean BS	Number hypermobile (BS≥4)	Number hypermobile (BS≥5)
FG (n=25)	4.76±2.05	17 (68%)	16 (64%)
MG (n=25)	4.08±2.14	14 (56%)	13 (52%)
FG/MG (n=50)	4.42±2.10	31 (62%)	29 (58%)
FG<13 yr (n=15)	4.93±1.87	7 (46.7%)	4 (26.7%)
MG<12 yr (n=17)	4.71±1.86	12 (70.59%)	11 (61.11%)
FG/MG <13 yr (n=32)	4.81±1.84	19 (59.36%)	15 (46.88%)
FG ≥13 years (n=10)	4.50±2.37	6 (60%)	6 (60%)
MG ≥13 years (n=8)	2.75±2.19	2 (25%)	2 (25%)
FG/MG ≥13 years (n=18)	3.72±2.40	8 (44.44%)	8 (44.44%)
FG regional (n=17)	4.81±2.13	11 (64.71%)	11 (64.71%)
MG regional (n=22)	3.86±2.17	11 (50%)	10 (45.45%)
FG/MG regional (n=39)	4.26±2.20	22 (56.41%)	21 (53.85%)
FG national (n=8)	4.81±2.13	11 (64.71%)	11 (64.71%)
MG national (n=3)	3.86±2.17	11 (50%)	10 (45.45%)
FG/MG national (n=11)	4.26±2.20	22 (56.41%)	21 (53.85%)

Abbreviations: FG; Female gymnasts, MG; Male Gymnasts, BS; Beighton Score, Yr; years

Beighton Score: Gender and age

There was homogeneity of variance as determined by the Levene’s test of homogeneity of variance (p=0.731) for gender and age specific groups of male and female gymnasts. There was no statistically significant difference between female gymnasts <13, female gymnasts ≥13, male gymnasts <13 and male gymnasts ≥13 for BS as determined by one-way Anova (F=(3,46)=2.25, p=0.095)

Beighton Score: Regional and national level

Regional level gymnasts (male and female) demonstrated a lower BS (4.26±2.20) in comparison to national level gymnasts (male and female) (4.92±1.73). There was homogeneity of variance as assessed by Levens's test for equality of variances (p=0.178) for regional and national level combined sample of male and female gymnasts. An unpaired t-test revealed no statistical significant difference between regional and national level gymnasts for a combined sample of male and female gymnasts (F=1.87), p=0.35, 95% CI=-2.05 to 0.75. Due to the small sample size of male national level gymnasts (n=3) a comparison between male and female national level gymnasts was not performed. For male and female regional gymnasts there was homogeneity of variance (p=0.74). An unpaired t-test revealed no statistical significant difference between male and female regional gymnasts (F=0.11), p=0.74, 95% CI=-0.50 to 2.40.

Joint hypermobility prevalence

Table 4 reports JH prevalence for individual joints reported as number of hypermobile joints (percentage) with consideration of gender and age.

Table 4 Joint hypermobility prevalence: age and gender

Measurement	FG (n=25)	MG (n=25)	FG/MG (n=50)	FG <13 (n=15)	FG ≥13 (n=10)	MG <13 (n=17)	MG ≥13 (n=8)
L 5th metacarpophlangeal	19 (76%)	19 (76%)	38 (76%)	13 (87%)	6 (60%)	15 (88%)	4 (50%)
R 5th metacarpophalangeal	19 (76%)	19 (76%)	38 (76%)	13 (87%)	6 (60%)	15 (88%)	4 (50%)
L thumb	19 (76%)	15 (60%)	34 (68%)	11 (73%)	8 (80%)	13 (87%)	2 (20%)
R thumb	19 (76%)	13 (52%)	32 (64%)	11 (73%)	8 (80%)	13 (77%)	0 (0%)
L elbow	4 (16%)	3 (12%)	7 (14%)	2 (13%)	2 (20%)	1 (6%)	2 (25%)
R elbow	4 (16%)	1 (4%)	5 (10%)	2 (13%)	2 (20%)	1 (6%)	0 (0%)
L knee	7 (28%)	6 (24%)	13 (26%)	6 (40%)	1 (10%)	4 (24%)	2 (25%)
R knee	2 (8%)	5 (20%)	7 (14%)	1 (7%)	1 (10%)	3 (18%)	2 (25%)
LF	25 (100%)	24 (96%)	49 (98%)	15 (100%)	10 (100%)	17 (100%)	7 (88%)

Abbreviations: FG; Female gymnasts, MG; Male Gymnasts, L; Left, R; Right, LF; Lumbar Flexion

In both male and female gymnasts, hypermobility was most prevalent on lumbar flexion and in the metacarpophalangeal and thumb joints and this prevalence order was repeated when age and gymnastic level was considered. Table 5 reports JH prevalence for individual joints reported as number of hypermobile joints (percentage) with consideration of gymnastic level.

Table 5 Joint hypermobility prevalence: gymnastic level

Measurement	FG regional (n=17)	FG national (n=8)	MG regional (n=22)	MG national (n=3)
L 5th metacarpophlangeal	13 (77%)	6 (75%)	16 (73%)	3 (100%)
R 5th metacarpophalangeal	12 (71%)	7 (88%)	16 (73%)	3 (100%)
L thumb	12 (71%)	7 (88%)	12 (55%)	3 (100%)
R thumb	12 (71%)	7 (88%)	10 (45%)	3 (100%)
L elbow	3 (18%)	1 (13%)	3 (14%)	0 (0%)
R elbow	3 (18%)	1 (13%)	1 (5%)	0 (0%)
L knee	3 (18%)	4 (50%)	5 (23%)	1 (34%)
R knee	2 (12%)	0 (0%)	5 (23%)	0 (0%)
LF	17	8	21	3

Abbreviations: FG; Female gymnasts, MG; Male Gymnasts, L; Left, R; Right, LF; Lumbar Flexion

ROM

Table 6 outlines mean ROM values for male and female gymnasts with consideration of age and gender. Table 7 outlines mean ROM values for regional and national gymnasts.

Table 6 Male and female gymnasts ROM values

Joint	FG (n= 25)	MG (n= 25)	FG/MG (n=50)	FG <12 (n=15)	FG ≥13 (n=10)	MG <12 (n=17)	MG ≥13 (n=8)
L hip flex	140.60±5.06	138.36±5.18	139.48±5.20	142.45±4.22	137.80±5.12	140.00±4.77	134.87±4.45
R hip flex	139.84±5.15	138.08±4.51	138.96±4.87	141.33±3.77	137.60±6.28	139.47±4.14	135.26±3.98
Hip flex comb	140.22±4.92	138.22±4.79	139.22±4.91	141.90±3.81	137.70±5.49	139.74±4.14	135±4.17
L hip ext	41.04±6.39	34.60±4.82	37.82±6.48	42.80±6.25	38.40±5.94	35.70±3.53	32.25±6.08
R hip ext	40.72±5.28	34.86±4.70	37.60±5.86	41.87±5.05	39.00±5.39	35.64±3.53	32.00±6.07
Hip ext comb	40.88±5.61	34.70±4.51	37.79±5.92	42.33±5.51	38.70±5.27	35.91±3.14	32.12±5.99
L hip abd	73.52±8.12	62.88±6.58	68.20±9.08	76.20±8.04	69.50±6.37	65.58±5.53	57.13±4.76
R hip abd	74.16±6.71	65.60±6.28	69.88±7.75	76.33±7.20	70.90±4.43	68.29±4.59	59.87±5.67
Hip abd comb	71.84±7.09	64.24±6.14	69.04±8.16	76.26±7.34	70.20±5.07	66.94±4.57	58.50±5.11
L shoulder flex	202.20±9.57	201.64±9.43	203.30±9.16	207.13±7.86	194.80±6.86	206.24±9.01	200.37±7.13
R shoulder flex	201.64±9.41	204.40±8.77	202.82±8.48	205.40±8.12	196.00±8.63	204.64±7.88	202.65±6.63
Shoulder flex comb	201.92±9.22	204.00±7.43	203.06±8.48	206.26±7.64	195.40±7.57	205.47±8.19	201.50±6.06
L PF	71.36±5.87	70.20±7.68	70.12±6.54	72.60±4.79	69.50±7.05	70.47±7.30	65.50±5.35
R PF	71.84±6.34	68.88±7.04	70.16±7.33	72.40±6.82	71.00±5.77	69.59±8.83	66.12±5.5
PF comb	71.60±5.72	68.48±7.97	70.14±6.69	72.50±5.38	70.25±6.27	70.03±7.95	65.81±5.31
Lumbar ext	18.20±5.76	13.76±2.80	15.98±5.02	18.47±4.22	17.80±7.78	13.65±2.94	15.98±2.67

Abbreviations: L; left, R; right, Flex; flexion, Ext; extension, Abd; abduction, Comb; combined, PF; plantarflexion, FG; Female Gymnast, MG; Male Gymnast

Table 7 Regional and national level gymnasts ROM

Joint	FG regional (n=17)	FG National (n=8)	MG Regional (n=22)	MG National (n=3)
L hip flex	138.50±4.42	144.33±3.97	137.23±4.32	146.67±2.89
R hip flex	137.38±4.09	144.22±3.80	137.31±3.77	145±3.61
Hip flex comb	137.94±3.99	144.28±3.72	137.13±3.77	145.00±3.61
L hip ext	38.87±5.35	44.88±6.55	34.09±4.87	38.33±2.52
R hip ext	38.93±4.91	43.88±4.54	34.27±4.63	36.00±6.00
Hip ext comb	38.91±4.89	44.39±5.27	34.36±4.53	37.16±4.25
L hip abd	72.88±6.32	74.67±109.9	62.05±5.79	69.00±10.15
R hip abd	73.81±5.80	74.77±8.44	64.72±6.15	72.00±2.65
Hip abd comb	73.74±5.57	74.72±9.56	63.69±5.73	70.50±6.38
L shoulder flex	201.25±7.36	203.88±12.99	214.33±8.27	203.30±6.02
R shoulder flex	200.81±7.61	203.11±12.37	203.22±7.42	209.67±5.51
Shoulder flex comb	201.03±7.06	203.50±12.55	212.00±7.37	203.06±5.77
L PF	71.50±5.42	71.11±6.95	68.22±6.93	73.66±6.92
R PF	70.94±5.35	73.44±7.89	67.86±7.55	73.00±11.35
PF comb	71.20±5.00	72.27±7.11	68.04±7.10	73.33±9.29
Lumb ext	15.87±14.09	22.33±6.18	13.45±2.70	16.00±3.00

Abbreviations: L; left, R; right, Flex; flexion, Ext; extension, Abd; abduction, Comb; combined, PF; plantarflexion, FG; Female Gymnast, MG; Male Gymnast

ROM: Male and female gymnasts

There was homogeneity of variance as determined by a Levenes test of equality for all ROM measurements. An unpaired t-test for all ROM values revealed statistically significant differences between male and female gymnasts for left hip extension (p=0.001), right hip extension (p=0.001), hip extension combined (p=0.001), left hip abduction (p=0.001), right hip abduction (p=0.001), hip abduction combined (p=0.001) and lumbar extension (p=0.001). The results are reported in table 8.

Table 8 Comparison of ROM between male and female gymnasts

Joint	F value	P value
L hip flex	0.011	0.13 (-0.67 to 5.15)
R hip flex	0.206	0.21 (-0.99 to 4.51)
Hip flex comb	0.023	0.15 (-0.76 to 4.76)
L hip ext	0.297	0.001* (3.22 to 9.66)
R hip ext	1.044	0.001* (3.40 to 9.08)
Hip ext comb	0.650	0.001* (3.29 to 9.07)
L hip abd	1.160	0.001* (6.44 to 14.84)
R hip abd	0.312	0.001* (1.84 to 4.86)
Hip abd comb	1.02	0.001* (1.88 to 5.83)
L shoulder flex	0.325	0.401 (2.60 to -7.42)
R shoulder flex	1.829	0.330 (2.40 to -7.18)
Shoulder flex comb	1.047	0.35 (2.40 to -7.11)
L PF	0.059	0.182 (2.48 to 1.83)
R PF	0.556	0.106 (3.36 to 2.04)
PF comb	0.563	0.124 (2.92 to 1.87)
Lumbar ext	4.58	0.001*(1.28 to 1.86)

Abbreviations: L; left, R; right, Flex; flexion, Ext; extension, Abd; abduction, Comb; combined, PF; plantarflexion
** = P<0.05*

ROM: Gender and age

There was homogeneity of variance for all ROM measurements as determined by Levenes test. There was a statistically significant difference between female gymnasts <13, female gymnasts ≥13, male gymnasts <13 and male gymnasts ≥13 for left hip flexion (F=3.46)=5.23, p=0.003, right hip flexion (F=3,46)=3.68, p=0.019, combined hip flexion (F=3,46)=4.71,p=0.006, left hip extension (F=3,46=7.90), p=0.001), right hip extension (F=3,46)=8.66, p=0.001 hip extension combined (F=3,46)=8.97,p=0.001, left hip abduction (F=3,46=16.21), p=0.001, right hip abduction (F=3,46=15.48), p=0.001, hip abduction combined (F=3,46=17.95), p=0.001, left shoulder flexion (F=3,46=6.06), p=0.001, right shoulder flexion (F=3,46=3.29), p=0.03, left plantarflexion (F=3,46=4.95), p=0.01, lumbar extension (F=3,46=3.90), p=0.02 as determined by one-way Anova. No significant differences existed for right plantarflexion (F=3,46=1.38), p=0.26 and plantarflexion combined (F=3,46=3.89), p=0.17. These values are reported in table 9 in combination with post-hoc Tukey test analysis.

Table 9 Gender and age ROM values

Joint	F value	P value (95% CI)	Tukey test P value
L hip flex	0.56	0.01 (-9.96 to -4.34)	FG <13 MG ≥13 0.003*
R hip flex	0.65	0.05 (-19.56 to -0.19)	FG <13 MG ≥13 0.02*
Hip flex comb	0.74	0.01 (-16.03 to -2.10)	FG <13 MG ≥13 0.01*
L hip ext	0.01	0.01 (-11.27 to -1.39)	FG <13 MG <13 0.01* FG <13 MG ≥13 0.001*
R hip ext	0.07	0.13 (-10.30 to 1.33)	FG <13 MG <13 0.01* FG <13 MG ≥13 0.001*
Hip ext comb	0.02	0.01 (-11.30 to -2.76)	FG <13 MG <13 0.03* FG <13 MG ≥13 0.001*
L hip abd	0.16	0.05 (-16.90 to 0.09)	FG <13 MG <13 0.001* FG <13 MG ≥13 0.001*

R hip abd	0.20	0.07 (-15.44 to 0.75)	FG <13 MG <13 0.001* FG <13 MG ≥13 0.001*
Hip abd comb	0.01	0.06 (-16.05 to 0.30)	FG <13 MG <13 0.001* FG <13 MG ≥13 0.001*
L shoulder flex	0.06	0.32 (-29.84 to 10.00)	FG <13 FG ≥13 0.002* FG ≥13 MG <13 0.004*
R shoulder flex	5.51	0.42 (-10.28 to 4.51)	FG <13 FG ≥13 0.03 FG ≥13 MG <13 0.04*
Shoulder flex comb	0.07	0.36 (-28.98 to 10.83)	FG <13 FG ≥13 0.01* FG ≥13 MG <13 0.01*
L PF	0.12	0.26 (-12.10 to 3.39)	Non-significant
R PF	0.01	0.11 (-14.34 to 1.52)	Non-significant
PF comb	0.01	0.17 (-13.02 to 2.31)	Non-significant
Lumbar ext	3.38	0.01 (-9.40 to -3.47)	FG <13 MG ≤13 0.03*

Abbreviations: L; left, R; right, Flex; flexion, Ext; extension, Abd; abduction, Comb; combined, PF; plantarflexion, FG; Female Gymnast, MG; Male Gymnast
** = P<0.05*

ROM: Regional and national level gymnasts

There was homogeneity of variance as assessed by Levens's test for equality of variances for all ROM measurements for a regional and national level combined sample of male and female gymnasts except for right shoulder flexion. Unpaired t-test analysis of ROM values between a combined sample of regional and national gymnasts revealed significant differences for left hip flexion (p=0.001), hip flexion combined (p=0.01), left hip extension (p=0.01) and hip extension combined (p=0.002) and are reported in table 10. Due to the small sample size of male national level gymnasts (n=3) a comparison between male and female national level gymnasts was not performed. For male and female regional gymnasts there was homogeneity of variance for all ROM measurements. An unpaired t-test revealed a statistical significant difference between male and female regional gymnasts for hip flexion combined (p=0.01), left hip extension (p=0.01), right hip extension (p=0.01), hip extension combined (p=0.01), left hip abduction (p=0.01), right hip abduction (p=0.01), hip abduction combined (p=0.01). These findings are reported in table 11.

Table 10 Comparison of regional and national gymnasts' ROM

Measurement	F value	P value (95% CI)
L hip flex	0.56	0.001* (-9.96 to -4.34)
R hip flex	0.65	0.05 (-19.56 to -0.19)
Hip flex comb	0.74	0.01* (-16.03 to -2.10)
L hip ext	0.007	0.01* (-11.27 to -1.39)
R hip ext	0.07	0.13 (-10.30 to 1.33)
Hip ext comb	0.02	0.02* (-11.30 to -2.76)
L hip abd	0.16	0.05 (-16.90 to 0.09)
R hip abd	0.20	0.07 (-15.44 to 0.75)
Hip abd comb	0.01	0.06 (-16.05 to 0.30)
L shoulder flex	0.06	0.32(-29.84 to 10.00)
R shoulder flex	5.51	0.42 (-10.28 to 4.51)
Shoulder flex comb	0.07	0.36 (-28.98 to 10.83)
L PF	0.12	0.26 (-12.10 to 3.39)
R PF	0.01	0.11 (-14.34 to 1.52)
PF comb	0.01	0.17 (-13.02 to 2.31)
Lumbar ext	3.38	0.001* (-9.40 to -3.47)

Measurement	F value	P value (95% CI)
L hip flex	0.56	0.001* (-9.96 to -4.34)
R hip flex	0.65	0.05 (-19.56 to -0.19)
Hip flex comb	0.74	0.01* (-16.03 to -2.10)
L hip ext	0.007	0.01* (-11.27 to -1.39)
R hip ext	0.07	0.13 (-10.30 to 1.33)
Hip ext comb	0.02	0.02* (-11.30 to -2.76)
L hip abd	0.16	0.05 (-16.90 to 0.09)
R hip abd	0.20	0.07 (-15.44 to 0.75)
Hip abd comb	0.01	0.06 (-16.05 to 0.30)
L shoulder flex	0.06	0.32(-29.84 to 10.00)
R shoulder flex	5.51	0.42 (-10.28 to 4.51)
Shoulder flex comb	0.07	0.36 (-28.98 to 10.83)
L PF	0.12	0.26 (-12.10 to 3.39)
R PF	0.01	0.11 (-14.34 to 1.52)
PF comb	0.01	0.17 (-13.02 to 2.31)
Lumbar ext	3.38	0.001* (-9.40 to -3.47)

Abbreviations: L; left, R; right, Flex; flexion, Ext; extension, Abd; abduction, Comb; combined, PF; plantarflexion, CI; Confidence intervals
** = P<0.05*

Table 11 A comparison of regional male and female gymnasts' ROM

Measurement	F value	P value (95% CI)
L hip flex	0.08	0.46 (-1.88 to 4.10)
R hip flex	0.17	0.88 (-2.50 to 2.89)
Hip flex comb	0.63	0.01* (-2.09 to 3.39)
L hip ext	0.08	0.01* (1.28 to 8.28)
R hip ext	0.53	0.01* (1.45 to 8.00)
Hip ext comb	0.47	0.01* (1.34 to 7.80)
L hip abd	0.16	0.001* (5.22 to 13.46)
R hip abd	0.09	0.001* (-15.44 to 0.75)
Hip abd comb	0.10	0.001* (6.42 to 14.14)
L shoulder flex	0.35	0.37 (-7.72 to 2.97)
R shoulder flex	0.02	0.42 (-10.28 to 4.51)
Shoulder flex comb	0.07	0.26 (-7.99 to 2.20)
L PF	0.46	0.13 (-0.99 to 7.74
R PF	1.14	0.18 (-1.50 to 7.77)
PF comb	1.03	0.13 (-1.09 to 7.60)
Lumbar ext	2.58	0.06 (-0.11 to 4.40)

Abbreviations: L; left, R; right, Flex; flexion, Ext; extension, Abd; abduction, Comb; combined, PF; plantarflexion, FG; Female Gymnast, MG; Male Gymnast
** = P<0.05*

Discussion

The primary aim of the current study was to report JH as determined by the BS in gymnasts with consideration of gender, age and gymnastic level. The highest BS was observed in male national level gymnasts (BS 5.67±1.15) however this group only consisted of 3 gymnasts. In larger samples the highest BS was in female gymnasts (BS 4.76±2.05) and female gymnasts ≤13 years (4.93±1.87). The finding of no significant difference between male and female gymnasts and that female gymnasts had higher BS agreed with previous findings.[30] The prevalence of 62% (BS≥4) and 58% (BS≥5) may reflect that hypermobility is a positive selection criterion in gymnastics[28] and the prolonged, repetitive stretching completed during gymnastic and dance training. Gannon and Bird (1999)[30] investigated the BS and the ankle, hip and shoulder ROM of 65 gymnasts, dancers and an age matched control group and reported a BS of 3.70 in male and female gymnasts combined (males 3.11, females 3.33) which were lower than the values obtained in the current study.

With regard to age the finding of no statistical difference between male and female gymnasts <13 and ≥13 contrasted with previous findings in a sample of school children[42] and of Quatman et al (2008)[7] who investigated high school athletes and reported that females had a greater BS than males in all age groups. In school children aged 9, 12 and 15 years the degree of joint laxity in males was at its highest at the age of 9 years and then decreased as age increased.[42] In contrast to this, the degree of joint laxity in females decreased from the age of 9 to 12 years, but then increased at the age of 15 years[42] while no significant change existed in male JH with increased age[7] and Rikken-Bultman et al (1997)[43] reported no reduction in joint laxity with age. Both Jansson et al (2004)[42] and Rikken-Bultman et al (1997)[43] measured chronological age, while Quatman et al (2008)[7] measured age dependent on pubertal stage which requires consideration.

The anatomical and hormonal changes that occur during puberty may influence joint laxity[44] with greater anterior knee laxity reported in females.[45] It is suggested that the generalised joint hypermobility peaks at the age of 15 in adolescent girls due the release of the relaxin hormone.[28] There is no consensus regarding the advantages of JH and association with increased injury risk however what it clear is the paucity of studies that have investigated hypermobility in gymnasts. In artistic gymnasts aged 11 to 26 years it was reported that years training and not hypermobility score predisposed to injury.[46] Training related repetitive hyperextension, extension and rotations have been found to induce spine lesions in gymnastics[47] and the hypermobility developed by intensive training may increase the incidence of spondylolysis.[48] A higher prevalence of hypermobility (BS ≥4) has been reported in elite adolescent gymnasts aged 13 to 16 years in comparison to handball players of a similar age but less than was reported in ballet dancers.[49] In rhythmic gymnastics flexibility was found to be associated with the skill of the gymnast and high correlations existed between technical elements scores and trunk flexibility with higher scores associated with greater trunk flexibility.[50] Clinch et al (2011)[51] reported no association between JH and age or puberty. A strong positive association existed between hypermobility (BS≥6) and girls performing >60 minutes vigorous physical activity weekly with these individuals almost 3 times more likely to be hypermobile and a similar trend was seen with a BS≥4.[51]

With reference to competition level, there was no significant difference between a combined sample of regional and national gymnasts and between male and female regional gymnasts.
With regard to JH at specific joints, 98% of gymnasts obtained a positive BS for lumbar flexion and this reflects a training adaptation[52] and has been reported to be an adaptation in dance.[18] The 5th metacarpophalangeal joints and thumbs demonstrated the second and third highest prevalence of JH. Clinch et al (2011)[51] evaluated the prevalence of hypermobility (BS ≥4) in 6,022 children (mean 13.8 years) and reported that hypermobility was prevalent in 27.5% of girls and 10.6% of boys. Girls were more likely to be hypermobile at the fingers, thumbs and lumbar spine with boys more likely to be hypermobile at the fingers, thumbs and knees.[51] This contrasted with the current study where lumbar flexion hypermobility was the most prominent hypermobile joint in males suggestive of a gymnastic performance adaptation. Hypermobility of the 5th metacarpophalangeal joint occurred in >40% of girls[51] which was less than in female gymnasts in the current study.

The secondary aim was to report ROM values for the hip, shoulder, ankle and lumbar spine.
For male and female gymnasts, a number of significant differences were observed in all hip extension and hip abduction movements and for lumbar extension with all these values greater in female gymnasts which supports the finding of higher BS in female gymnasts.

For age and gender groups, significant differences existed between female gymnasts <13 and male gymnasts ≥13 for all hip flexion, hip extension and hip abduction movements with values greater in the younger female age group. Between female gymnasts <13 and male gymnasts <13 significant differences existed for all hip extension and hip abduction movements with values greater in the younger female group. Between female gymnasts <13 and ≥13 significant differences existed for shoulder flexion on all movements with values greater in the <13 age group. Between female gymnasts ≥13 and male gymnasts <13 significant differences existed for all shoulder flexion movements and for lumbar extension was significantly greater in the <13 female gymnasts than ≥13 male gymnasts. Hypermobility decreases as age increases[42,53] however, research comparing ROM in joints that do not form part of the BS is limited. Sankar et al (2012)[54] reported that hip ROM decreased with age in male and female children aged 2 to 17 years and despite the potential for gymnastics to increase ROM this reduction was observed in the current study.

For regional and national level gymnasts significant differences existed for left hip flexion, combined hip flexion, left hip extension and hip extension combined with values greater in national level gymnasts while between male and female regional gymnasts significant differences existed for all hip extension and abduction movements with values greater in females. For all measurements ROM was greater in national gymnasts than regional when comparing gender except for left plantarflexion in female gymnasts however this difference was minimal (0.39cm). Increased hip ROM could potentially be attributed to progressive, passive stretching from an early age as well as repetitive skill preparations such as heel drives and leg kicks.[55] When gymnastic demands on the hip exceed functional ROM, compensatory stresses and subsequent pain may develop[33] and therefore this observed increased hip ROM may reduce injury risk. Gannon and Bird (1999)[30] reported that gymnasts and dancers demonstrated greater ROM for shoulder flexion and extension, hip flexion, extension, and abduction, lumbar spine extension, ankle plantarflexion and dorsiflexion compared to the age-matched controls which was thought to be due to repetitive, prolonged stretches performed at a young age. Lumbar flexion was significantly greater in national/international gymnasts than novice gymnasts ("*some experience*") and the control group. Male gymnasts demonstrated the smallest range of shoulder flexion however this group included six gymnasts who had suffered shoulder injuries. Professional dancers and international gymnasts achieved the highest scores for hip flexion. National gymnasts and dancers range of movement at the hip, shoulder, ankle and lumbar spine was greater than in the novice gymnasts and dancers however the results were not statistically significant. One limitation requiring consideration is that this study did not state the gymnastic level in sufficient detail. Gannon and Bird (1999)[30] suggested that gymnast's shoulders are targeted when stretching to avoid excessive extension of the lumbar spine and therefore the shoulders must flex beyond 180° to achieve certain movements. Previous research in dancers found significantly greater plantarflexion ROM in comparison to age matched controls.[56] Their results support the findings from the current study as they reported a significant difference between groups, with dancers having significantly greater plantarflexion ROM than age-matched controls. Normal ROM values in the general population for hip flexion (0-120°), extension (0-30°), abduction (0-45°), shoulder flexion (0-180°) and ankle plantarflexion (50°)[57] are less than those observed within this study.

Clinical implications

JH is known to be an asset in certain sports[30] however, there is a significant relationship between JH and injury.[58,59] Hakim and Grahame (2003)[28] suggest that when measuring JH, other joints not covered by the BS should be considered including the shoulder, ankle and hip. Increased joint laxity is a positive selection factor for entry into dance and gymnastics[28] and JH can be improved from the repetitive stretching that forms part of the training for these activities and the requirements for gymnastics include high ROM in multiple joints.[33] The identification of JH is important for both performance enhancement and injury prevention. The measurement of ROM values in addition to the BS is important to identify JH in those joints that are not part of the BS to increase understanding. No significant differences were observed for the BS between gender, age and performance level groups however significant differences did exist for several ROM values highlighting the importance of ROM measurement.

For gymnasts it is important to be able to control their ROM as it is known that laxity of soft tissue structures can cause a joint to exceed the normal ROM[19,60]which can result in injury. Stabilising a joint during movement reduces injury risk by preventing the joint moving into extreme ranges[61] however in gymnastics this may be required. Therefore, strength exercises of the surrounding musculature are advocated to support the joint during the movement and to strengthen the stabilizing muscles around the hypermobile joint.[62] Sahin et al (2008)[63] measured muscular strength at the knee of 40 hypermobile and 45 non-hypermobile participants and reported that hypermobile participants demonstrate muscle imbalances and strength deficits between knee flexors and extensors compared to non-hypermobile participants. Ligament laxity in the knee increases the ROM available at the joint which can affect the function of activation of the flexor and extensors.[64]

Limitations

It must be acknowledged that some limitations existed in this study and include sample size and future studies may consider recruiting a larger group of gymnasts. Age was measured chronologically, and pubertal status was not measured and future research may wish to consider this factor. Ethnicity was reported, as previous studies have suggested a higher prevalence of joint hypermobility in the Asian population, followed by the African population and then white Caucasians.[65] The majority of our population (n=47, 94%) were classified as white Caucasian.

Conclusion

No significant differences were observed for the BS between gender, age and performance level groups however significant differences did exist for several ROM values particularly at the hip for in relation to gender, age and level and therefore this joint may be an important focus for performance enhancement and injury prevention. Lumbar extension and shoulder flexion were also identified as having significant differences in gender and age. These differences highlight the importance of ROM measurement in addition to BS measurement and the need to consider gender age and gymnastic level when working with child gymnasts.

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