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**The impact of age and gender  
with respect to general joint laxity,  
shoulder joint laxity and rotation**  
- A study of 9, 12 and 15 year old students



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**I would like to show my enormous gratitude to all the young students participating in these studies, who made this thesis possible.**

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## **Abstract**

The overall aim of this thesis was to study the natural development of general joint laxity, shoulder joint laxity and shoulder joint rotation in young students, and compare these to age-matched competitive swimmers to detect possible discrepancies between these groups. A further aim was to evaluate the clinical examination techniques used whether they correlate to each other in search of better understanding and interpretation of achieved measurement results.

## **Material**

Forty-eight randomly selected schools participated in this Swedish nation-wide research study ('The School project 2001') with a total of 1846 students aged 9-15 included. Data concerning these subjects are reported in study I-III. An additional study group of 120 competitive swimmers, aged 9 and 12 year, were included and compared to the previously described group. Data concerning these subjects are reported in study III. Out of the original 1846 students, 156 of ages 12 and 15 years participated in a follow-up examination in 2004. A geographic selection was made for practical reasons. Data concerning these subjects are reported in study IV.

## **Methods**

General joint laxity was scored according to Beighton. Anterior, posterior and inferior shoulder joint laxity was assessed with the drawer test and the sulcus sign, respectively. Shoulder joint rotation was measured with a Myrin™ OB goniometer. One and the same examiner (AJ) performed all tests in the same standardized manner both in 2001 and 2004.

## **Results**

*General joint laxity:* A cut-off point scheme was designed by Jansson *et al* and differed with respect to age and gender in 2001 and was confirmed in 2004. Girls had a higher degree of general joint laxity compared to boys and male competitive swimmers had a higher degree compared to their references. Nine year old female competitive swimmers had a lower degree of general joint laxity compared to their references. The individual differences between 2001 and 2004 showed only minor changes.

*Shoulder joint laxity:* Fifteen year old boys had a lower anterior and posterior laxity compared to girls. No significant difference was seen between competitive swimmers and their references. The individual change, over three years, showed a decrease in anterior laxity in boys.

*Shoulder joint rotation:* Girls had higher external rotation compared to boys at the age of 12 and 15 years. Shoulder joint rotation was noted as lower in all competitive swimmers at the age of 12 years compared to their reference group. Fifteen year old students had decreased their shoulder rotation at follow-up.

## **Conclusion**

Based on this study of Swedish students and competitive swimmers, the degree of general joint laxity and shoulder joint rotation is specific in terms of age, gender and sports participation. Shoulder joint laxity, however, was found to be only age and gender specific and were not associated with general joint laxity. The scheme for cut-off points regarding general joint laxity was gender and age dependent and confirmed at the three year follow-up. There were only minor changes in general joint laxity and shoulder joint laxity at follow-up, but a majority of students had a decrease in shoulder joint rotation over the same time period.

## List of publications

This thesis is based on the following papers, which will be referred to in the text by their Roman numbers (*studies I-IV*)

**I. General joint laxity in 1845 Swedish school children of different ages - age and gender specific distributions.**

Anna Jansson, Tönu Saartok, Suzanne Werner, Per Renström  
*Acta Paediatrica* 93 1202-1206, 2004

**II. Is general joint laxity an indicator of excessive laxity of the shoulder joint in children?**

Anna Jansson, Tönu Saartok, Per Renström, Suzanne Werner  
*Submitted for publication*

**III. Evaluation of hypermobility, shoulder laxity and mobility in competitive swimmers during growth and in normal controls.**

Anna Jansson, Tönu Saartok, Suzanne Werner, Per Renström  
*Scandinavian Journal of Medicine and Science in Sports. Online publication date: 27-Oct-2004*

**IV. The impact of age and gender with respect to general joint laxity, shoulder joint laxity and rotation in adolescents – a three year follow-up.**

Anna Jansson, Per Renström, Suzanne Werner  
*Manuscript*

We acknowledge with thanks Acta Paediatrica and Scandinavian Journal of Medicine and Science in Sports to which the copyright to the original papers (I and III) belong. The journals have given their permission for the publication of reprints in this thesis.

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## Abbreviations

<b>AMBRI</b>	Atraumatic, multidirectional, bilateral, rehabilitation, inferior capsular shift
<b>ANOVA</b>	Analysis of variance
<b>AROM</b>	Active range of motion
<b>C.I.</b>	Confidence Interval
<b>DZ twins</b>	Dizygotic twins
<b>Fisher LSD</b>	Fisher least significant difference method
<b>IGHL</b>	Inferior glenohumeral ligament
<b>ICC</b>	Intraclass-correlation coefficient
<b>MCP V</b>	Metacarpal phalangeal five (fifth finger)
<b>MGHL</b>	Middle glenohumeral ligament
<b>MZ twins</b>	Monozygotic twins
<b>ROM</b>	Range of motion
<b>SD</b>	Standard deviation
<b>SGHL</b>	Superior glenohumeral ligament
<b>TROR</b>	Total range of rotation
<b>TUBS</b>	Traumatic, unidirectional instability, Bankart lesion, surgery

## **Definitions**

### **Laxity**

The physiological translation during a passive motion within the joint without the influence of pain.<sup>63</sup>

### **Instability**

The subjective experience by the individual with respect to his/her perceived joint stability, which presupposes an excessive joint play with the influence of pain during an active motion.<sup>63</sup>

### **TUBS**

The 'TUBS' group defines individuals who have a traumatic aetiology of instability. The problem is usually unilateral, patients often have a Bankart lesion, and they generally require a surgical solution of the problem.<sup>75</sup>

### **AMBRI**

The 'AMBRI' group includes individuals with atraumatic aetiology. These patients usually have multidirectional instability, bilateral symptoms, and often respond to conservative rehabilitation program. In the event of failure in rehabilitation, an inferior capsular shift is the choice of surgical procedure.<sup>75</sup>

### **Multidirectional instability**

An excessive inferior instability in combination with an additional direction of instability (anterior/posterior).<sup>61</sup>

### **Hypermobility**

A hypermobile joint is one whose range of movements exceeds the norm for that individual, taking into consideration age, sex, and ethnic background.<sup>30</sup>

## Introduction

There is a report suggesting documentation of hypermobility as early as the mid 1600. This statement by Dequeker<sup>18</sup> would, if correct, change the common belief that Kirk *et al* were among the first to describe this condition in 1967.<sup>48</sup> In the painting "The Three Graces" by Peter Paul Rubens, females with a clearly manifest S-shape scoliosis, positive Trendelenburg, hyperextension of the distal interphalangeal and metacarpophalangeal joints are subjects of interest (figure 1). Further investigations by Dequeker reveal that the three females are sisters and therefore likely to have the same genetic traits. To conclude this rather unusual investigation the author suggests the working diagnosis of the three graces most likely to be 'familial benign hypermobility'. These rheumatic features could, however, be explained by so called "contrapposto postures" common in the Renaissance period, 'to give the impression of vigorous muscular characters capable of performing great tasks'.<sup>38</sup> Who actually has the correct opinion one can speculate, but it would not be fair to deprive Kirk *et al* of being pioneers in strictly scientifically describe this interesting field of hypermobile features.



**Figure 1:** Three Graces by Peter Paul Rubens 1638-1640 (Ann Rheum Dis 2001;60:894).

In epidemiological studies of sport injuries there have been discussions about a possible correlation between the risk of overuse injuries and the individual joint stability.<sup>39, 51, 78</sup> In gymnastics, it seems favourable to have an increased joint mobility and being 'abnormally' flexible for optimal performance.<sup>26</sup>

In competitive swimming, which may be regarded as a bilaterally repetitive overhead sport, a high percentage of the swimmers seems to have increased shoulder joint mobility. The risk of getting symptomatic shoulder joint laxity, often referred to as 'swimmer's shoulder', seems to increase with years of participation in competitive swimming.<sup>4, 46, 59</sup>

A crucial question in this regard is whether repetitive activities over years of participation may lead to 'tissue fatigue' and increased laxity and in some cases eventually to pathological hyperlaxity. Alternatively, if individuals with a 'favourable' joint laxity may have benefits in certain sports, thereby choosing to remain in that sport and possibly leading to future success. The early sport success due to hypermobility may, in the long run, lead to instability.

### ***Shoulder joint anatomy***

In any joint, the architecture of bony structures, the tension and quality of the stabilizing soft tissue (*e.g.* ligaments and capsule) and the surrounding skeletal muscle and tendons all contribute to functional stability. The bony structures, the labrum, glenohumeral ligaments, joint capsule and the negative joint pressure all contribute to static stability in the shoulder. The rotator cuff muscles, biceps muscle and deltoid muscle all constitute dynamic restraints. This collaboration allows large movements of the joint, but also enhances the risk of getting excessive shoulder joint laxity, which may lead to instability problems.

### ***Bony structures***

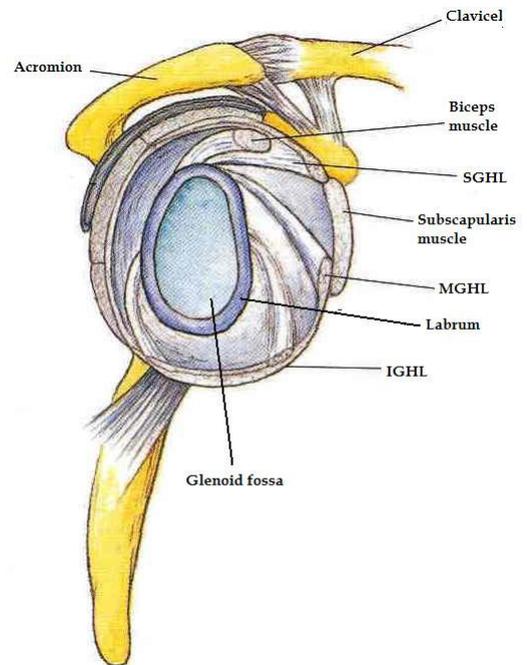
The glenohumeral joint is a shallow form of ball joint, with a relatively big head (humeral head) placed in a shallow socket (the glenoid). The adult glenoid cavity is less than 10 mm deep, shaped somewhat like a 20 by 30 mm comma and may be either anteverted or, most commonly (75%), retroverted in relation to the body of scapulae. Also, it is described having an inferior-lateral tilt of about 15°. The adult humeral head has a diameter of about 40-50 mm, thereby being 'oversized' in relation to the glenoid. Since only 25-35% of the humeral head is in contact by the glenoid the bony contribution to the stability of the glenohumeral joint is limited.<sup>20</sup>

### *Labrum*

The labrum acts primarily as a deepening and stabilizing structure to the glenoid cavity, adding an additional 2-3 mm of depth both anteriorly and posteriorly. It consists of dense fibrous tissue and its function resembles that of the meniscus in the knee.<sup>20</sup>

### *Capsuloligamentous structures*

The capsule of the shoulder joint consists of a variably thick layer of collagen, where the discrete variable thickenings constitute the three glenohumeral ligaments.<sup>20, 79</sup> The superior glenohumeral ligament (SGHL) is regarded as a static stabilizer in anterior-posterior direction, but has also been shown to be the primary restraining component in the inferior direction.<sup>20, 79</sup> The middle glenohumeral ligament (MGHL) is stabilizing the inferior translation during adduction and external rotation and restricts external rotation during simultaneous adduction.<sup>20, 79</sup>



**Figure 2:** The shoulder joint anatomy (Peterson, Renström: Sports Injuries. Their Prevention and Treatment, Dunitz, London, p: 114, Nov 2000, with permission)

The IGHL consists of an anterior and posterior band and act as restraining components of the humeral head during rapid anterior displacement. The IGHL is the primary static anterior and posterior stabilizing component but also offers support in the inferior direction during abduction. In case of injury to the anterior part of the (IGHL) the MGHL steps in and gives support in the anterior direction.<sup>20, 79</sup>

### *Glenohumeral muscles*

The largest and perhaps most important muscle in the glenohumeral region is the deltoid muscle with its three major parts. They originate from the lateral one-third of the clavicle, from the acromion and from the spine of the scapulae and inserts on to the deltoid tubercle of the humerus. The middle part is involved in all sorts of elevation of the arm. Scapular elevation and abduction in the coronal plane is mainly performed by the anterior and middle part of the deltoid.<sup>20, 42</sup>

The rotator cuff consists of four muscles, namely supraspinatus, infraspinatus, teres minor and subscapularis. Together they surround the glenohumeral joint, humeral head, and the joint capsule. The supraspinatus muscle originates from the supraspinatus fossa of the scapula and inserts into the greater tuberosity. It is active during any sort of elevation but has the maximum effort at about 30° of abduction. The supraspinatus plays an important stabilizing role in the shoulder joint. Together with the infraspinatus and subscapularis muscles, the supraspinatus provides a downward force on the humeral head to resist the upward force originated from the large deltoid during elevation of the arm.<sup>20, 42</sup>

The infraspinatus muscle is regarded to be the 'second most active' rotator cuff muscle. It originates from the infraspinatus fossa of the scapulae and inserts on the great tuberosity. It acts mainly as an external rotator but also as a depressor of the humeral head. The infraspinatus also stabilizes the humeral head against posterior subluxation during internal rotation by creating a forward force.

The teres minor muscle originates from the middle portion of the lateral border of the scapulae and the fascia of the infraspinatus and inserts into the greater tuberosity of the humerus. It acts as an external rotator in controlling for anterior stability.<sup>20, 42</sup>

The subscapularis muscle originates from the subscapularis fossa, which covers most parts of the anterior surface of the scapulae, and inserts into the lesser tuberosity on the humerus. It functions as an internal rotator and stabilizer to anterior subluxation and depresses the humeral head during elevation of the arm.

The teres major muscle originates from the posterior surface of the scapulae and inserts together with latissimus dorsi into the lesser tuberosity of the humerus. The teres major mainly function as an internal rotator, adductor and in extension of the arm.<sup>20, 42</sup>

The coracobrachialis muscle originates from the coracoid process together with the short head of the biceps muscle and inserts onto the humerus on the anteromedial surface in the midportion. The coracobrachialis functions as a flexor and adductor.<sup>20, 42</sup>

The long head of the biceps muscle originates from the superior labrum of the glenoid, overrides the humeral, continues into the biceps groove, and inserts at the lower arm. This two-joint muscle acts as a depressor of the humeral head and a flexor of the glenohumeral joint.<sup>20, 42</sup>

### ***Range of motion***

The shoulder joint has greater mobility than most other joints and can be moved in several planes. The greatest motion is often achieved by a compounded movement of the shoulder joint.

For example, in order to perform a shoulder joint flexion one needs to include a slight external rotation and abduction to achieve maximal flexion. Normal range of motion (ROM) of the shoulder joint has been described by Boone and Azen and is based on 109 male subjects between the ages of 1.6 years and 45 years.<sup>11</sup> For details, see Table 1. Specific sport participation has been reported to cause changes in the shoulder mobility pattern in young athletes. Ellenbecker *at al* found a decrease in internal rotation in the dominant arm in tennis players.<sup>23</sup> An increase in external rotation is often seen in the dominant arm in baseball players and competitive swimmers often display an increased external rotation together with a increased internal rotation.<sup>5, 55</sup> Regardless of an increase or decrease in rotation, one need to take these findings into consideration in the development of rehabilitation and preventative flexibility/range of motion programs.

**Table 1:** Active range of motion (AROM) of the shoulder joint in male subjects according to Boone and Azen. Degree (°) of motion is displayed in mean values (M) and standard deviation (SD).<sup>11</sup>

	AROM	
	M	SD
<b>Flexion</b>	167°	4.7°
<b>Extension</b>	62°	9.5°
<b>External rotation (in 90° abd)</b>	104°	8.5°
<b>Internal rotation (in 90° abd)</b>	69°	4.6°
<b>Abduction</b>	184°	7.0°

### ***Shoulder joint laxity/stability***

Laxity describes the physiological translation during a passive motion within the joint without the influence of pain.<sup>63</sup> This is a normal feature of the soft tissue surrounding the shoulder joint and is required for normal glenohumeral motion. The degree of laxity differs between individuals and is suggested to be affected by factors such as age and gender.<sup>12, 24, 57</sup>

Instability, on the other hand, describes the subjective experience of the individual with respect to their perceived joint stability and presupposes an excessive joint play with the influence of pain during an active motion.<sup>63</sup> A spectrum of instability exists and represents increasing degrees of injury to either the dynamic or static stabilizing components of the shoulder joint. Instability can be classified according to direction (anterior, posterior, inferior), degree (subluxation, dislocation), aetiology (traumatic, atraumatic and 'overuse') and finally to interval of time (acute, relapse and inveterate).<sup>1</sup>

A well-known concept describing the spectrum of instability is **TUBS** (traumatic aetiology, unidirectional instability, Bankart lesion, surgery required) and **AMBRI** (atraumatic, multidirectional instability (possibility), bilateral symptoms, rehabilitation (conservative), inferior capsular shift (if surgery required)). This classification was introduced by Tomas and Matsen in 1989.<sup>75</sup> The idea of an instability classification based on aetiology may be misleading in young athletes involved in overhead sports according to Pollock and Flatow. They state that 'These patients demonstrate that overlap between etiology categories rather than two or three discrete groups, may exist in a clinical population'.<sup>67</sup> A multidirectional instability describes an excessive inferior instability in combination with an additional direction of instability (anterior/posterior).<sup>61</sup>

### ***Hypermobility***

Wood stated in 1971 that 'hypermobility merely represents the upper end of a Gaussian distribution of the 'normal' joint range of motion'.<sup>80</sup> This statement has been challenged by the notion that the difference in hypermobility, especially seen in the clinic, may be so called abnormal.<sup>30</sup> Two types of hypermobility are nowadays described in the literature.

The first is occurring in people whose joints are just like everyone else's but which have the capacity to move more than most people's joints, so called *benign hypermobility syndrome*.<sup>29</sup> This has been recognized during the last decades. Secondly, a more marked form has features that suggest that it may be part of an inherited connective tissue disorder<sup>29</sup>.

'A hypermobile joint is one whose range of movements exceeds the norm for that individual, taking into consideration age, sex, and ethnic background'.<sup>30</sup> Joint hypermobility was described by Kirk *et al* in 1967 who stated that this phenomenon was a combination of musculoskeletal disorders and joint laxity without other rheumatic diseases.<sup>48</sup> Previous authors have shown that hypermobility can either be inherent in a person's genes and/or can be acquired.<sup>16, 30, 50</sup> Age, gender and ethnic background are the three most discussed factors that might have an impact on the degree of joint mobility. Normal joint range can also be changed into hypermobility by hard training such as for example ballet dancers.<sup>28, 30, 32</sup>

In 1964, Carter & Wilkinson were the first to design a score evaluating general hypermobility *e.g.* general joint laxity.<sup>15</sup> In 1973, Beighton *et al* modified the score, which now appears to be the most used score to estimate general joint laxity.<sup>9</sup>

The score cannot however be relied upon to identify pauci-articular hypermobility and authors suggest using the score together with a careful examination of contiguous joints.<sup>30, 37</sup> The additional joints of interest are the temporomandibular joint, cervical spine, shoulder joint, wrist, proximal and distal interphalangeal, hip, ankle and first metacarpophalangeal joints.

### ***Test of shoulder joint laxity***

Little is known about normal translation in both asymptomatic and symptomatic shoulder joints, especially in growing individuals. Anterior drawer test and sulcus sign are the most commonly used clinical methods to determine the degree of laxity of the static stabilizing components.<sup>4, 13, 27</sup> These represent tests based on subjective evaluations relying on the examiners 'feeling' of laxity. Previous authors have reported poor reproducibility and poor diagnostic value using examination based on subjective evaluations.<sup>52, 53, 71</sup> When performing the drawer test the examiner should be aware of the existing structures of the glenoid fossa in case of varying anatomy. Otherwise a false degree of laxity may be observed if the applied translational force is misdirected. The amount of the force applied is another important factor to take into consideration when measuring laxity.<sup>45, 66, 73</sup> Sauers *et al* found an increase in AP-laxity with increasing applied force.<sup>72</sup>

### ***The unstable shoulder joint***

The static and dynamic stabilizers play a most crucial role in the maintenance of a stable shoulder joint. No single factor can alone be responsible for the development of an unstable and perhaps pathologic shoulder joint. The stabilizing structures are also influenced by age, congenital variations, muscle function, overuse, and trauma. A traumatic injury to the capsule could, for example, result in an increased translation of the humeral head. This increase in translation could later contribute to an increased stress to the other stabilizing structures.

The risk of developing an unstable shoulder joint is most likely directly related to the level of risk activity, the quality of the static stabilizers, and the strength and condition of the dynamic stabilizers. For example, a person with uncoordinated or under conditioned dynamic stabilizers might theoretically be at a greater risk of developing a pathology.

### ***The growing individual***

The growth spurt of skeletal tissue, and thereby body height, regulated by *e.g.* genetic drive, nutritional factors and hormonal milieu, occurs during early puberty.

On average in Sweden, the pubertal spurt begins at 10.0 years in girls and at 12.1 years in boys. In both boys and girls the peak height velocity happens two years after the onset of the spurt (12.0 and 14.1 years, respectively).<sup>74</sup> Termination of growth occurs at 17.5 years in girls and 19.5 years in boys. <sup>74</sup> The peak of weight increase occurs at the age of 12.0 years in girls and 14.5 years in boys. Changes in these figures may, however, be expected throughout the decades.

The gain in bone length occurs throughout ossification, *e.g.* spreads from diaphysis and epiphysis ossification centre. The secondary ossification centres of the glenoid fossa appear at around 10 years of age, and fuse about 5 years later. In the proximal humerus, skeletal fusion between the shaft and the head does not occur until late adolescence at about 19 years of age.<sup>64</sup> Therefore, it may be assumed that growth of these skeletal structures occur after the years of growth spurt. Physiological loading to the skeletal system in growing individuals is beneficial, but excessive strains may result in injuries. An injury to the epiphysis increases the risk of early termination of growth which is common in baseball 'Little League injury'.<sup>54, 55</sup> Overhead, repetitive sport such as swimming and tennis, may also be at risk of developing these type of injuries.

It is assumed that the dimensions of the soft tissues (labrum, capsule and the glenohumeral ligaments) develop parallel to the bony changes, but little is known about this process. Changes such as volume and strength of skeletal muscle during puberty usually are delayed some years compared to the growth spurt. Total muscle mass increases in males from about 25% of body weight at birth to about 40% or more in the adult stage. In boys this peak in muscle mass occurs between the ages of 18 and 25 years. Girls also experience an increase, but at a much slower rate. Girls display their muscle mass peaks between 16 and 20 years of age. The gain in muscle mass is mostly explained by hypertrophy (increase in fibre size) and little or no increase in hyperplasia (more fibres). Increased number and longer sarcomeres most likely explain the increase in muscle length.

### ***Genetics and environmental factors***

Genetic and environmental factors might play an important role of the degree of hypermobility, but have not received the same amount of attention in the literature. Possible environmental factors include hormone status and physical training. Hakim *et al* found in a survey of Caucasian female twins that genetic factors have a substantial contribution to hypermobility in the adult female population. The concordance in hypermobility was almost twice the size in monozygotic (MZ) twins compared to dizygotic (DZ) twins (60% and 36%).<sup>36</sup>

### ***The competitive swimmer***

Competitive swimming is often combined with overuse disorders affecting the shoulder joint. Secondary impingement is one out of many explanations of the so-called 'swimmer's shoulder'.<sup>46</sup> Rapid increase in quantity and amount of training sessions has been shown to promote these disorders.<sup>46, 59</sup>

According to Swedish training routines, an average 12 year old competitive swimmer covers about 25.000 meters per week. With approximately 48 weeks of training per year they cover about 1.2 million meters (1.200 km). If translated into quantity of swim-strokes, this adds up to about 72.0000 strokes per arm over a period of one year. Subsequently, swimming at a competitive level is a highly repetitive overhead activity even at early ages with huge stress put on the stabilizing components of the shoulder joint. Athletes in swimming depend on, and may benefit from, an hypermobility of their shoulder joints due to the demands of the swimming technique.<sup>58</sup> There are, however, a very fine line between hypermobility and instability. So far, neither general joint laxity nor shoulder joint laxity has been clearly verified to be a risk factor for overuse injuries. During childhood and adolescence it might possible to develop an unstable shoulder joint as a consequence of sports participation such as swimming.

## **Aim of thesis**

### **The overall aim of the present thesis was:**

To study the natural development of general joint laxity, shoulder joint laxity and shoulder joint rotation in growing individuals and to compare these results to those of competitive swimmers in order to detect possible discrepancies between these groups.

### **The specific aims were:**

- To examine and describe a population of young students concerning general joint laxity and if possible determine a cut-off point for normal and general joint laxity, respectively. (paper I)
- To examine and describe a population of young students regarding shoulder joint laxity and shoulder joint rotation. (paper II)
- To evaluate whether general joint laxity predict shoulder joint laxity and shoulder joint rotation. (paper II)
- To evaluate possible differences between competitive swimmers and a reference group of age and gender matched young students regarding general joint laxity, shoulder joint laxity and shoulder joint rotation. (paper III)
- To study the changes over a period of three years regarding general joint laxity, shoulder joint laxity and shoulder joint rotation in students. (paper IV)

## Material and Methods

### Subjects

As part of a Swedish nation-wide cohort based, cross-sectional, multi-disciplinary research study ('The School project 2001'), randomly selected schools from three age groups were invited to participate in the study. Forty-eight schools accepted to participate, and a total of 1846 students were evaluated regarding general joint laxity, shoulder joint laxity and shoulder joint rotation. These groups of students voluntarily participated (with appropriate guardian consent) and were divided according to school grade, thus representing three age groups (9, 12 and 15 years). An additional study group comprised of 120 age and gender matched competitive swimmers was evaluated using the same methods and compared to the previously described group. The inclusion criteria for the group of swimmers were a minimum of three training session per week and participation in competition during at least one year (Table 2).

A selection among the initial 1846 students were re-examined in 2004 making a total of 156 students in the follow-up study. The selection included all students, aged 12 and 15 years, living in the Stockholm area that had been tested in 2001. All 156 students were divided into four groups (Table 3).

**Table 2:** Descriptive statistics of subjects included in study I-III, mean (M) and standard deviation (SD), number of subjects (n) and gender in different age (year) groups.

	Competitive Swimmers			Non-competitive swimmers		
	n	Age (M)	SD	n	Age (M)	SD
<b>Boys</b>	17	10.4	0.6	317	9.0	0.3
<b>Boys</b>	36	13.3	1.2	349	12.0	0.3
<b>Boys</b>				284	15.0	0.2
<b>Girls</b>	30	10.4	0.8	256	9.0	0.3
<b>Girls</b>	37	13.8	1.2	355	12.0	0.5
<b>Girls</b>				285	15.0	0.2
<b>Total</b>	<b>120</b>			<b>1846</b>		

**Table 3:** Descriptive statistics of subjects included in study IV. n = number of subjects.

Gender	Year of birth	Age in 2001	Age in 2004	n
<b>Boys</b>	1991	9	12	24
<b>Girls</b>	1991	9	12	31
<b>Boys</b>	1988	12	15	59
<b>Girls</b>	1988	12	15	42
<b>Total:</b>				<b>156</b>

### ***General joint laxity***

General joint laxity was scored according to Beighton, where the students were supervised and asked to try their best to perform the following five manoeuvres. <sup>9</sup> (Figure 3).

1. Bilateral passive opposition of the thumb to the flexor aspect of the forearm
2. Bilateral passive hyperextension of the fifth finger to  $>90^\circ$
3. Bilateral hyperextension of the elbow  $>10^\circ$
4. Bilateral hyperextension of the knee  $>10^\circ$
5. Flexion of the trunk with knees extended, and both palms easily resting on the floor

One point was given to each correctly performed manoeuvre with a total score ranging from 0-9. The examiner demonstrated every manoeuvre along with oral instructions to each individual whereupon the subject imitated the task. The instruction to the subject was to try his/her best to perform the above described manoeuvres without evoking any pain.



**Figure 3:** General joint laxity according to Beighton score.

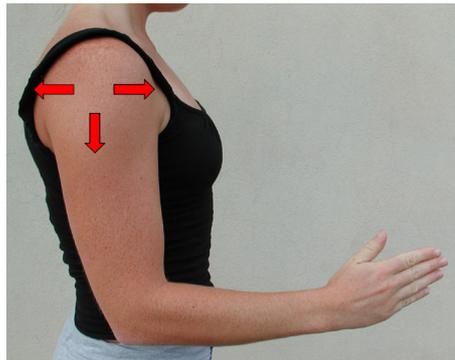
### ***Shoulder joint laxity***

#### *Drawer test*

Anterior and posterior shoulder joint laxity was assessed according to the drawer test with a subjective four-grade rating: Grade 1: normal translation; Grade 2: excessive translation within the glenoid; Grade 3: translation of the humeral head onto the glenoid rim; and Grade 4: translation of the humeral head over the glenoid rim (frank dislocation). Examinations were performed with the subject in a seated position. The examiner stood by the side of the students. The right hand of the examiner grasped the student's humeral head and the left hand stabilized the scapula and thereafter the right hand pushed the humeral head in anterior direction followed by a pulling in posterior direction. The same procedure was then performed on the opposite side.<sup>4, 27</sup> (Figure 4).

### *Sulcus sign*

Inferior shoulder joint laxity was evaluated according to the sulcus sign using the following subjective three grades: Grade 1:  $\leq 1$  cm; Grade 2: 1-2 cm; and Grade 3:  $>2$  cm inferior translation. Examinations were performed with the subject in a seated position. The examiner stood by the side of the students. The right hand of the examiner grasped the student's distal humerus, and the left hand stabilized the scapula. An inferior pull of the humerus was performed and the gap between the acromion and the humeral head was estimated according to the grading system in centimetres.<sup>13</sup> (Figure 4).



**Figure 4:** Direction of force applied to the shoulder joint during anterior, posterior and inferior shoulder joint laxity testing.

### *Shoulder joint rotation*

Range of rotation was recorded with a Myrin™ OB goniometer (Lic Rehab AB, Linköping, Sweden), measuring internal and external rotation with a weighted pointer controlled by gravity and axial rotation with a compass. The measuring procedures recommended by the American Academy of Orthopaedic Surgeons were followed.<sup>33</sup> Using Velcro® straps the goniometer was placed proximally on the subjects forearm just proximal to the head of ulna. The subject was in supine position with the shoulder joint in 90° of abduction and the elbow in 90° of flexion. Maximal active internal and external rotation was measured until noticeable movement of the trunk (Figure 5).



**Figure 5:** The position for testing shoulder joint rotation.

### ***Test for intra-reliability***

A group consisting of 36 students, 15 year old, was tested at two separate occasions with one week interval. The aim of these tests was to evaluate the stability over time of the examiner's ratings of general joint laxity, shoulder joint laxity and rotation.

### ***Test for inter-reliability***

A group of 66 competitive swimmers was used and three examiners performed, all at the same time, tests regarding general joint laxity, shoulder joint laxity and shoulder joint rotation. The competitive swimmers were randomly examined by the examiners whom were inexperienced (2 & 3) and an experienced physical therapist (1). Total time for all measurements was seven minutes and in the order mentioned above.

### ***Statistics***

Descriptive statistics were used to summarize all variables (median value and range, mean value and standard deviation) Factorial analysis of variance (ANOVA) was used to test for differences between means concerning shoulder joint rotation. ANOVA, repeated measurement design was used for multiple comparisons within the individual. Fisher LSD was used as *post hoc* test to compensate for the multiple comparisons. Due to positively skewed data, Mann-Whitney's U test was used to analyze differences in general joint laxity and in the shoulder joint laxity tests. Wilcoxon signed rank test was performed when analyzing changes within the individual concerning distribution of the Beighton score and the shoulder joint laxity test.

Spearman rank order correlation was used to determine the proportion of variability between general joint laxity, shoulder joint laxity and shoulder joint rotation and to determine intra-reliability scores. Intra-class-correlation coefficient (ICC) was used, regarding parametric data, in order to determine the agreement in-between three examiners. Kappa coefficient was used to determine the agreement in-between examiners regarding non-parametric data. The level of significance of  $p < 0.05$  was used in study I and IV and level of significance of  $p < 0.01$  was used in study II and III.

### ***Ethical consideration***

The present study was one part of a collaboration project between Stockholm University College for Physical Education and Sports, the Stockholm Institute of Education and Karolinska Institutet, Stockholm, Sweden. The study was approved by the Ethical Committee of the Medical Faculty, Karolinska Institutet, Stockholm (Dnr: 00-416. 98-348).

## Results

### *General joint laxity*

*Cut-off point for Swedish students:* If one assumes that 95% of the population in each group of age and gender represents normality in the Beighton score, the cut-off values for general joint laxity in this Swedish cohort is suggested to be age and gender specific. The percentage scheme of cut-off points for general joint laxity are shown in table 4 and 5 for both the examinations made in 2001 and 2004, respectively.

**Table 4:** Percentage scheme of cut-off points for general joint laxity estimated by the Beighton score. The bold numbers indicate the closest upper limit for 95% of the study population (n=1846).

Age	Gender	Beighton score					
		≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	9
9	Boys	37.6	20.2	16.1	5.6	<b>5.0</b>	0.3
	Girls	47.9	26.4	21.8	7.3	<b>5.7</b>	1.2
12	Boys	21.0	8.6	<b>6.2</b>	0.6	0.3	0.0
	Girls	37.8	19.9	14.9	<b>5.4</b>	3.0	0.9
15	Boys	15.5	7.9	<b>7.2</b>	2.8	1.7	0.3
	Girls	53.0	33.4	24.0	13.9	<b>7.4</b>	2.0

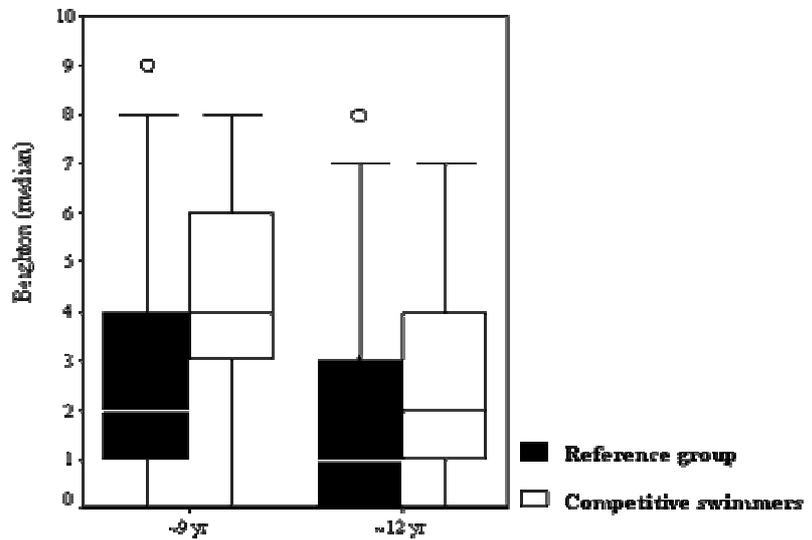
**Table 5:** Percentage scheme of cut-off points for general joint laxity estimated by the Beighton score. The bold numbers indicate the closest upper limit for 95% of the study population (n=156).

Age	Gender	Beighton score					
		≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	9
12	Boys	41.7	8.3	<b>8.3</b>	0.0	0.0	0.0
	Girls	32.3	12.9	6.5	<b>6.5</b>	3.2	0.0
15	Boys	16.9	5.1	<b>5.1</b>	3.4	1.7	0.0
	Girls	38.1	23.8	14.3	9.5	<b>7.1</b>	0.0

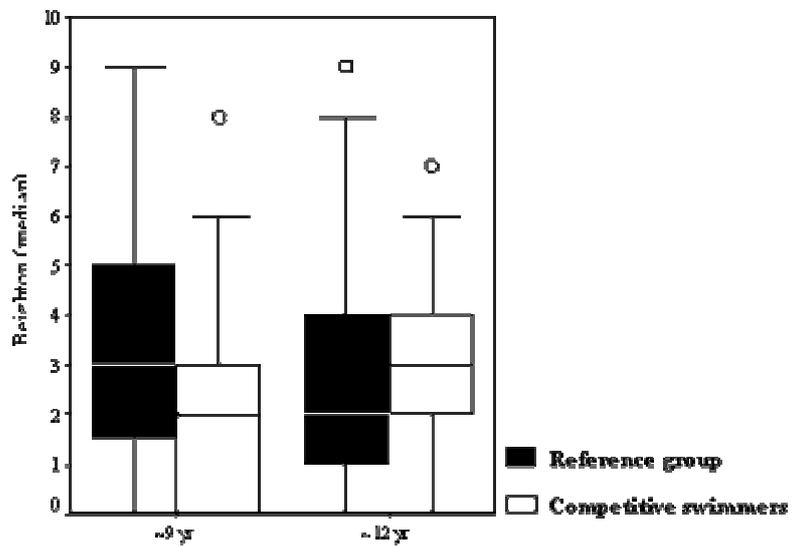
*1846 students and gender differences:* There was a significantly higher degree of general joint laxity in girls at all ages ( $p < 0.05$ ).

*1846 students and age differences:* Boys presented the highest degree of general joint laxity at the age of 9 years, decreased until the age of 12 years and showed no change between ages 12 and 15 years. Girls presented the highest degree of general joint laxity at the age of 15 years and the lowest at the age of 12 years ( $p < 0.05$ ).

*Competitive swimmers vs. students:* Male swimmers showed a higher degree of general joint laxity at all ages (Figure 6). Female swimmers showed a lower degree of general joint laxity at the age of 9 years ( $p < 0.05$ ). No significant difference was found at the age of 12 years (Figure 6).



**Figure 5:** Box plot of Beighton score for males 9 and 12 years. Competitive swimmers (open box) and reference groups (black box).



**Figure 6:** Box plot of Beighton score for females 9 and 12 years. Competitive swimmers (open box) and reference groups (black box).

*Changes within the individual over three years in general joint laxity:* Neither boys nor girls at the age of 12 and 15 years showed significant difference in general joint laxity compared to the initial examination in 2001 with one exception, see table 8. Detailed information about age and gender differences at follow-up are presented in table 9.

### **Shoulder joint laxity**

**1846 students and gender differences:** There were no gender differences at the age of 9 years in either of the three laxity tests. At the age of 12 and 15 years girls presented a higher anterior laxity and 15 year old girls had also a higher posterior laxity compared to boys. Twelve and 15 year old girls had a higher inferior laxity in the left shoulder joint ( $p < 0.01$ ).

**1846 students and age differences:** Twelve and 15 year old boys had a lower anterior laxity compared to 9 year old boys. Fifteen year old boys had also, compared to 9 year olds, a lower degree of posterior laxity. The right shoulder joint of 15 year old boys had a higher laxity when compared with 9 year olds ( $p < 0.01$ ). Nine and 12 year old girls had lower anterior laxity of the right shoulder joint when compared with 15 year old girls. The left shoulder joint of 9 year old girls showed higher posterior laxity when compared with both older groups. Nine year old girls had a lower inferior laxity in comparison with 15 year olds. Compared to the 12 year old girls, the 15 year old girls had higher inferior laxity of the left shoulder joint ( $p < 0.01$ ). For frequencies see Table 6.

**Table 6:** Frequency table for shoulder joint laxity tests. One equals grade 1 and 2 (non excessive translation) and 2 equals grade 3 and 4 (excessive translation). For inferior laxity, 2 equals grade 3 (excessive translation). (n=1846)

	Shoulder joint laxity tests											
	Anterior right		Anterior left		Posterior right		Posterior left		Inferior right		Inferior left	
	1	2	1	2	1	2	1	2	1	2	1	2
<b>Boys 9 yrs</b>	91	9	89	11	98	2	98	2	100	0	100	0
<b>Girls 9 yrs</b>	88	12	91	9	97	3	98	2	100	0	100	0
<b>Boys 12 yrs</b>	93	7	94	6	99	1	99	1	100	0	100	0
<b>Girls 12 yrs</b>	85	15	87	13	98	2	99	1	99	1	99	1
<b>Boys 15 yrs</b>	89	11	94	6	99	1	100	0	99	1	99	1
<b>Girls 15 yrs</b>	76	24	79	21	98	2	98	2	99	1	99	1

**Competitive swimmers vs. students:** There were no significant differences between competitive swimmers and their references concerning anterior or inferior laxity of the shoulder joint. In search for multidirectional laxity, there were no significant differences between competitive swimmers and references when combining both anterior and inferior laxity measures.

**Changes within the individual over three years in shoulder joint laxity:** Fifteen year old boys had decreased their grade of anterior laxity. Their highest grade of inferior laxity in boys was grade two (1-2 cm inferior translation) in contrast to 2001 when their highest grade was three (>2 cm inferior translation) (p<0.05). For detailed information see table 8. Age and gender differences at follow-up are presented in table 9.

### **Shoulder joint rotation**

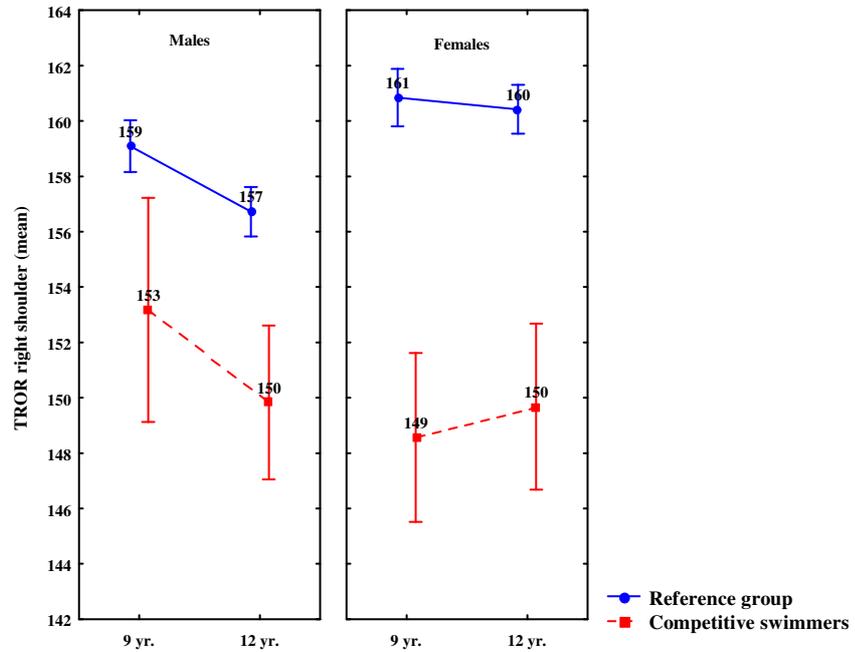
**1839 students and gender differences:** Fifteen year old girls had a higher degree of external rotation and internal rotation was higher in 12 year old girls compared to boys (Table 7). Total range of rotation (TROR) was higher in girls both at the age of 12 and 15 years.

**1839 students and age differences:** Twelve and 15 year old boys showed less external rotation and TROR than 9 year old boys. Nine year old girls had a higher degree of external rotation compared to both 12 and 15 year old girls. Twelve year old girls had a higher internal rotation as compared to 9 year olds. Fifteen year old girls had a lower degree of TROR compared to the two younger age groups of girls (p<0.01).

**Table 7:** Differences between boys and girls in mean value (M) and standard deviation (SD) concerning rotation of the shoulder joint (°). \* Indicates a statistical gender difference (p<0.01) at specific ages and shoulder joint (n = 1839).

	Age	External rotation						Internal rotation					
		Left (°)			Right (°)			Left (°)			Right (°)		
		M	SD	P	M	SD	P	M	SD	P	M	SD	P
<b>Boys</b>	<b>9</b>	99	6		99	6		60	6		60	5	
<b>Girls</b>		100	6		101	6		61	5		60	5	
<b>Boys</b>	<b>12</b>	96	7		97	7		60	6		59	6	
<b>Girls</b>		97	8		98	7		63	6	*	62	6	*
<b>Boys</b>	<b>15</b>	92	8		93	8		61	6		60	6	
<b>Girls</b>		97	8	*	97	8	*	62	5		61	5	*

**Competitive swimmers vs. students:** Shoulder joint rotation was noted as lower in all competitive swimmers compared to their reference group except for one variable namely external rotation in 9 year old boys where no significant difference could be found. Competitive swimmers showed a lower TROR at both ages ( $p < 0.01$ ) (Figure 8).



**Figure 8:** TROR of the **right** shoulder joint in males and females, who are competitive swimmers and the reference group. Vertical bars display 95% confidence interval (C.I.).

**Changes within the individual over three years in shoulder joint rotation:** The degree of external and internal rotation in both gender and at both ages was significantly decreased at the follow-up with two exceptions where no significant differences were noted (Table 8). Age and gender differences at follow-up are presented in table 9.

**Table 8:** Individual changes in general joint laxity, shoulder joint laxity and shoulder joint rotation in 2004 compared to 2001, (ns = non significant. <sup>1</sup> = grade 2 of inferior shoulder laxity was the highest value used. <sup>2</sup> = only the left shoulder joint). (n=156)

	Boys 15 yr	Girls 15 yr	Boys 12 yr	Girls 12 yr
<b>General joint laxity</b>	ns	Fewer were able to hypertext knees	ns	ns
<b>Anterior laxity</b>	Decreased	ns	Decreased	ns
<b>Inferior laxity</b>	Decreased <sup>1</sup>	ns	ns	ns
<b>External rotation</b>	Decreased	Decreased	Decreased	Decreased <sup>2</sup>
<b>Internal rotation</b>	Decreased	Decreased	Decreased <sup>2</sup>	Decreased

**Table 9:** Age and gender differences in general joint laxity, shoulder joint laxity and rotation in 2004. ns = non significant (♂ = boys and ♀ girls. <sup>1</sup> = only the right shoulder joint) (n = 156)

	♂ 15 yrs / ♂ 12 yrs	♂ 15 yrs / ♀ 15 yrs	♀ 15 yrs / ♀ 12 yrs	♀ 12 yrs / ♂ 12 yrs
<b>General joint laxity</b>	Fewer 12 yr old could hypertext. 5:th fingers	Fewer ♂ could hypertext. elbows	ns	ns
<b>Anterior laxity</b>	ns	Lower in ♂	ns	ns
<b>Inferior laxity</b>	ns	ns	ns	ns
<b>External rotation</b>	ns	ns	ns	Lower in ♀ <sup>1</sup>
<b>Internal rotation</b>	ns	Lower in ♂	Lower in 15 yr	ns

### ***Correlation of examination techniques & stability***

The examination techniques used in this study, Beighton score, anterior- and posterior drawer test, sulcus sign, and Myrin™ OB goniometer showed low correlations in-between tests according to Spearman rank order correlation coefficients. In every case, the correlation coefficients showed values below 0.3, except for the correlation between anterior and posterior drawer test (0.49) (Table 10).

**Table 10:** Correlation according to Spearman in-between the seven separate methods used.  
(n = 1844)

Spearman	Beighton	Anterior	Posterior	Sulcus sign	External
<b>Anterior</b>	0.197				
<b>Posterior</b>	0.104	0.490			
<b>Sulcus sign</b>	0.069	0.184	0.135		
<b>External rot</b>	0.205	0.158	0.129	0.046	
<b>Internal rot</b>	0.136	0.135	0.130	0.037	(-)0.017

### ***Intra-reliability***

The intra-reliability (according to Spearman rank order correlation test) of Beighton score showed fair results for thumb, fifth finger (MCP V) and elbow (>0.550) (Table 11). The intra-reliability for the laxity and rotation tests of the shoulder joint is shown in Table 12 and 13. The posterior laxity test showed the lowest intra-reliability correlation.

**Table 11:** Intra-reliability of the Beighton score. Data presented with percentage of concordance and non concordance and Spearman rank order correlation test.(n =37)

		Concordant %	Non concordant %	Spearman rank
<b>Thumb</b>	Right	84	16	0.63
	Left	84	16	0.63
<b>MCP V</b>	Right	86	14	0.56
	Left	89	11	0.65
<b>Elbow</b>	Right	92	8	0.63
	Left	92	8	0.63
<b>Knee</b>	Right	84	16	0.45
	Left	81	19	0.33
<b>Trunk</b>		89	11	0.30

**Table 12:** Intra-reliability of the shoulder joint laxity tests. Data presented with percentage of concordance and non concordance and Spearman rank order correlation test. (n =36)

Examination techniques		Concordance	Non concordance	Spearman
		%	%	
Anterior drawer test	Right	69	31	0.77
	Left	67	33	0.68
Posterior drawer test	Right	89	11	0.30
	Left	86	14	-0.06
Sulcus sign	Right	89	11	0.21
	Left	92	8	0.53

**Table 13:** Intra-reliability of the shoulder joint rotation. Data presented with percentage of concordance and non concordance and Spearman rank order correlation test. (n =36)

External rotation	Right	0.32
	Left	0.58
Internal rotation	Right	0.60
	Left	0.60

### ***Inter-reliability***

Inter-reliability regarding general joint laxity is described in table 14. Examiner 1 is the experienced physical therapist and the other two are inexperienced. Data concerning shoulder joint laxity showed low agreement in-between the three examiners with a range in kappa coefficient between 0.043-0.193 (n=66). The agreement in-between examiners regarding shoulder joint rotation showed fair results (Table 15).

**Table 14:** Inter- reliability regarding Beighton score with Kappa coefficient. (n=66)

	Agreement examiners 1 & 2	Agreement examiners 1 & 3	Agreement examiners 2 & 3
Thumb right	0.88	0.85	0.91
Thumb left	0.79	0.76	0.82
MCP V right	0.61	0.56	0.68
MCP V left	0.59	0.62	0.83
Elbow right	0.32	0.32	0.56
Elbow left	0.38	0.29	0.73
Knee right	0.38	0.26	0.39
Knee left	0.42	0.30	0.42
Trunk	0.78	0.84	0.93

**Table 15:** Inter- reliability regarding shoulder joint rotation with ICC. (n=67)

	<b>Agreement examiners 1 &amp; 2</b>	<b>Agreement examiners 1 &amp; 3</b>	<b>Agreement examiners 2 &amp; 3</b>
External rotation right	0.35	0.58	0.42
External rotation left	0.35	0.51	0.43
Internal rotation right	0.41	0.34	0.55
Internal rotation left	0.27	0.31	0.19

***Agreement in-between 2001 and 2004*** (Detailed subject information in table 16).

***Twelve year old students (2004 versus 2001):*** A lesser ability to hyperextend the fifth fingers beyond 90° according to Beighton score was observed in 12 year old boys, tested in 2004 ( $p < 0.05$ ). There were no significant differences in shoulder joint laxity between the two groups of 12 year old boys.

Twelve year old girls, tested in 2004, showed a lesser ability to hyperextend both knees. Anterior laxity of the right shoulder joint and inferior laxity of both shoulder joints in girls, tested in 2004, showed a lower degree of laxity ( $p < 0.05$ ).

Both boys and girls, tested in 2004, showed overall a decrease in shoulder joint rotation ( $p < 0.05$ ) with only one exception, namely regarding girls aged 12 years, where no significant difference could be found in external rotation of the right shoulder joint.

***Fifteen year old students (2004 versus 2001):*** Fifteen year old boys at both test occasions showed data in accordance to each other concerning general joint laxity. Anterior laxity was lower in boys tested in 2004 ( $p < 0.05$ ).

Fifteen year old girls, tested in 2004, showed a lesser ability to hyperextend both knees beyond 10°. Anterior and inferior laxity was found to be lower in girls, tested in 2004 ( $p < 0.05$ ).

Data concerning shoulder joint rotation in 15 year old students displayed somewhat varying results. There was a clear decrease in shoulder joint rotation in students tested in 2004 where significant difference could be seen ( $p < 0.05$ ). For detailed information see table 17.

**Table 16:** Detailed information about students of the same age in 2001 vs. 2004 n = number of subjects.

Gender	Year of birth	Age in 2001	n	Tested in 2001		Tested in 2004	
				Reason for involvement in the present study	n	Reason for involvement in the present study	n
Boys	1985	15	291	Comparison to 15 year old boys tested in 2004			
Girls	1985	15	303	Comparison to 15 year old girls tested in 2004			
Boys	1988	12	334	Comparison to 12 year old boys tested in 2004	59	Compare the individual development since 2001	
Girls	1988	12	333	Comparison to 12 year old girls tested in 2004	42	Compare the individual development since 2001	
Boys	1991	9			24	Compare the individual development since 2001	
Girls	1991	9			31	Compare the individual development since 2001	

**Table 17:** Agreement in-between 15 year old students, tested in 2001, with 15 year old students, tested in 2004, concerning shoulder joint rotation. ns = non significant. Displayed in degrees.

				Boys 2001		Girls 2001	
				Mean	SD	Mean	SD
Internal left		Mean	SD	60	7	61	6
	Boys 2004	52	8	p<0.05			
	Girls 2004	57	7			p<0.05	
External left				92	8	96	9
	Boys 2004	89	11	p<0.05			
	Girls 2004	92	8			p<0.05	
Internal right				59	8	61	6
	Boys 2004	51	10	p<0.05			
	Girls 2004	58	9			p<0.05	
External right				94	9	96	9
	Boys 2004	88	14	p<0.05			
	Girls 2004	94	9			ns	

## Discussion

This thesis based on Swedish students and competitive swimmers has helped us to improve our knowledge of the growing individual between the ages of 9 and 15 years regarding general joint laxity and shoulder joint laxity and rotation. The main finding was a custom made scheme, made in 2001, of cut-off points with regards to general joint laxity, which is gender and age dependent.<sup>41</sup> This cut-off point scheme was confirmed in 2004. Furthermore, we found that general joint laxity and shoulder joint rotation is specific in terms of age, gender and sports participation. Shoulder joint laxity, however, is only age and gender specific and not associated with general joint laxity. After a period of three year only few changes were seen in general joint laxity and shoulder joint laxity but a majority of students had a decreased shoulder joint rotation over the same time period. We came across some difficulties in carrying out this sort of study. The main problem was the subjective elements of the methods used. Techniques based on subjective evaluations continue to be a subject for debate compared to objective research techniques. This should, however, not limit future studies, but inspire researchers to improve these clinical methods.

### *General joint laxity*

There has been a lack of a clear cut-off point for general joint laxity in growing individuals. The spectrum of arbitrary cut-off points seems to be almost as wide as the range in the scale of the Beighton score. A review of the literature reveals that the most common cut-off point used to describe 'abnormal' hypermobility is  $\geq 4$  out of possible 9 points.<sup>3, 10, 21, 25, 31, 68, 69</sup> If this cut-off point ( $\geq 4$  out of 9) was used in study I, approximately every second girl aged 9 and 15 years would be considered hypermobile and nearly 40% of boys at the age of 9 years in our observed population. We believe this is a rather high prevalence with overestimation of hypermobility in normal students. Therefore, we worked out a suggestion for a cut-off point scheme, which should separate the extreme variations of general joint laxity from normal mobility.<sup>41</sup> We chose a cut-off point (rounded to the nearest score), which included the highest 5<sup>th</sup> percentile of the study population. This method of classification generated a scheme of cut-off points with respect to the students age and gender and was higher than previously reported in the literature.<sup>3, 10, 21, 25, 31, 68, 69</sup> In light of our findings we suggest that both boys and girls at the age of 9 years should be considered as having general joint laxity if  $\geq 8$  manoeuvres of the Beighton score are successfully performed. At the age of 12 years, the divergence between genders becomes clearer and the cut-off point for boys should be at  $\geq 6$ , and for girls at  $\geq 7$ . The largest difference concerning cut-off point for boys and girls is at the age of 15 years when the cut-off point for boys would be at  $\geq 6$  manoeuvres while the cut-off point for girls would be at  $\geq 8$  manoeuvres performed correctly.

When analyzing the data from 2004 in the same manner we found similar result in the cut-off point scheme compared to the initial study. These findings enhance our conviction that the cut-off for general joint laxity in the growing individual, must be made on the basis of age and gender.

Girls displayed the highest degree of general joint laxity at the age of 15 years and the lowest at the age of 12 years. This is in contrast to boys, who declined in degree of general joint laxity with increasing age. Hormonal factors and growth may be affecting the degree of laxity in these age groups. Furthermore, we found a lower degree in female swimmers compared to their reference group at the age of 9 years, while no difference was shown at the age of 12 years. Male swimmers, on the other hand, showed a higher degree at both 9 and 12 years of age when compared to their reference group. Only minor changes were found at the three year follow-up.

The findings we have obtained throughout the years of using the Beighton score are difficult to compare with other studies, since there is a lack of comparable studies with similar age groups and type of comparisons. Beighton *et al* state that general joint laxity is scored highest at birth, then declining rather quickly throughout childhood, less quickly during adolescence, and even more slowly during adult life.<sup>8</sup> However, Rikken-Bultman *et al* found no significant decline in hypermobility with aging in their study.<sup>69</sup> The results from our follow-up study are in line with Rikken-Bultman *et al*.<sup>69</sup> In the initial study in 2001 the age and gender differences were more evident than in 2004. Therefore, we can only speculate on whether or not a decline is actually taking place with increasing age since data are conflicting. The advantages of the Beighton score are that it is easy to use and does not require a laboratory environment. However, the score does not give an indication of the severity of the hypermobility at a certain joint and merely indicates how widely it is distributed throughout the body. Other area worth examining is for example the shoulder joint.

### ***Shoulder joint laxity***

In contrast to boys, girls showed a more complex pattern of age specific shoulder joint laxity with side differences for all laxity directions. Whereas there was no gender difference at age of 9 years in terms of the laxity tests, the 12 year old girls showed higher anterior laxity, while the 15 year old girls showed higher anterior and posterior laxity compared to boys of the same ages, respectively. These findings are in line with the common belief that females are more lax than males.<sup>12, 57</sup> However, no conclusive data support this. Even less conclusive are data concerning normal laxity of gender related differences in growing students, although Marshall *et al* examined 124 preadolescent individuals concerning laxity of 13 joints and found it to be a trait.

Females were prone to have statistical looseness in some joints, but not of the shoulder joint. When adding the results from all 13 joints no differences were found for gender.<sup>56</sup> We found a development towards an increase of shoulder joint laxity in girls compared to boys after childhood.

There were no significant differences in anterior and/or inferior laxity between competitive swimmers and the reference group.

Lintner *et al* did not find an increase in shoulder joint laxity in college competitive swimmers compared to non-overhead athletes.<sup>53</sup> Jobe *et al* suggested that overhead-college athletes were prone to have an increased shoulder joint laxity as a result of the technical demands of their sport.<sup>43</sup> There are, in other words, no clear consensus describing a higher degree of shoulder joint laxity in overhead compared to non-overhead athletes. We found no significant difference in degree of multidirectional laxity between competitive swimmers and the reference group. Epidemiological studies of the prevalence of this condition in males and females are rare. Neer and Foster described an equivalent number of males and females with multidirectional laxity.<sup>61</sup> It is generally believed that females tend to be more lax than males and this may result in a higher risk for women to develop overuse syndromes. There is, however, no consensus whether athletes in overhead sports, without consideration of gender, have a higher frequency of multidirectional laxity/instability than non-athletes.

The individual development of shoulder joint laxity over three years revealed few significant differences. Boys aged 15 years had decreased their degree of anterior shoulder joint laxity. The highest grade of inferior shoulder joint laxity was grade two (1-2 cm inferior translation) in contrast to 2001 when the highest grade was three (> 2 cm inferior translation). The only difference in-between gender was found in anterior shoulder joint laxity at the age of 15 years with higher grades in girls. Boys at the age of 15 years showed, as mentioned earlier, a decrease in shoulder joint laxity, while girls displayed an unchanged shoulder joint laxity pattern over a time period of three years. There are only a few comparable studies in the literature. What is known about shoulder joint laxity, is that the degree of shoulder joint laxity is suggested to be affected by sport participation and gender.<sup>43, 53, 57</sup> There is to this day, however, no existing consensus in this matter.

The need for a classification of shoulder joint laxity and instability has been a matter for discussion during the last decades. The normal range of shoulder joint laxity is wide and sometimes difficult to establish, especially in the awake condition.<sup>17, 81</sup>

Previous authors have reported poor reproducibility and thus poor diagnostic value using these tests which are based on subjective evaluations.<sup>12, 22, 52, 53, 70, 73, 78</sup>

Furthermore, it has been suggested that the results from studies using methods with subjective evaluations, depend on factors such as the experience of the examiner, the inconsistencies of the force applied, centring of humeral head, patient positioning and muscular tension.<sup>17, 52, 65, 70</sup> The last factor may be even more important when comparing athletes, such as competitive swimmers with non-competitive swimmers. Competitive swimmers are known to have large and well-defined muscles surrounding the shoulder girdle, which may contribute to an apparent underestimation of laxity. When performing the anterior drawer test the examiner should press the humeral head along the structure of the glenoid fossa. In case of slightly protracted shoulder joints the examiner needs to redirect the pressure of the humeral head to the existing and sometimes varying anatomy, otherwise a false degree of laxity may be observed.

The applied force has been shown to be highly relevant when measuring laxity. Sauers *et al* found an increase in range of anterior-posterior (AP) laxity when applying 89 N compared to 67 N. With increasing applied force an increase in AP-laxity was noted.<sup>71</sup>

The different grades of laxity in these tests are difficult to define and the distinctions between them can be unclear.<sup>52</sup> These theoretically well-defined grades are somewhat difficult to transfer into practice without using objective measurements. Given the poor intra-reliability of these tests, a more objective and reliable examination technique may be needed to more clearly define shoulder joint laxity for research purposes.

There are some reports on instrumented arthrometry of the glenohumeral joint.<sup>45, 52, 53, 73</sup> Jørgensen *et al* used a Don Joy knee laxity tester and found differences between symptomatic shoulder joints compared to non-symptomatic shoulder joints.<sup>45</sup> Nevertheless, there were some setbacks concerning the application with the result of a 20% drop-out in their study material. The use of the KT1000 in the shoulder joint with a known force of 67 N revealed a moderate to good reliability.<sup>66</sup> The fitting of both these instruments to the shoulder joint could perhaps be questioned, especially when examining children and adolescents with a relatively short humerus in comparison to the size of these instruments. However, an obvious benefit of the instruments is the possibility to use them in both a clinical environment and on the field like the non-invasive applications.

In order to create a 'gold standard' instrumented arthrometer for the glenohumeral joint will need to have high accuracy, high reproducibility, be non-invasive and easy to use in the clinic. To date, we have not found such an instrument.

### ***Shoulder joint rotation***

Girls showed a higher degree of shoulder joint rotation compared to boys at the three studied ages. There have been suggestions in the literature that the increased ROM in females is secondary to a greater ligamentous laxity. This suggestion has been documented by some authors but questioned by others concerning the validity for all joints.<sup>60</sup>

Furthermore, Greene and Heckman also suggested that the increased ROM in children is correlated to a greater ligamentous laxity.<sup>33</sup> We found that boys had a clear decrease in ROM with age, while the differences in girls between age groups were more complex. These differences were, however, small and support the findings of Green and Heckman.<sup>33</sup>

Our evaluation of active internal and external shoulder joint rotation showed a significant difference between competitive swimmers and the reference group. Internal rotation of both shoulder joints was lower among competitive swimmers, in both males and females, compared to their reference groups. These data are in agreement with Bak *et al*, who explained their findings as a result of the technical demands in competitive swimming.<sup>5</sup> They found that competitive swimmers had an excessive external rotation and a decreased internal rotation of the shoulder joint compared to a control group. They also suggested that this finding ought to promote extensive stretching to restore original flexibility.<sup>5</sup> Some authors further extend these findings suggesting that it could be due to a tight posterior capsule in competitive swimmers and they therefore stress the importance of stretching these structures.<sup>7</sup>

External shoulder joint rotation was lower at the age 12 years in male swimmers compared to their reference group. Female swimmers showed lower external rotation at all ages compared to their reference groups. These data are in contrast to other studies, where excessive external rotations have been observed in overhead athletes.<sup>5,7,76</sup> Lintner *et al* found no significant relationship between the number of active years in competitive sports (both overhead and non-overhead athletes) and the degree of shoulder joint rotation.<sup>53</sup>

In the three year follow-up study shoulder joint rotation was decreased or unchanged when looking at the individual changes over three years. The only age difference to be found was a higher internal shoulder joint rotation in 12 year old girls compared to girls aged 15 years.

Differences in-between genders were noted concerning internal shoulder joint rotation with a lower value in boys at the age of 15 years.

Barnes *et al* found a decrease in external rotation but an increase in internal rotation with increasing age and females had a higher range of rotation than males in both directions of rotation. The increase of internal rotation was, however, largest in the group of 0-10 year old children and thereafter relatively small increases.<sup>6</sup> These data are in line with our initial study in 2001.<sup>40</sup>

Knowledge of the normal range of motion in any joint is of great importance when assessing clinical pathology and selecting treatment. Earlier clinical observations suggest that age and gender are factors that affect the degree of shoulder joint rotation.<sup>2, 33, 34, 44</sup>

When measuring shoulder joint rotation it is very important to be aware of the slightest trunk movement in order to reduce the risk of a falsely large shoulder joint rotation measurement. This could be somewhat easier to account for in supine position. The choice of measurement tool is another important factor when measuring ROM. The universal goniometer (international standard goniometer) is the most commonly used tool, especially when evaluation the hip and shoulder joints.<sup>62</sup> This type of instrument can, however, be difficult to use when evaluating rotational movements, *i.e.* external and internal shoulder joint rotation. We used a Myrin™ OB goniometer in the present work which is based on a compass method when measuring rotation.<sup>35, 47, 70</sup>

The changes that we have found in shoulder joint rotation show statistical significance, but the clinical importance can be questioned. The shoulder joint has higher mobility than most other joints and can be moved in several planes with for example a normal abduction of about 184°. This fact together with the knowledge of the specificity and sensitivity of the goniometer raises the question whether discrepancies of less than 5° should be of any clinical value.

### ***Subject selection bias and subject power***

The type of subject selection used in the three year follow-up study could cause a selection bias depending on the sensitivity of the variables for environmental differences. Our strong belief, however, is that general joint laxity, shoulder joint laxity and shoulder joint rotation do not differ with respect to the geographic residence in the present work.

Data concerning the agreement between 'old' 12 and 15-year old students (tested in 2001) and the 'new' 12 and 15-year old students (tested in 2004) were in general poor.

Possible reasons for these results could be insufficient number of subjects *e.g.*  $\beta$  error, poor reliability of the instruments or the fact that there is no normal course of development concerning these variables. The smaller group, tested in 2004, constituted about a tenth of the original group in 2001. The risk of including individuals with similar properties increases as the quantity of subjects decreases.

### ***Intra-reliability***

Intra-reliability tests showed poor results when measuring Beighton's so called '*fifth manoeuvre*' (the ability to flex the trunk with the knees extended and both palms resting on the floor). It has been debated whether this manoeuvre is a good indicator of generalized laxity or not. After studying ballet dancers, Klemp *et al* strongly believe that this manoeuvre is trainable.<sup>49</sup> However, it remains questionable to what extent this trainability is valid in a non-athletic study sample.

Whereas there were acceptable intra-reliability scores for the anterior laxity testing, the posterior and inferior laxity testing showed poor reliability. An explanation worth considering might be the examination technique used. The fact that both the drawer test and the sulcus sign are tests based on subjective evaluations can, as mentioned before, lead to poor reproducibility and thus poor diagnostic value of the tests.<sup>22, 52, 53, 70, 78</sup> The intra-reliability of rotational testing was acceptable.

### ***Inter-reliability***

When examining general joint laxity with the Beighton score Dijkstra *et al* recommend the use of a goniometer in order to get a reliable measurement.<sup>19</sup> There is, however, as mentioned before, documentation of a margin of error of 5 to 10° when using the goniometer, which may lead to difficulties in measuring 10° of hyperextension for example.<sup>14</sup> The assessment of hyperextension of the fifth finger, the knee and elbow joints showed poor agreement in the present thesis. The reason for this could be the lack of clear anatomical references together with the surrounding soft tissue in deceiving the eye.

Shoulder joint laxity tests showed poor agreement between the three examiners. The drawer tests and sulcus sign are measurements based on subjective elements and a certain amount of experience is necessary to fully recognize the surrounding structures. The importance of a certain starting position of the patient has been discussed.<sup>27, 77</sup> Seated position, used in this thesis, could influence the activity of the muscles when the patient is trying to obtain a good posture. A muscle activation, conscious or not, may contribute to a 'falsely' high stability of the joint of interest.

### ***Correlation between examination techniques***

Based on the data of the present thesis there are only poor correlations between general joint laxity, shoulder joint laxity and shoulder joint rotation.

Subsequently, examining general joint laxity does not help the investigator to predict laxity of the shoulder joint. This supports similar findings reported by Emery *et al* who examined 150 asymptomatic shoulder joints in students.<sup>24</sup> With this knowledge, our opinion is that the Beighton score may be only one part of a battery of tests in a clinical examination.

### ***Conclusion***

Based on this study of Swedish young students and competitive swimmers, the degree of general joint laxity and shoulder joint rotation is specific in terms of age, gender and sports participation. Shoulder joint laxity, however, was found to be only age and gender specific and was not associated with general joint laxity. In 2001 we worked out a scheme for cut-off points with regards to general joint laxity, which is gender and age dependent. This cut-off point scheme was confirmed at the three year follow-up. There were only minor changes in general joint laxity and shoulder joint laxity at follow-up, but a majority of students showed decreased shoulder joint rotation over the same time period.

The present thesis of general joint laxity, shoulder joint laxity and rotation in growing individuals has generated new information. Examination techniques based on subjective evaluations compared to objective techniques continue to be a subject for debate. This should inspire researchers to improve these clinical methods. Further studies should evaluate the clinical importance of the findings of the present thesis.

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