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## Accepted Manuscript

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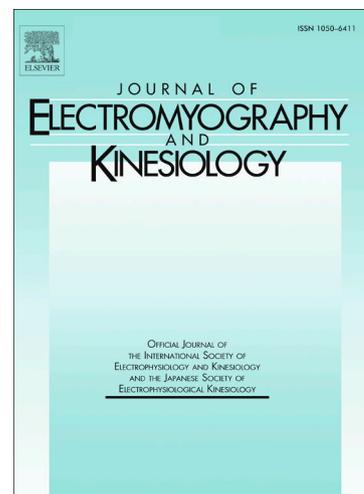
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**Competitive swimmers with hypermobility have strength and fatigue deficits in shoulder medial rotation**

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## 1. Introduction

Generalised Joint Hypermobility (GJH) is described as lack of structural stability of the passive system due to ligamentous or capsular looseness. The condition implies increased risk of traumatic and non-traumatic shoulder dislocations (Cameron et al., 2010; Chahal et al., 2010), and is a risk factor for overuse shoulder injuries (Zemek & Magee, 1996). The reason for this is not yet known, but is probably due to decreased strength, muscle activity and coordination, and eventually increased fatigue. Decreased isokinetic strength has been found in children and adults with symptomatic and non-symptomatic GJH and knee hypermobility (Juul-Kristensen et al., 2012). In contrast, recent studies of children with non-symptomatic GJH showed no reduced maximum isometric knee strength and hop length (Jensen et al., 2013; Junge et al., 2015). In fact, these studies reported that individuals with GJH use altered or compensatory muscle activation strategies in both agonist and stabilizing leg muscles. To our knowledge no studies have reported shoulder strength and muscle activity in individuals with GJH including hypermobile shoulders (GJHS).

Individuals with GHJS may also be characterised by multidirectional instability (MDI) (Borsa et al., 2000), glenohumeral instability and/or increased risk of recurrent joint luxation (Cameron et al., 2010; Chahal et al., 2010). In this aspect, previous findings indicate that these individuals present more precisely with altered muscle activity of scapular stabilisers and rotator cuff muscles (Barden et al., 2005), decreased shoulder muscle strength (Edouard et al., 2011), scapular function (Struyf et al., 2011) and shoulder proprioception (Laudner et al., 2012). In line with studies on MDI, it can be hypothesised that individuals with GJHS have functional deficits and altered muscle activity in the shoulder; however, this remains scientifically unanswered.

Young competitive swimmers represent a group with high prevalence of GJHS (Junge et al., 2016). This may be due to the demand of a greater range of shoulder motion to achieve a body position that reduces drag and increases stroke length, which ultimately results in better swimming performance (Wanivenhaus et al., 2012). Having GJHS in addition to being exposed to repetitive shoulder rotation movements during competitive swimming, these individuals may be predisposed

to muscle-tendon overload, muscle fatigue and pain. Thus, the aim of this study was to investigate whether young competitive swimmers with GJHS have reduced shoulder strength, increased isokinetic fatigue development and altered muscle activity during swimming-related movements of shoulder rotation.

## **2. Methods**

### *2.1 Study Design and Recruitment*

This study was cross-sectional comparing 13-17 years old competitive swimmers (highest national level) with GJHS and control swimmers without GJHS, individually matched on age, sex and swimming club. Participants were recruited from local sports clubs by initial email and phone contacts with coaches and parents. Study procedures were approved by the Research Ethics Approval Committee for Health at the University of Bath (EP 14/15 175). Participants and their parent/guardian provided written informed consent according to the Helsinki Declaration.

Data were collected during two sessions: (i) the screening session consisting of clinical tests for GJHS (approximately 10 min), performed by a second trained physiotherapist to ensure blinding of the principal investigator to the participants' health status (controls or GJHS); and (ii) the test session comprising isokinetic and EMG measurements (approximately 90 min) conducted on another day.

An element of shoulder laxity and GJHS is seen in many competitive swimmers, and both a combination of acquired and inherent factors contribute to shoulder laxity in swimmers. Due to the study design the included swimmers had to be inherently joint hypermobile and not only present with acquired hypermobility due to the swimming exposure, hence the Beighton tests for GJH were used during the screening session. Beighton tests have been found reproducible for testing GJH (Juul-Kristensen et al., 2007) and include nine tests: apposition of the thumbs, hyperextension of elbows and knees, dorsalflexion of the fifth fingers, all bilaterally, and forward bending in standing. Each positive test scores one point with nine points being the highest possible score.

Since the Beighton tests do not specifically include the shoulder joint, a shoulder test included in a Spanish test battery (Rotes-Querol, 1957) for GJH was added to ensure shoulder hypermobility. The test was shoulder lateral rotation (positive score  $>90^\circ$ ) with the upper arm in neutral along the side of the body, previously found to have satisfactory reliability (Juul-Kristensen et al., 2007).

The group with GJHS was defined with Beighton score  $\geq 5$  (Juul-Kristensen et al., 2007), and positive shoulder hypermobility in at least one shoulder. Inclusion criteria for controls were a Beighton score  $\leq 3$  and no shoulder hypermobility. Further inclusion criteria for both groups were: being swimmer, having normal training and competition activity within the latest seven days, and being matched for age and sex. Exclusion criteria were previous serious trauma to the upper extremity, shoulder surgery, diagnoses of Ehlers Danlos syndrome or Marfan syndrome.

During the actual test session, the participants firstly answered questionnaires about training activity, competitive swimming, other sports activities, previous injuries, perceived shoulder instability by the Western Ontario Shoulder Instability Index (WOSI) questionnaire and pain intensity measured by pain rating on Visual Analogue Scale (VAS) for current pain, pain during the latest 24 hours, and pain during the latest seven days (Table 1). Subsequently, information on anthropometric data was collected followed by the EMG electrode placement procedure. Then the participants completed a standardised warm up program for 10 minutes, comprising unilateral and bilateral shoulder movements (10 repetitions of flexion, extension, horizontal abduction and adduction), scapular protractions against a wall, and standing push-ups against a 90-cm high table, followed by simultaneous EMG recordings during maximum voluntary isometric contraction (MVIC) tests, and isokinetic measurements. After the isokinetic testing procedure, clinical tests for glenohumeral instability were performed.

## *2.2 Isokinetic Measurement*

The isokinetic concentric shoulder medial and lateral rotation measurements were performed on a calibrated Cybex NORM dynamometer (Cybex Inc., Ronkonkoma, New York,

USA) with the dominant arm defined as the side used for handwriting. One swimmer had GJHS on his non-dominant shoulder, in which case the non-dominant shoulder was tested on him and his matched control. The test position was selected to be close to the freestyle swimming stroke. The participants were prone lying with 90° shoulder abduction and 90° elbow flexion (Figure 1), and were fixated with belts around the mid lumbar spine and 10 centimetres above knee level. Centre of rotation for the shoulders were placed to be in line with the rotation arm of the dynamometer. To minimise risk of injuries in end range, total range of motion was set to 95°, ranging from 35° of medial rotation to 60° of lateral rotation.

*Insert Figure 1 about here...*

Five repetitions of maximum shoulder rotation strength were performed at 60°/s, and 10 repetitions at 180°/s, with 60 seconds of rest periods between each test, and the current velocities were selected as those most similar to the estimated velocities performed during swimming (Bak & Magnusson, 1997). Before each test, participants had five trials to familiarise with movements and velocities. No visual feedback was allowed, however, participants were encouraged to perform maximally with verbal instructions. Outcome measures were peak torque (the maximal value of the moment angle position curve) and maximum work (the repetition with highest value in torque x angular displacement) for both directions at both velocities (60°/s and 180°/s) normalised to body mass. Fatigue development in isokinetic strength was calculated as the decrease in work (J/repetition) during repetitions from 2-10 at 180°/s.

### 2.3 Electromyography

During isokinetic testing, surface EMG (Telemyo DTS, Noraxon Inc. Scottsdale, USA) was measured in the scapular stabilising muscles (mm. upper trapezius, lower trapezius and serratus anterior), the primary medial rotation agonist (m. pectoralis major), and the primary lateral rotation agonist muscle (m. infraspinatus). Once the exact point for electrode placement attachment was identified, the skin was lightly shaved, rubbed and cleaned with alcohol to keep skin impedance lower than 10 kOhm, measured with a digital multimeter. Bipolar electrodes (Ag/AgCl,

Ambu Blue Sensor, N-00-S/25, Ballerup, Denmark) were attached to the skin with a two-centimetre inter-electrode distance, and in line with muscle fibres. The locations of electrodes were as follows: *upper trapezius*, 20% medial to the mid distance between seventh cervical vertebra and acromion's lateral border (Holtermann et al., 2009); *lower trapezius*, 33% medial to the midpoint between the medial border of the scapula and eighth thoracic vertebra (Holtermann et al., 2009); *serratus anterior*, at the seventh rib, below the axilla, posterior to pectoralis major and anterior to latissimus dorsi (Holtermann et al., 2010) in line with the xiphoid process and the axillary border; *infraspinatus*, two and a half cm distal to the centre of the scapular spine (Barden et al., 2005); *pectoralis major*, one third of the distance from tuberculum major to the xiphoid process (Pontillo et al., 2007).

#### 2.4 Maximum Voluntary Isometric Contraction

For each muscle, maximum voluntary electrical activity (MVE) signal was recorded during MVIC in standardised anatomical positions. *Upper trapezius* was tested in standing with the arm in 90° elevation in scapula's plane with the thumb pointing upwards, while performing elevation. For *serratus anterior*, a similar testing position was used with the arm elevated to 135°. *Lower trapezius* was tested in prone with the arm in 125° of abduction along muscle fibres, performing horizontal abduction. *Infraspinatus* was tested in prone lying with the arm in 90° of abduction and the elbow in 90° of flexion during performance of shoulder lateral rotation, and *pectoralis major* was tested in supine lying with 90° of shoulder flexion during horizontal adduction performance. An external load of 40 kg was used for resistance, and to stabilise the body a manual isometric resistance was applied on the non-measured arm while the participants were fixated with belts in the prone and supine lying positions. A total of three sets, with each contraction lasting five seconds, were performed with 60 seconds rest period between each set.

#### 2.5 Clinical Tests

Three clinical tests for glenohumeral instability were used, including Gagey hyperabduction, sulcus and load-and-shift tests. The Gagey hyperabduction test for the inferior glenohumeral ligament was

considered positive with shoulder abduction beyond  $105^\circ$  (Gagey & Gagey, 2001). For the sulcus test, multidirectional instability was defined as more than two centimeters widening between acromion and the humeral head (Neer & Foster, 1980). In the load-and-shift test, severe ventral or dorsal glenohumeral instability was defined as grade two or three (i.e. humeral head moved beyond the glenoid labrum, and was relocated spontaneously or remained dislocated), on a scale from 0-3 (Bak & Faunø, 1997).

### 2.6 Analyses of EMG Signals

Raw EMG signals were amplified with gain 500 and bandpass filtered with 10-500 Hz (Noraxon Inc. Scottsdale, USA). The analogue signal was recorded on a computer via laboratory interface (CED Power 1401 16 bit, Spike2 software, Cambridge Electronic Design Limited, UK) with analogue to digital converting at 1000 Hz. For medial and lateral rotation, muscle analyses were performed with custom-made software (Hedera 3.0, The University of Southern Denmark). In EMG signals, changed shoulder rotation directions were marked by triggers defining start/stop of each medial and lateral rotation movement. EMG signals of each muscle during peak torque and maximum work repetitions were normalised to the respective muscle's MVE, defined as the highest Root Mean Square (RMS) amplitude in a moving window of 100 ms across the whole MVIC expressing relative MVE (%MVE).

### 2.7 Statistical Analysis

Baseline variables were tested for normality (Shapiro-Wilk, histograms and QQ-plots), and found to be normally distributed except for pain intensity and WOSI. For demographic data, un-paired t-tests were used to test for group differences on continuous data (Beighton score, age, height, body mass, swimming competitive experience, swimming during practice and other sports activities), while Mann-Whitney was used for non-normal data (pain intensity and WOSI), and Fisher's exact test for dichotomous data (Rotes-Querol and glenohumeral instability tests). For between-group differences in the outcomes of peak torque, maximum work and %MVE, a linear regression model was estimated adjusting for gender, age and body mass, without violating the assumption of

normality. For isokinetic fatigue (J/repetition) calculations during repetitions from 2-10 at 180°/s, a linear regression mixed effect model was applied with age, gender and body mass as covariates, using ID number as random factor. For the isokinetic fatigue development, a negative coefficient denotes a decrease in maximum work.

Sample size was calculated to be minimum 16 per group based on previous isokinetic values (Bak & Magnusson, 1997), with estimated standard deviation and minimum mean difference of 0.10 Nm/kg and 0.07 Nm/kg, respectively, with  $\alpha = 0.05$  and  $\beta = 0.20$ . To accommodate for drop-outs, 19 participants per group were recruited, however, there were no drop-outs. P-values  $<0.05$  were reported as statistically significant, while tendencies to significance were defined as p-values  $>0.05 <0.10$ . All statistical analyses were performed using STATA (StataCorp, 2015, Stata Statistical Software: Release 14. College Station, TX: StataCorp LP.)

### 3. Results

In total, 97 competitive swimmers were screened for eligibility, of which 38 swimmers, 11 girls and eight boys in each group, completed the study. The groups were comparable on demographics (age, height, body mass, sports participation, previous and current pain levels, WOSI and clinical tests for shoulder instability) except for the Beighton and Rotes-Querol tests, as expected due to the study design (Table 1).

*Insert Table 1 about here...*

#### 3.1 Isokinetic strength

In medial rotation at 60°/s, GJHS swimmers had significantly lower (12%) peak torque (0.53 vs 0.60 Nm/kg;  $p=0.047$ ), and significantly lower (14%) maximum work (0.62 vs 0.71 J/kg;  $p=0.031$ ) compared with controls (Table 2).

*Insert Table 2 about here...*

### 3.2 Isokinetic fatigue

Based on linear regression models, swimmers with GJHS showed significantly larger isokinetic fatigue development in medial rotation at 180°/s (-0.257 vs 0.064 J, SE=0.088; p=0.010) with a between groups difference in time effects of 0.321 J/Repetition (SE= 0.124). There were no significant group differences in lateral rotation (-0.428 vs -0.553 J, SE=0.097; p=0.362).

*Insert Figure 2 about here...*

### 3.3 Muscle activity

There were tendencies to lower %MVE (20%) for GJHS swimmers in infraspinatus in peak torque (60°/s medial rotation) ( $29.1 \pm 10.6$  vs.  $35.5 \pm 11.4$  %MVE; p=0.066), and lower %MVE (34%) in maximum work in pectorals major ( $30.0 \pm 22.1$  vs.  $42.3 \pm 25.8$  %MVE; p=0.092), but generally there were no significant group differences in EMG activity (Figure 2).

## 4. Discussion

Swimmers with GJHS, despite having no formal diagnosis, displayed both lower isokinetic peak torque and maximum work in medial rotation at 60°/s, and larger fatigue development in isokinetic strength during medial rotation strength measurements at 180°/s. There were no significant group differences in muscle activity during the corresponding isokinetic measurements at 60°/s.

### 4.1 Isokinetic strength

Velocities under 120°/s have been defined as those corresponding to strength (the amount of force muscles can exert against an external load), while higher velocities such as 180°/s have been defined as corresponding to power (the ability to generate as much force and as fast as possible) (St. Pierre et al., 1984). The significantly lower isokinetic performance at 60°/s (12-14%) indicates that participants with GJHS lacked muscle strength rather than power. The lower medial rotation strength in comparison (and no group differences in lateral rotation strength) was an interesting finding, because the medial rotation movement is one of the main propulsive

movements throughout the acceleration phase in swimming strokes. In fact, up to 4000 strokes per day in medial rotation with each arm are performed by high-level competitive swimmers (Bak & Faunø, 1997). These findings suggest that swimmers with GJHS could exert less force during the isokinetic test due to the musculoskeletal impairment itself, with the inclusion criteria of an external shoulder rotation of more than 90°. Similar sized strength deficits in GJH (ranging from 18-19%), however, in knee strength, were found in 10-year old girls and women with GJH and knee hypermobility (Juul-Kristensen et al., 2012). Since these two studies differ with respect to body regions and athletic status (competitive swimmers vs non-athletes), comparison should be made with caution. The reduced strength in the current study (12-14%) is in line with previous studies of elite swimmers with shoulder pain (17.5% reduced medial rotation strength) compared with those without pain (Bak & Faunø, 1997), and athletes with subacromial impingement (11% reduced scapular retraction-protraction strength) compared with their non-injured shoulder (Cools et al., 2004). The 'safe' limit of maximum 10% side difference before an increased risk of injuries has been advocated for knees (Tol et al., 2014). Since the shoulder is anatomically and biomechanically different from the weight bearing knee, it is unknown whether reduced shoulder strength within the present level (12-14%) represents a risk factor for future injury development. However, reduced strength in competitive sport may threaten joint integrity with potentially detrimental consequences. Further, the present result of lower maximum work suggests that swimmers with GJHS are weaker during the total range of swimming strokes, which may decrease swimming propulsion and increase joint stress exposure close to end range.

#### 4.2 Isokinetic Fatigue

Swimmers with GJHS further showed significantly larger fatigue development during isokinetic strength measurements in medial rotation (180°/s). This corresponds with the current reduced maximum work in medial rotation (60°/s) indicating lower endurance compared with controls, which may alter swimming strike coordination (Suito et al., 2008) and hence increase the risk of developing fatigue related shoulder pain (Crotty & Smith, 2000; Matthews et al., 2017). The current result on shoulder fatigue is in line with previous studies of patients with GJH generally

showing increased fatigue (Voermans et al., 2010; Scheper et al., 2014), however, the long-term consequences of this is unknown. If the included population develop clinical symptoms (impingement, rotator cuff tendinopathy and labral tears), preventive measures to avoid this development is important. Based on the current results, swimmers with GJHS may benefit from medial rotation endurance and strength training in addition to lateral rotation strength (Cools et al., 2015) to prevent such injuries. This may be an important topic for future studies.

#### 4.3 Muscle activity

It was hypothesised that the group with GJHS would show lower muscle activity in serratus anterior and lower trapezius indicating muscular imbalance in the scapular stabilisers, which was not confirmed. There was only a tendency to lower muscle activity in medial rotation in infraspinatus during peak torque and pectorals major during maximum work. The current results indicate decreased dynamic stabilisation of the humeral head in the hypermobile shoulder due to altered length-tension conditions for the medial rotators (which was found) and capsular looseness (not measured). Although a previous study has shown swimmers with shoulder problems to have lower activity of serratus anterior than swimmers without pain (Pink et al., 1991), such difference could not be seen in those with GJHS, probably due to the non-pain population. Generally, a lower activity of this muscle may influence scapular kinematics negatively by positioning the acromion to impinge on the rotator cuff, with increased risk for pain development (Cools et al., 2004). Lower muscle activity during medial rotation has previously been found in individuals with MDI as well as in individuals with subacromial impingement (Barden et al., 2005; Struyf et al., 2011), and may suggest altered muscle activation in the shoulders. The deeper lying medial rotator of subscapularis muscle, which requires needle-EMG for measuring its muscle activity, has also shown significantly lower muscle activity in swimmers with shoulder pain (Pink et al., 1991). Again, the present population was pain-free, but may have shown same characteristics as swimmers with shoulder pain with limited optimal working conditions (pain or altered length-tension conditions) for the working muscles. However, since the subscapularis muscle activity was not measured in the current study, its contribution to medial rotation remains unknown. The lack of statistically

significant group differences in EMG activity may be due to large inter-individual variability (SD range between 19.5 and 34.6 %MVE), thereby increasing the risk of type 2 error. It is not known whether a more functional task may have shown a clearer pattern of changed EMG-activity in GJHS, as seen previously in GJH with knee hypermobility during functional tasks such as balance, gait and jumping (Jensen et al., 2013; Junge et al., 2015).

#### *4.4 Strength and limitations*

One of the limitations in the current study may be the risk of selection bias since the inclusion criteria were healthy competitive swimmers without pain, thereby eliminating a potential effect of pain in GJHS. Although the inclusion criteria did not include instability, large positive prevalence of at least one of the shoulder instability tests was seen in GJHS swimmers indicating instability to be a potential inherent characteristic of GJHS. Further, clearer signs of fatigue development, as shown in previous studies, may have been present with higher number of repetitions and/or faster velocities than the present. This was, however, not chosen to avoid exposing the current participants to potential injuries during the testing procedure. Another limitation was increased risk of type 2 error in EMG measurements with large standard deviations since the sample size was based on group differences in isokinetic variables.

The strengths of the study are the strict inclusion criteria, group similarity in demographics and the standardised procedures in isokinetic and EMG measurements to ensure reliable data (Edouard et al., 2011; Seitz & Uhl, 2012). Also, the standardized procedures used in the selected clinical tests for shoulder instability provide satisfactory reliability (Eshoj et al., 2017). The strict inclusion criteria of healthy swimmers may also be a strength, since it was possible to study the clear effect of GJHS in swimmers without pain interference. The study population included 57.9% girls and 42.1% boys making it possible to generalise data to both genders in contrast to previous studies on GJH with few or no boys included (Juul-Kristensen et al., 2012; Jensen et al., 2013; Junge et al., 2015).

## 5. Conclusion

In conclusion, young competitive swimmers with generalised and shoulder joint hypermobility (GJHS), despite having no formal diagnosis, displayed both strength and fatigue deficits in medial rotation, which may be some of the contributing mechanisms for development of shoulder injury. Whether swimmers with GJHS will benefit from medial rotation strength training and not as per now only lateral rotation strength as injury prevention is an important topic for future studies.

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## References

- Bak K, Faunø P. Clinical findings in competitive swimmers with shoulder pain. *Am J Sports Med.* 1997;25(2):254-260.
- Bak K, Magnusson SP. Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am J Sports Med.* 1997;25(4):454-459.
- Barden JM, Balyk R, Raso VJ, Moreau M, Bagnall K. Atypical shoulder muscle activation in multidirectional instability. *Clin Neurophysiol.* 2005;116(8):1846-1857.
- Borsa PA, Sauers EL, Herling DE. Patterns of glenohumeral joint laxity and stiffness in healthy men and women. *Med Sci Sports Exerc.* 2000;32(10):1685-1690.
- Cameron KL, Duffey ML, DeBerardino TM, Stoneman PD, Jones CJ, Owens BD. Association of generalized joint hypermobility with a history of glenohumeral joint instability. *J Athl Train.* 2010;45(3):253-258.
- Chahal J, Leiter J, McKee MD, Whelan DB. Generalized ligamentous laxity as a predisposing factor for primary traumatic anterior shoulder dislocation. *J Shoulder Elbow Surg.* 2010;19(8):1238-1242.
- Cools AM, Johansson FR, Borms D, Maenhout A. Prevention of shoulder injuries in overhead athletes: a science-based approach. *Braz J Phys Ther.* 2015;19:331-339.
- Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *Br J Sports Med.* 2004;38(1):64-68.
- Crotty NM, Smith J. Alterations in scapular position with fatigue: a study in swimmers. *Clin J Sport Med.* 2000;10(4):251-258.
- Edouard P, Degache F, Beguin L, Samozino P, Gresta G, Fayolle-Minon I, Farizon F, Calmels P. Rotator cuff strength in recurrent anterior shoulder instability. *J Bone Joint Surg Am.* 2011;93(8):759-765.
- Edouard P, Samozino P, Julia M, Gleizes Cervera S, Vanbiervliet W, Calmels P, Gremeaux V. Reliability of isokinetic assessment of shoulder-rotator strength: a systematic review of the effect of position. *J Sport Rehabil.* 2011;20(3):367-383.
- Eshoj H, Ingwersen KG, Larsen CM, Hougs Kjær B, Juul-Kristensen B. Inter-tester reliability of clinical shoulder instability and laxity tests in subjects with and without self-reported shoulder problems. 2017;(accepted, BMJ Open).
- Gagey OJ, Gagey N. The hyperabduction test. *J Bone Joint Surg Am.* 2001;83:69-74.
- Holtermann A, Mork PJ, Andersen LL, Olsen HB, Sjøgaard K. The use of EMG biofeedback for learning of selective activation of intra-muscular parts within the serratus anterior muscle: a novel approach for rehabilitation of scapular muscle imbalance. *J Electromyogr Kinesiol.* 2010;20(2):359-365.
- Holtermann A, Roeleveld K, Mork PJ, Grönlund C, Karlsson JS, Andersen LL, Olsen HB, Zebis MK, Sjøgaard G, Sjøgaard K. Selective activation of neuromuscular compartments within the human trapezius muscle. *J Electromyogr Kinesiol.* 2009;19(5):896-902.
- Jensen BR, Olesen AT, Pedersen MT, Kristensen JH, Remvig L, Simonsen EB, Juul-Kristensen B. Effect of generalized joint hypermobility on knee function and muscle activation in children and adults. *Muscle Nerve.* 2013;48(5):762-769.
- Junge T, Henriksen P, Andersen HL, Byskov LD, Knudsen HK, Juul-Kristensen B. The association between generalized joint hypermobility and active horizontal shoulder abduction in 10-15 year old competitive swimmers. *BMC Sports Sci Med Rehabil.* 2016;8:19.
- Junge T, Wedderkopp N, Thorlund JB, Sjøgaard K, Juul-Kristensen B. Altered knee joint neuromuscular control during landing from a jump in 10-15 year old children with

- Generalised Joint Hypermobility. A substudy of the CHAMPS-study Denmark. *J Electromyogr Kinesiol.* 2015;25(3):501-507.
- Juul-Kristensen B, Hansen H, Simonsen EB, Alkjær T, Kristensen JH, Jensen BR, Remvig L. Knee function in 10-year-old children and adults with Generalised Joint Hypermobility. *Knee.* 2012;19(6):773-778.
- Juul-Kristensen B, Røgind H, Jensen DV, Remvig L. Inter-examiner reproducibility of tests and criteria for generalized joint hypermobility and benign joint hypermobility syndrome. *Rheumatology (Oxford).* 2007;46(12):1835-1841.
- Laudner KG, Meister K, Kajiyama S, Noel B. The relationship between anterior glenohumeral laxity and proprioception in collegiate baseball players. *Clin J Sport Med.* 2012;22(6):478-482.
- Matthews MJ, Green D, Matthews H, Swanwick E. The effects of swimming fatigue on shoulder strength, range of motion, joint control, and performance in swimmers. *Phys Ther Sport.* 2017;23:118-122.
- Neer CS.II, Foster CR. Inferior capsular shift for involuntary inferior and multidirectional instability of the shoulder. A preliminary report. *J Bone Joint Surg Am.* 1980;62:897-908.
- Pink M, Perry J, Browne A, Scovazzo ML, Kerrigan J. The painful shoulder during freestyle swimming: an electromyographic and cinematographic analysis of twelve muscles. *Am J Sports Med.* 1991;19:569-576.
- Pontillo M, Orishimo KF, Kremenec IJ, McHugh MP, Mullaney MJ, Tyler TF. Shoulder musculature activity and stabilization during upper extremity weight-bearing activities. *N Am J Sports Phys Ther.* 2007;2(2):90-96.
- Rotes-Querol J. [Articular laxity considered as factor of changes of the locomotor apparatus.] *Rev Rhum Mal Osteoartic.* 1957;24:535-539.
- Scheper MC, de Vries JE, Juul-Kristensen B, Nollet F, Engelbert RH. The functional consequences of generalized joint hypermobility: a cross-sectional study. *BMC Musculoskelet Disord.* 2014;15:243.
- Seitz AL, Uhl TL. Reliability and minimal detectable change in scapulothoracic neuromuscular activity. *J Electromyogr Kinesiol.* 2012;22(6):968-974.
- St Pierre RK, Andrews L, Allman, F, Fleming LL. The Cybex II evaluation of lateral ankle ligamentous reconstructions. *Am J Sports Med.* 1984;12:52-56.
- Struyf F, Nijs J, Baeyens JP, Mottram S, Meeusen R. Scapular positioning and movement in unimpaired shoulders, shoulder impingement syndrome, and glenohumeral instability. *Scand J Med Sci Sports.* 2011;21(3):352-358.
- Suito H, Ikegami Y, Nunome H, Sano S, Shinkai H, Tsujimoto N. The effect of fatigue on the underwater arm stroke motion in the 100-m front crawl. *J Appl Biomech.* 2008;24:316-324.
- ToI JL, Hamilton B, Eirale C, Muxart P, Jacobsen P, Whiteley R. At return to play following hamstring injury the majority of professional football players have residual isokinetic deficits. *Br J Sports Med.* 2014;48(18):1364-1369.
- Voermans NC, Knoop H, van de Kamp N, Hamel BC, Bleijenberg G, van Engelen BG. Fatigue is a frequent and clinically relevant problem in Ehlers-Danlos Syndrome. *Semin Arthritis Rheum.* 2010;40(3):267-274.
- Wanivenhaus F, Fox AJ, Chaudhury S, Rodeo SA. Epidemiology of injuries and prevention strategies in competitive swimmers. *Sports Health.* 2012;4(3):246-251.
- Zemek MJ, Magee DJ. Comparison of glenohumeral joint laxity in elite and recreational swimmers. *Clin J Sport Med.* 1996;6(1):40-47.

**Table 1.** Demographic variables, (mean  $\pm$  standard deviation, median [range], or number (percentage)) for self-reported ratings on pain (VAS), and shoulder-related instability and function (WOSI), in addition to clinical tests for glenohumeral instability, for swimmers with Generalised Joint Hypermobility and shoulder hypermobility (GJHS) and controls.

	GJHS (n = 19)	Controls (n = 19)	p-value
Gender: female, n (%)	11 (57.9)	11 (57.9)	1.000
Beighton score, 0-9	7.1 $\pm$ 1.1	1.1 $\pm$ 1.2	<0.001*
Rotes-Querol, positive, n (%)	19 (100)	0 (0)	<0.001*
Age, years	14.8 $\pm$ 1.3	14.7 $\pm$ 1.1	0.678
Height, cm	172.5 $\pm$ 8.4	170.6 $\pm$ 9.8	0.515
Body mass, kg	65.8 $\pm$ 12.8	62.7 $\pm$ 10.9	0.423
Swimming competitive experience, years	4.3 $\pm$ 1.9	4.9 $\pm$ 1.7	0.339
Swimming practice duration, h/week	8.3 $\pm$ 3.9	8.7 $\pm$ 5.2	0.783
Other sports activities, h/week	6.1 $\pm$ 2.1	5.5 $\pm$ 3.0	0.516
Pain intensity			
VAS 0-100 (mm) current pain	0 [0-20]	0.5 [0-10]	0.716
VAS 0-100 (mm) pain during latest 24 h	2 [0-50]	4 [0-39,5]	0.633
VAS 0-100 (mm) pain during latest seven days	2.5 [0-49]	9 [0-49]	0.175
WOSI overall score, 0-2100			
Physical symptoms, 0-1000	50 [6-358]	84 [12-349]	0.280
Sports/recreation/work, 0-400	17 [2-235]	18 [0-127]	0.540
Lifestyle, 0-400	12 [0-151]	14 [1-71]	0.619
Emotions, 0-300	33 [1-178]	74 [5-183]	0.540
Glenohumeral instability tests			
Gagey hyperabduction test, positive, n (%)	12 (63.2)	6 (31.6)	0.103
Sulcus test, positive, n (%)	3 (15.8)	0 (0)	0.230
Load-and-shift test, positive, n (%)	6 (31.6)	1 (5.3)	0.090

WOSI= Western Ontario Shoulder Instability Index.

Significant difference,  $p < 0.05$ , is marked with \*.

**Table 2.** Peak torque (Nm/kg) and max work (J/kg), including mean  $\pm$  standard deviation, during isokinetic medial and lateral rotation movements at 60°/s (five repetitions) and 180°/s (10 repetitions), for swimmers with Generalised Joint Hypermobility and shoulder hypermobility (GJHS) and controls.

	Velocity (degrees/s)	Medial rotation			Lateral rotation		
		GJHS (n = 19)	Controls (n = 19)	p-value (group difference)	GJHS (n = 19)	Controls (n = 19)	p-value (group difference)
<b>Peak Torque</b>							
Nm/kg	60°/s	0.53 $\pm$ 0.10	0.60 $\pm$ 0.13	0.047*	0.38 $\pm$ 0,07	0.40 $\pm$ 0.07	0.274
Nm/kg	180°/s	0.48 $\pm$ 0.09	0.51 $\pm$ 0.11	0.323	0.32 $\pm$ 0.05	0.33 $\pm$ 0.05	0.927
<b>Maximum Work</b>							
J/kg	60°/s	0.62 $\pm$ 0.12	0.71 $\pm$ 0.17	0.031*	0.41 $\pm$ 0.10	0.43 $\pm$ 0.08	0.373
J/kg	180°/s	0.58 $\pm$ 0.11	0.62 $\pm$ 0.15	0.236	0.34 $\pm$ 0.08	0.35 $\pm$ 0.08	0.615

Nm=Newton meter, J=Joules

Significant difference,  $p < 0.05$ , is marked with \*.

**Figure 1.** Experimental set-up for the electromyographic and isokinetic testing procedure.

**Figure 2.** Electromyographic activity of upper trapezius (UT), lower trapezius (LT), serratus anterior (SA), pectoralis major (PM) and infraspinatus (INF) at peak torque (A-D) and maximum work (E-H), expressed as percentage of maximal voluntary contraction (%MVE), during isokinetic glenohumeral rotation movements at low ( $60^\circ/\text{s}$ ) and high ( $180^\circ/\text{s}$ ) velocity, for swimmers with Generalised Joint Hypermobility and shoulder hypermobility (GJHS) and controls. Bars are means, and standard deviations are shown as error bars. (\*) Tendency to significance,  $p < 0.10$ .

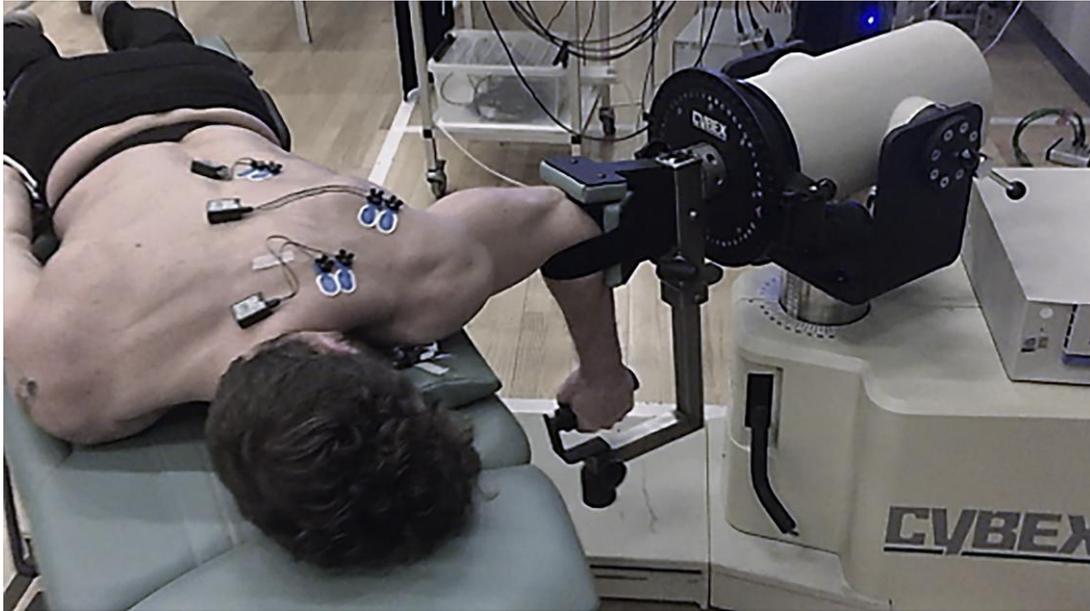
**Abstract**

Generalised Joint Hypermobility including shoulder hypermobility (GJHS) in swimmers is considered an intrinsic risk factor for shoulder injuries. The aim was to investigate the association of GJHS with shoulder strength, fatigue development and muscle activity during swimming-related shoulder rotations. Totally, 38 competitive swimmers (aged 13-17 years) participated, 19 were competitive swimmers with GJHS and 19 were age, sex and club matched swimmers without GJHS. Concentric isokinetic force in medial and lateral rotations were measured at 60°/s (5 repetitions) and 180°/s (10 repetitions). Electromyographic activity was measured from upper trapezius, lower trapezius, serratus anterior, infraspinatus and pectoralis major muscles. Swimmers with GJHS produced significantly lower peak torque (0.53 vs. 0.60 Nm/BW;  $p=0.047$ ) and maximum work (0.62 vs. 0.71 J/BW;  $p=0.031$ ) than controls during medial rotation (60°/s). Swimmers with GJHS showed significantly larger isokinetic fatigue at 180°/s (0.321 J/repetition;  $p=0.010$ ), and tendencies to lower levels of muscle activity in infraspinatus (20%,  $p=0.066$ ) and pectoralis major (34%,  $p=0.092$ ) at 60°/s during medial rotation. Young competitive swimmers with GJHS, despite no formal diagnosis, displayed strength and fatigue deficits in medial rotation, potentially inherent with greater risk of shoulder injury. Whether GJHS swimmers benefit from medial rotation strengthening is an important topic for future studies.

**Keywords** Joint instability; swimming; shoulder; muscle strength; electromyography; adolescent

**Disclosure of interest**

The authors report no conflicts of interest.



ACCEPTED MANUSCRIPT

