DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

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JOINT MOBILITY IN TRUNK FORWARD FLEXION: METHODS AND EVALUATION

VELLO HEIN

TARTU 1998

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PRESS

Dissertation is accepted for the commencement of the degree of Doctor of Philoshopy in Exercise and Sport Sciences on March 25, 1998 by the Council of the Faculty of Exercise and Sport Sciences, University of Tartu, Tartu, Estonia.

Opponents: PhD, Associate Professor, Aalo Eller, University of Tartu
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Commencement: room 302, Jakobi St. 5, on May 20, 1998, at 4 p.m.

The publication of this dissertation is granted by the University of Tartu

Tartu Ülikooli Kirjastuse trükikoda
Tiigi 78, EE 2400 Tartu
Tellimus nr. 111

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

I. Hein, V. Knee extension range of motion: limits to sit-and-reach test. Biology of Sport 1995, 12(3): 189–193.

II. Hein, V., Jürimäe, T. Measurements and evaluation of the trunk forward flexibility. Sports Medicine, Training and Rehabilitation 1996, 7(1): 1–6.

III. Hein, V. A method to evaluate spine and hip range of motion in trunk forward flexion and normal values for children at age of 8–14 years. Medicina Dello Sport 1996, 49(4): 379–385.

IV Hein, V. Extension and hyperextension of the knee joint among young children. In: Armstrong, N., Kirby, B., Welsman, J. ed. Children and Exercise XIX, London, E & Spon; 1997: 331–334.

V Hein, V. Comparison of a new linear instrument and the gravity goniometer for assessing knee extension ROM among children. Journal of Sport Rehabilitation 1998, 7(1): 61–68.

VI Hein, V., Vain, A. Joint mobility and the oscillation characteristics of muscle. Scandinavian Journal of Medicine & Science in Sports 1998, 8(1): 7–13.

1. INTRODUCTION

The need for a method of assessing range of motion at a joint was first recognized after World War I, when the disability and pension boards demanded specific criteria for determining state of impairment or injury among soldiers (Dorinson and Wagner, 1948).

Since that time, goniometer or other instruments for measuring joint range of motion (ROM) have been used throughout the medical profession to assess dysfunction, determine rehabilitation progress, and evaluate treatment effectiveness. Measuring and recording the ROM of joint is also important for sport instructors or coaches to estimate the flexibility fitness of athletes to perform one or another movement. Practical, everyday experience substantiates that flexibility enhances the learning, practice, and performance of skilled movement. Therefore, some skills may be enhanced more effectively by increasing the ROM around certain joints (Sigerseth, 1971; Hebbelinck, 1988). Flexibility also helps athletes to perform different movements more skilfully and with greater self-assurance, and amplitude (George, 1980).

Flexibility is one of the important components of physical fitness (Jette, 1978; Corbin and Noble, 1980; Balogun, 1987; Borms, 1989; Shephard *et al.*, 1990). Trunk forward flexion measured by the sit-and-reach test is included in several fitness test batteries (Adams *et al.*, 1993; Oja and Tuxworth, 1996), as it provides a simple measure of flexibility in the hip, spine and hamstring muscles (Wells and Dillon, 1952; Shephard *et al.*, 1990). Trunk flexibility may also have health implications for back problems (Bouchard *et al.*, 1993). Therefore, several authors (Jackson and Backer, 1986; Jackson and Langford, 1989; Salminen *et al.*, 1993; Kujula *et al.*, 1994; Porter *et al.*, 1997) have investigated the relation between low back flexibility and low back pain. In order to enhance the trunk forward flexibility, it is important to determine the joint, where the ROM is more restricted. Based on a review of literature, it is unclear to what extent the ROM of different joints such as the vertebral column, the hip, and the knee joint, are reflected in total trunk forward flexion measurement.

Therefore, the purpose of this study was the evaluation of two new methods to determine separately the extent of the ROM of different joints as the components of total trunk forward flexion.

The method, based on the gravity goniometer instrument (Leighton, 1955, 1957), was used to estimate the spine forward flexibility. The instrument of linear measurement, constructed by the author, was used to determine the knee extension ROM. The intratester and intertester measurement errors were between 1.3–1.9 mm, and the reliability of measurements, expressed by correlation coefficients between test-retest scores were r=.96 and r=.95. The extent of the ROM of different joints in total trunk forward flexion was evaluated among the schoolchildren and university students with different physical activities.

2. REVIEW OF LITERATURE

2.1. Trunk forward flexion

Flexibility is of considerable importance in numerous athletic events, specially in gymnastics. The most frequently used methods for evaluation trunk forward flexion are the sit-and-reach test and finger-to-floor test. Both tests provide a simple measure of flexibility in the hip, spine and hamstring muscles (Wells and Dillon, 1952; de Vries, 1978; Shephard *et al.*, 1990). The sit-and-reach test and finger-to-floor test have been the subject of lots of studies (Mathews *et al.*, 1957; Mathews *et al.*, 1959; Broer and Galles, 1958; Wear, 1963; Harvey and Scott, 1967; Jackson and Baker, 1986; Wilmore and Costill, 1988; Jackson and Langford, 1989; Hoeger *et al.*, 1990; Hopkins and Hoeger, 1992; Cornbeet and Woolsey, 1996). Measurements of sit-and-reach test and finger-to-floor test have proved reliable in healthy subjects (Jackson and Baker, 1986; Kippers and Parker, 1987; Gauvin *et al.*, 1990) and patients with low back pain (Newton and Waddell, 1991).

It is well known that the range of motion (ROM) is influenced by muscles, tendons, ligaments, as well as body constitution and bone structure (Alter, 1996). Johns and Wright (1962) evaluated the relative contribution of tissue components to joint stiffness. It was found that the torque required to move the bones of a joint in its midrange was 47% attributable to the joint capsule, 41% to passive motion of muscles, 10% to tendons, and 2% to skin. Tendons contributed a greater proportion at the extreme ROM.

Several studies have documented the normal range of joint motion for different population age-groups (Ahlback and Lindahl, 1964; Allander *et al.*, 1974; Boone and Azen, 1979; Einkauf *et al.*, 1987) and athlete groups (Sigerseth and Haliski, 1950; Leigthon, 1957; Kirby *et al.*, 1981). Extensive cross-sectional data on sit-and-reach test scores in male and female subjects of various ages have been reported by many authors (Boone *et al.*, 1979; Shephard, 1986; Shephard and Berridge, 1990; Hubley-Kozey, 1991). Some investigators have studied the influence of flexibility of lower back and hip on the results of this test or its modifications (Jackson and Baker, 1986; Kippers and Parker, 1987; Jackson and Langford, 1989; Hoeger *et al.*, 1990; Hoeger and Hopkins, 1992; Liemohn *et al.*, 1994; Minkler and Patterson, 1994; Patterson *et al.*, 1996). In order to enhance the trunk forward flexibility, it is important to determine the joint in which the ROM is more restricted. A significant relationship of hip joint flexibility and negligible effect of lower back mobility on sit-and-reach or on finger-to-floor test have been documented by several authors (Jackson and Baker, 1986; Liemohn *et al.*, 1994; Minkler and Patterson, 1994). However, there are only a few records which have investigated the relationship between the total back flexibility and trunk forward flexion (Jackson and

Baker, 1986). Tully and Stillman (1997) noted that despite widespread use of the toe touch test, the relative contribution from vertebral and hip movement has not been clearly established, largely because of unsatisfactory measurement techniques. Awareness of the ROM in each joint which attributes to the trunk forward flexion allows to determine where the motion of muscle is more restricted.

One of the restricting factors, the hamstring flexibility (Alter, 1996), is usually measured by supine straight-leg-raising test (Ekstrand *et al.*, 1982; Shephard and Berridge, 1990). Also, the active knee extension test (Gajdosik and Lusin, 1983) and passive knee extension test (Fredriksen *et al.*, 1997) are used to measure hamstring muscle tightness. However, these tests do not reflect the influence of the hamstring flexibility on the hip and knee joint ROM separately. Since several muscles and tendons of the lower extremities cross the knee joint, special attention should be paid to the ROM of the knee joint. Unfortunately, only a few authors (Kirby *et al.*, 1981; Suni, 1994) have reported the measurement methods with the gravity goniometer for knee extension beyond the conventional two-arm goniometer. Some of the authors (Shelbourne and Johnson, 1994; Axe *et al.*, 1996; De Carlo and Sell, 1997) have reported the results of knee extension ROM using the linear measurement.

In addition, there is little information on how the configurations of body segment influence the measurements of hamstring muscles tightness as determined by the trunk forward flexibility test. Sharpe *et al.* (1994) reported that the sit-and-reach test score with ankle dorsiflexion was significantly lower than with plantar flexion. Significant relationships have been recorded between the sit-and-reach and stand-and-reach, or fingertip-to-floor test (Hubley-Kozey, 1991). Up to now, extensive cross-sectional data on trunk forward flexion at various ages have been obtained from the Canada Fitness Survey (Shephard, 1983, 1986). However, the extent of different joint ROM which is attributed to trunk forward flexion in different configurations of body segments is still unclear among different population groups.

2.2. Spine flexibility

Spinal mobility tasks, such as forward flexion, backward extension and lateral bending have been used to assess dysfunction and to evaluate progress with rehabilitation (Mellin *et al.*, 1988; Mellin *et al.*, 1990; Morini *et al.*, 1996).

Numerous techniques have been developed to assess spinal flexibility. Skin distraction tests for total spine flexibility (Green and Heckman, 1994) and for lumbar spine (Schober, 1937; Macrae and Wright, 1969; van Adrichmen and van der Korst, 1973) have been obtained. With these methods, specifically measured anatomical landmarks are established cephalad and caudad to the lumbosacral junction (the dimples of Venus), with the subject in the upright position. The subject is then asked to flex the spine maximally, and the distance between the cephalad and caudad points is measured again. The increase in length compared with the original measurement is recorded as the moment of lumbar flexion. Critics of the Schober method (Mayer *et al.*, 1991; Miller *et al.*, 1992) have pointed out that individual variation in the landmarks used to establish the starting position and the differential elasticities of the skin over the sacral and lumbar spine can lead to errors on the part of the examiner. However, the authors of the modified Shober test (Macrae and Wright, 1969) have found high correlation (r=.97) between skin distraction and radiographic measurements of lumbar spine flexion. It may be explained by the statement of Gajdosik *et al.* (1992), who noted that errors introduced by the vertebral skin movement are likely to be systematic and therefore lead to relatively constant bias in the results obtained. In addition, the fascia over the spinous processes is relatively rigidly fixed to bone, and thus the skin movement will follow bone movement more closely than in many other regions (Lundberg, 1996). According to the results of Hyytiäinen *et al.* (1991) intra- and interobserver reliability for the modified Schober test were r=.88 and .87, respectively. Stokes *et al.* (1987) who investigated the surface measurements of total lumbar spinal motion and its distribution by vertebral level, reported that surface measurements based on changes in back curvature are complicated, since the back surface has a variable relationship with spine shape and an accurate measurement of curvature is very difficult. They found the correlation coefficient to be r=.58 between surface and radiographic measures. One of the reasons for that is radiography being the most powerful method to study the validity of clinical measurements (Gajdosik and Bohannon, 1987). In addition, several devices, such as inclinometers and spondylometers have been developed for spinal flexibility measurements (Twomey and Taylor, 1979; Fitzgerald *et al.*, 1983; Mayer *et al.*, 1984).

The inclinometer provides a practical alternative to the two-arm goniometer for measurement the ROM of the joints. The ability of the inclinometer to measure complex motion of the spine, such as lumbar flexion and extension, has been widely studied and established (Asmussen *et al.*, 1959; Loebl, 1967; Troup *et al.,* 1968; Tichauer *et al.*, 1973; Reynolds, 1975; Mayer, 1983; Portek *et al.*, 1983; Mayer *et al.*, 1984; Keeley *et al.*, 1986; Gerhard and Rippstein, 1990). Mayer *et al.* (1984) suggested that, unless an individual's body habitus is such that landmarks cannot be clearly identified, inclinometer measurements are within 10 percent of those obtained with radiographic evaluation. To find out whether a manual determination of the reference points for measuring lumbar ROM is as reliable as radiologic determination for positioning the inclinometer, Saur *et al.* (1996) have determined the lumbar ROM in degrees by radiographs and inclinometer techniques. The results of the investigation showed a very close correlation (r=.93; p<0.001) between lumbar ROM measurements taken with and without radiologic determination. Satisfactory intertester and intratester correlation coefficients (r=.74–.98; p<0.001) were obtained when the inclinometer was used to evaluate the ROM of the lumbar spine (Keeley *et al.*, 1986). Several authors (Newton and Waddell, 1991; Chiarello and Savidge, 1993; Hilde and Storheim, 1997) have investigated the reproducibility of electronic digital inclinometer Cybex EDI 320 for measuring spinal mobility. Hilde and Storheim (1997) have found the reproducibility of electronic digital inclinometer for measuring spinal mobility in ventral flexion to be, with intertester and intratester correlation coefficients, r=.83 and r =.92 respectively

Although the range of motion (ROM) in the lumbar region is the most extensive of the vertebral column, the investigators (Jackson and Baker, 1986; Kippers and Pakker, 1987; Batti'e *et al.*, 1987; Jackson and Langford, 1989) have found that lumbar ROM as measured through the modified Schober method has little relation to the outcome of the sit-and-reach test. However, Jackson and Baker (1986) have determined the total back flexibility and were not able to find a significant relation with the sit-and-reach test. These findings indicated that different tests of trunk forward flexion (sit-and-reach or fingertip-to-floor) are not adequate expressions of spinal flexibility. Biering-Sorenson (1984) and Grant (1986) have noted, that such measures likely reflect mobility at the hips rather than at the spine. However, during the trunk forward flexion an increased spine curvature is followed and consistence of it in anterior flexion is beyond doubt.

Based on a review of literature, it is still unclear to what extent the ROM of spine contributes to the total trunk forward flexion. The above-mentioned methods for assessing the spinal flexibility do not allow the quantification of its role in trunk forward flexion. The detection of the consistence of trunk forward flexion allows to receive more information about the flexibility fitness. It is specially important for athletes, such as gymnasts requiring good flexibility.

2.3. Knee extension range of motion

Stretching the hamstring occurs with flexion of the hip and extension of the knee. During the first part of the trunk forward flexion, strong myoelctric activity is found in the hamstring muscles and it remains active throughout the flexion performance (Okado, 1970). Since the hamstring muscles cross the knee joint, special attention should be paid to the ROM of the knee joint.

Two methods of assessing knee joint motion — direct (angular measurement) and indirect (linear measurement of distances between segments or from an external object) — have been used throughout the medical profession to asses dysfunction, determine rehabilitation progress, and evaluate treatment effectiveness.

The objective assessment of the ROM depends on the reliability and validity of the measurements. The reliability of goniometric measurements has been documented by several authors (Boone and Azen, 1978; Ekstrand *et al.*, 1982; Rothstein *et al.*, 1983; Reid *et al.*, 1987; Gogia *et al.*, 1987; Clapper and Wolf, 1988; Rome and Cowieson, 1996). Eleveru *et al.* (1988) and Youdas *et al.* (1993) have reported that the reliability of goniometry is dependent upon standardized measurements. Boone and Azen (1978) have determined that reliability is greater for upper extremity motion than for lower extremity motion. According to the results of Rothstein *et al.* (1983), intertester reliability of goniometer measurements of passive motion of knee extension is low (r=.63 to .70). A little bit higher reliability values (r=.85) for measurements of active motion of knee extension have been recorded by Clapper and Wolf (1988).

A few articles have provided some information about the different types of goniometer to measure the knee extension ROM. Clapper and Wolf (1988) did not find that the electronic goniometer is more accurate than a standard goniometer. Visual estimation and goniometer measurement of the knee extension has been compared by Watkins *et al.* (1991) and they concluded that visual estimates of knee passive ROM would add slightly more error to the therapists measurements than those taken with a goniometer.

Although the reliability of the goniometer measurements has been found by Boone and Azen (1978) to be with intratester variation of 4°, and that joint motion should differ by at least 5° before a true increase or decrease in joint motion may be recorded, some investigators (Cheng *et al.*, 1991) have registered a quite small ROM of the knee extension; amounting from 16°±9 at age 3 to 7°±9 at 10 years. Young children typically have some degree of knee extension. Wynne-Davies (1971) in a study of 3.000 Edinburgh children have noted that 15% of the 3-year old children could extend their knee beyond 10°, but this degree of extension was observed in <1% at age 6 years. Daniel and Anderson (1992) have evaluated the knee extension ROM at 3° or less as the normal and 3°–5° as a nearly normal at the age of 11–12 years. Minus 2°±3 for healthy adult males was recorded by Roaas and Anderson (1982). The ROM of the knee extension recorded by Watkins *et al.* (1991), among 43 adults whose ages ranged from 18 to 80 years, was minus 12°±14. These negative values could represent a knee flexion contracture (*i.e.*, the number of degrees short of 0° of extension) or it could mean hyperextension. De Carlo *et al.* (1994) recommended documenting ROM as three numbers written as A-B-C, with A indicating the degree of hyperextension, B indicating the degree of lacking extension, and C documenting the degree of flexion. For example, ROM of the knee from 5° hyperextension to 130° flexion is documented as 5-0-130.

However, there is still a problem how to determine the criteria for hypermobility. The first scoring system that established the criteria for hypermobility was devised by Carte and Wilkinson (1964). They assessed the ability to hyperextend the knees more than 10° as hyperextension. Greene and Heckman

(1996) have noted that if the motion is atypical, such as extension of the elbow or knee in an adult, or when it is asymmetrically increased at any age, it is referred to as hyperextension. Anderson and Hall (1995) have defined the hyperextension as the extension of a limb or body part beyond the normal limits. The results of the investigation of the passive knee extension ROM (De Carlo and Sell, 1997) showed that among healthy high school athletes (n=889) most have some degree of knee hyperextension. The mean range of motion was 5-0-140 for males and 6-0-143 for females and assessed by the authors as the normal amount of hyperextension.

Based on a review of literature, some authors of recent years (Shelbourne and Johnson, 1994; Axe *et al.*, 1996; De Carlo and Sell, 1997) have reported the results of knee extension ROM using the linear measurement. They measured the hyperextension of the knee joint, when the patient was in a supine position, the knee maximally extended, and the foot in a neutral position. The distance from the posterior border of the heel to the table in centimetres after the passive knee extension performance was recorded. A measuring tape was attached to the wall with the zero line at the height of the table. Repeated testing of the knee hyperextension of 20 injured and healthy knees demonstrated an intraclass correlation coefficient of r=.94 (Axe *et al.*, 1996). The results of this study demonstrated that individuals with anterior cruciate ligament injuries whose knees hyperextended 3 cm or more sustained significantly more joint damage at the time of injury than in those whose knees hyperextended less than 3 cm. Thus, hypermobility may be the risk factor for knee injuries. Previously to these methods, Sachs *et al.* (1989) reported evaluating knee extension with the subject in the prone position, with the lower parts of the legs hanging off the end of the table. By means of this method it is only possible to observe the difference in heel height, but not to determine the exact ROM.

No data exist, however, how the ROM of the knee joint extension affects measurements of sit-and-reach test scores.

3. OBJECTIVES OF THE PRESENT STUDY

The general objective of the present study was to evaluate the components of the trunk forward flexion in young schoolchildren at the age of 8–14 years and in university students.

The specific aims were:

1) to work out a simple method for measuring the knee extension ROM and to evaluate its effect on the results of the sit-and-reach test;

2) to contribute to the understanding of the constituents of the trunk forward measurement and to describe a simple method of estimating the flexibility of spine;

3) to evaluate a simple method for assessing the consistence of spine and hip flexibility in trunk forward flexion in young schoolchildren and rhythmic gymnasts.

4. MATERIALS AND METHODS

4.1. Subjects

Studies were carried out on 330 subjects. Two hundred and nine schoolchildren (92 boys and 117 girls) from 8–14 years of age (twenty-nine of them participated 1–2 years in a special training of rhythmic gymnastics) and 121 university students (68 males and 53 females) participated in this study. Informed consent was obtained from each subject beforehand. No subjects had limitation of joint movement due to injury.

Warm-up exercises included two initial practice attempts for each measurement procedure. Anthropometric characteristics of the subjects in the papers are presented in Table 1

Table 1

Anthropometric characteristics of the subjects (Mean ± SD)

	Age (yrs)	Weight (kg)	Height (cm)
Paper I			
men n=22	18–22	76.3±10.3	182.9±5.5
women n=38	18–22	61.0±7.5	170.6±5.4
boys n=23	11–15	52.4±7.5	164.5±10.6
girls n=31	11–15	48.6±11.9	159.1±8.3
Paper II			
men n=24	18–20	73.4±5.2	182.7±6.1
women n=15	18–20	61.0±7.5	170.7±4.5
Paper III			
girls n=30	8–9	28.1±4.9	134.5±5.7
girls n=27	13–14	49.3±6.8	163.0±6.2
r.gymnasts n=29	8–9	24.9±2.8	131.2±4.8
boys n=32	8–9	32.1±5.1	134.3±5.1
boys n=37	13–14	52.7±7.4	160.3±6.6
Paper IV,V			
girls n=30	8–9	28.1±4.9	134.5±5.7
girls n=29	11–12	39.7±5.8	156.5±7.5
girls n=27	13–14	49.3±6.8	163.0±6.2
boys n=25	8–9	31.2±4.6	133.8±4.8
boys n=17	11–12	43.4±6.7	154.2±6.6
boys n=29	13–14	52.1±7.1	161.2±8.3
Paper VI			
men n=22	18–20	74.3±9.4	182.2±5.9

4.2. Methods

4.2.1. Sit-and-reach test

The subject placed the soles of both feet against the testing box, 0.3 m height. The zero- point of measurement was taken at the edge of the box. The linear measurement to the nearest half centimeter was obtained by having the subject reach and hold for two seconds with feet together and knees fully extended which corresponded to a stretching maneuver (Figure 1).

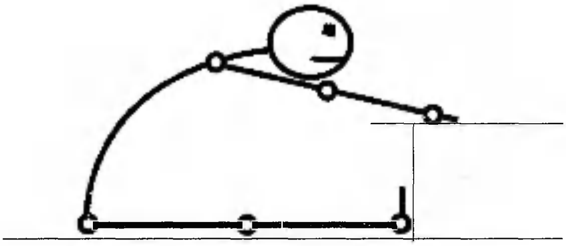


Figure 1

4.2.2. Modified sit-and-reach test

The measurement procedure was similar to sit-and-reach test procedure. The knee joint extension ROM was previously eliminated by special thickness plates, whose thickness was equal to the ROM of the knee extension, fitted under the heels after the knee extension has been performed. Stabilizing straps were placed around the thighs to prevent associated motions and the subject performed the traditional forward flexion (Figure 2).

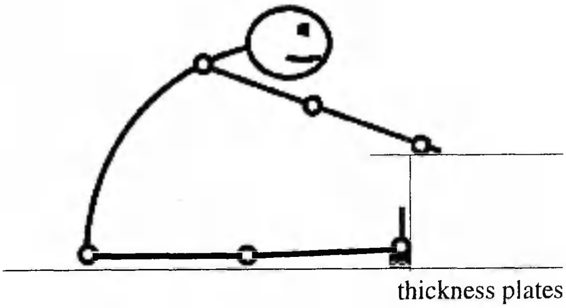


Figure 2

4.2.3. Method to determine the knee extension range of motion

A special instrument was constructed to measure the knee joint extension ROM (Figure 3). The design enabled recording the ROM of knee extension on a linear scale with an accuracy of 1 mm. The measurement plate (A) was placed into a special box (B) and fixed with the fixing holders (C) to the edge of the measurement table on the same level. The subject was in sitting position, feet extended and heels on the measurement plate. The up-movement of the measurement plate during the knee extension performance takes place due to the pressure of the springs, constructed inside the instrument. The knee extension ROM was read from the scale and expressed as the distance (h) between the heel support (measurement plate in zero position) and maximally uplifted heels performed by the active force of the subject. The fixing screw (D) enabled the hight of the measurement plate (A) at the end of the knee extension performance to be fixed. The measurement procedure is presented in Figure 4.

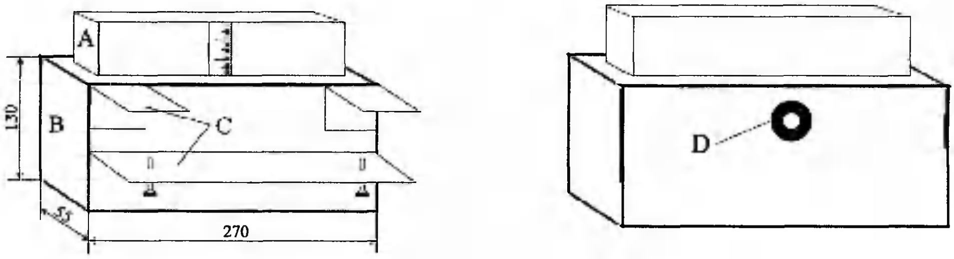


Figure 3. Instrument for measuring the knee extension range of motion
A — Measurement plate; B — Box containing the measurement plate guide; C — Fixing holder; D — Fixing screw of the measurement plate

Figure 4. Positioning subject's feet during the measurement knee extension ROM in (mm)

Reliability of measurement

A pilot study, aimed to estimate the reliability of knee extension measurement procedure and to determine the within- and between-tester errors, was conducted on 15 male students of the physical education. The intraobserver and interobserver reliability of the knee extension measurement procedure has been estimated. The formula, reported by Malina *et al.* (1973)

$$S_d = \sqrt{\frac{\sum d_i^2}{2n}},$$

(S_d — the technical error of measurement; d_i — the difference between two measurement; n — total number of individuals examined) was used to estimate the technical error of measurements (in mm). There were calculated intertester error 1.5 mm (averages and standard deviations of two measurement sessions: 30.6±1.7 mm and 29.9±1.7 mm) and correlation coefficient between two sessions $r=.95$ ($p<0.001$). The corresponding results for the intratester intrassay error was 1.3 (29.9±1.7 mm and 30.7±1.7 mm, $r=.96$; $p<0.001$). Intratester interassay error 1.9 was determined by 2 measurement sessions with one- week interval (averages and standard deviations of two sessions: 31.26±1.96 mm, 32.66±1.76 mm, $r=.95$; $p<0.001$). The coefficients of variance estimated by formula

$$CV = \frac{SD\ of\ \Delta^*}{\frac{\overline{X}+\overline{Y}}{2}}$$

were for intertester-, intratester intrassay- and intratester interassay tests 6.7%, 5.9% and 7.0% , respectively.
Δ^* — difference between the two test being compared

4.2.4. Method to determine the spine flexibility

Forward flexion was measured by a gravity goniometer at two points in the standing (Figure 5) and sitting position (Figure 6) in order to compare of the configuration of body segments influence on the components of trunk forward flexion. The subject was asked to hold his/her arms behind his/her head. The gravity goniometer was fastened to one side of the chest (midaxillary line) at nipple height according to the guideline reported by Hubley-Kozey (1991) and needle placed to zero. A subject was instructed first to bend forward with a straight vertebral column (the first point), which allowed determination of ROM in the hip joint. A subject then performed a full forward bend (the second point). The difference between the two measures was taken as the flexibility of spine (spine flexion = trunk flexion – hip flexion). For comparison, the ROM in hip joint measurement in the supine position described by Hubley-Kozey (1991) was made.

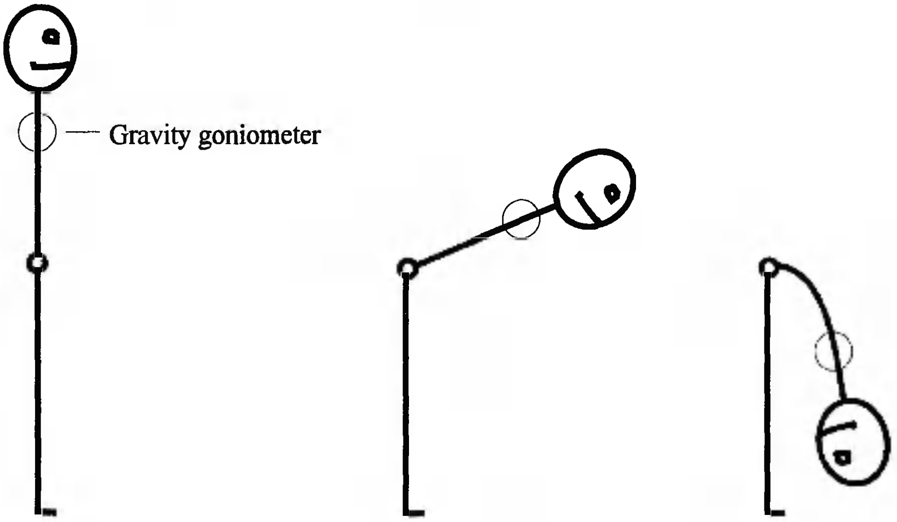


Figure 5

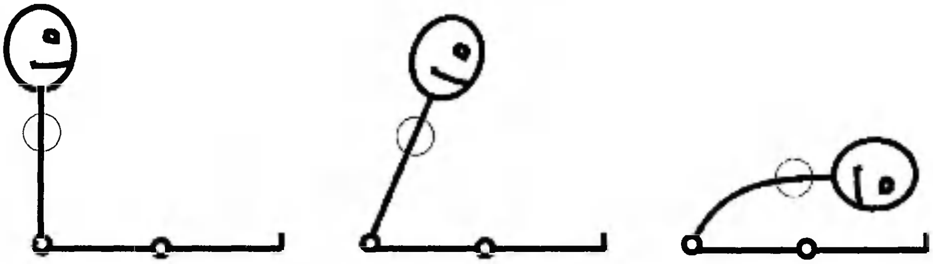


Figure 6

Reliability of measurement

A pilot study, aimed to estimate the reliability of the spinal flexibility measurement procedure by the gravity goniometer was conducted on 10 male students of physical education. The intraobserver and interobserver testing was arranged. Intraobserver reliability was determined by 2 measurement sessions with one-week interval. Correlation coefficient between two tests scores of spinal flexibility was r=.93. Interobserver reliability was determined by 2 measurement session with 5 min. interval. The corresponding correlation coefficient was r=.75.

The calculated intratester error was ±6.2° (average and standard deviation of two measurements sessions: 50.8°±16.4 and 57.5°±14.1). The corresponding results for the intertester error was ±8.2° (50.8°±16.4 and 53.0°±16.3). Coefficients of variance, estimated by the previously noted formula were for intra- and interobserver tests 9.9% and 12.3%, respectively.

4.2.5. Statistical evaluation of the data

The appropriate procedures in the Systat and Statgraphics packages were used. The results were expressed by the mean ±SD. Pearson product moment correlation between test scores were established. LSD test of one way ANOVA (Paper I, II) and Mann-Whitney U-test (Paper III) were used to determine the significant differences between groups. Z value was used to estimate the means of the range of motion at 95% levels of confidence interval (Paper III).

Percentage proportion of the hip and the back ROM in the trunk forward flexion was calculated by following formula: hip ROM / trunk forward flexion × 100 and back ROM / trunk forward flexion × 100.

The $p<0.05$ levels was selected as the criteria of statistical significance.

5. RESULTS

5.1. The knee extension ROM as a component of trunk forward flexion

Mean values of knee extension ROM (mm), sit-and-reach test scores and modified sit-and-reach test scores (cm) in male and female students and in boys and girls groups are presented in Table 2. The means of the knee extension ROM at 95% levels of confidence interval for boys and girls are presented in Paper IV.

Table 2

Mean range of movement (±SD) recorded in male and female groups

Movement	Men	Women	Boys	Girls
	(n=22)	(n=38)	(n=23)	(n=31)
Knee extension ROM (mm)	34.4±11.3	37.2±15.6	23.3±11.2[a]	24.0±10.8[b]
Sit-and-reach test (cm)	13.2± 7.0	15.1± 7.4	4.3± 5.6[a]	9.3±5.9[bc]
Modified sit-and-reach test (cm)	11.2± 7.4	13.0± 7.0	4.2± 5.6[a]	9.1±5.7[bc]
Difference	2.2± 1.4	2.0± 1.2	0.3± 1.3[a]	0.2±1.7[b]

Significantly different from the respective value: [a] — in men, [b] — in women, [c] — in boys (all $p<0.05$)

Significant, albeit low correlation computed for all subjects (n=114), were found between the ROM in the knee joint and the results of the sit-and-reach test (r=.37; $p<0.05$). A slightly higher value (r=.48; $p<0.05$) were established for 22 males (Paper VI). Higher differences between the conventional and modified sit-and-reach test scores were found in adult groups, with no significant differences between men and women (2.04±1.26 cm), than in children. Although no differences between scores of traditional and modified sit-and-reach test scores were found in schoolchildren, a significant correlation between the knee extension ROM and sit-and-reach test scores was found (r=.40; $p<0.05$).

5.2. Spine and hip flexibility as the components of trunk forward flexion

The consistence of spine flexibility in trunk forward flexion is presented in Paper II and Paper III. Mean values and SD of spine flexion, hip flexion and trunk forward flexion measured by gravity goniometer and sit-and-reach tests scores in university male (n=24) and female (n=15) students from the faculty of physical education are presented in Table 3. These variables of schoolchildren (n=155) are presented in Table 4, 5.

Table 3

Mean values and SD of spine flexion, hip flexion and trunk forward flexion in university students*

Movement	All subjects (n=39)	Male (n=24)	Female (n=15)
Standing position			
Hip flexion	83.8±14.2	81.0±13.6	88.1±14.5
Forward flexion	137.0±13.5	137.1±15.0	136.9±11.0
Spine flexion	53.3±15.6	56.1±16.6	48.8±13.0
Sitting position			
Hip flexion	35.3±10.8	32.3±10.8	39.9± 9.4
Forward flexion	58.3±15.7	58.4±13.3	58.2±13.0
Spine flexion	24.4±10.0	25.8±10.9	22.2± 8.2
Supine position			
Hip flexion	106.7±14.6	100.7±13.5	116.3±10.9
Stand-and-reach	13.2± 6.8	12.5± 7.5	14.4± 5.6
Sit-and-reach	14.5± 7.6	13.9± 8.3	15.3± 6.7

* Numbers are mean and standard deviation and are degrees except for stand-and-reach, sit-and-reach, which are in cm.

To compare the hip flexion and trunk forward flexion in the standing position with that in the sitting position, the configuration of two body segments (the trunk and lower extremities) must be taken into account. The ROM in the hip joint and trunk flexion is higher in sitting position than in the standing among all observed groups. Similar results were obtained from the linear measurement of stand-and-reach and sit-and-reach tests in students of the faculty of the physical education. However, the hip ROM and spine ROM percent contribution to trunk forward flexion were approximately 60% and 40%, respectively, in both positions. The calculation of the percent contribution of the hip and spine ROM to the total trunk forward flexion in the standing and in sitting position for all children and adults showed that approximately 60% belongs to the hip joint ROM and 40% to the spine ROM.

Table 4

Sample means, standard deviations, 0.95 confidence-intervals (CI) for the girls' groups and differences by the Mann-Whitney U-test procedure

	girls 8–9 yr. (n=30)	girls 13–14 yr. (n=27)	gymnasts girls 8–9 yr. (n=29)
	$\bar{X}$±SD CI	$\bar{X}$±SD CI	$\bar{X}$±SD CI
Standing position			
Hip flexion	77.2°±15.7	86.1°±18.6**	92.6°±17.6*
	71.3–83.1	78.8–93.5	85.9–99.2
Forward flexion	128.4°±12.4	137.6°±17.2	148.4°±12.2*
	123.8–133.0	130.7–144.4	143.8–153.0
Spine flexion	51.2°±11.8	51.5°±15.9	56.0°±17.1
	46.8–55.6	45.2–57.8	49.5–62.5
Sitting position			
Hip flexion	22.4°±8.7	21.9°±11.9	44.4°±10.9*
	19.2–25.7	17.1–26.6	40.3–48.6
Forward flexion	54.2°±13.6	52.0°±14.2	74.6°±11.4*
	49.2–59.3	46.4–57.6	70.2–78.9
Spine flexion	31.8°±12.9	30.2°±12.7	30.1°± 8.9
	27.0–36.6	25.2–35.2	26.8–33.5
Sit-and-reach (cm)	10.3±4.8	10.5±4.7	15.3°±3.6*
	8.5–12.1	8.7–12.4	13.9–16.6

* denotes the differences between untrained and trained groups at age of 8–9 yr.

** denotes the differences between the groups at age of 8–9 yr and 13–14 yr.

Table 5

Sample means, standard deviations, 0.95 confidence-intervals (CI) for the boys' groups and differences by the Mann-Whitney U-test procedure

	boys 8–9 yr. (n=32)	boys 13–14 yr. (n=37)
	$\overline{X}$±SD CI	$\overline{X}$±SD CI
Standing position		
hip flexion	72.7°±20.7 65.2–80.1	80.1°±15.2 75.0– 85.2
total trunk flexion	121.7°±16.5** 115.8–127.7	125.4°±16.2** 120.0–130.8
spine flexion	49.1°±21.1 41.4–56.7	45.3°±17.1 39.6–51.0
Sitting position		
hip flexion	18.4°±6.8 16.0–20.9	26.5°±10.3* 23.0–29.9
total trunk flexion	43.6°±9.9** 40.0–47.2	54.5°±13.3* 50.0–58.9
spine flexion	25.2°±8.9** 21.9–28.4	30.0°±13.4 23.5–32.5
Sit-and-reach (cm)	7.0±2.8** 6.1–8.0	5.2±5.3** 3.4–7.0*

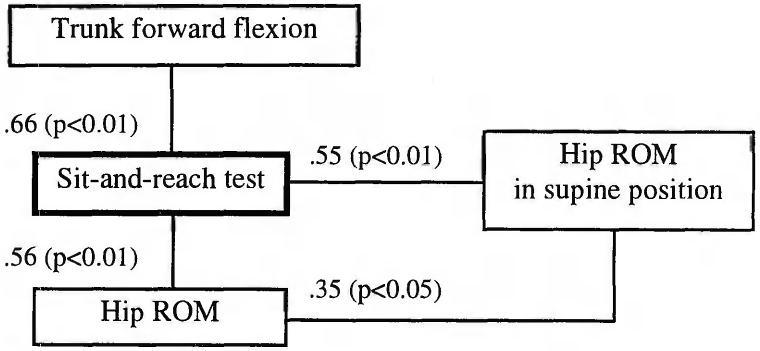
* denotes the differences between two groups,

** denotes the differences between the boys and girls groups at the according age (data for girls groups are presented in Table 3).

The estimated means of spine flexion by Z values at 95% levels of confidence in the groups of girls and boys at the age of 8–9 and 13–14 were similar. In standing position these values ranged from 40° to 63° and in sitting position from 22° to 27°.

The coefficients of correlation between the linear and goniometer test scores in standing and in sitting position are presented in Figure 7. (correlation matrix in Table 2, Paper II).

Sitting position



Standing position

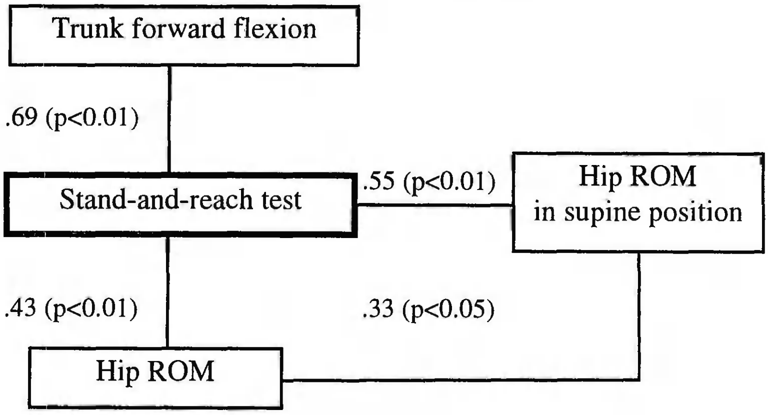


Figure 7. The coefficients of correlation between the linear and goniometer test scores in standing and in sitting position (n=39)

5.2.1. Age and gender differences in the components of trunk forward flexion

Age related significant difference was followed between girls groups at the age of 8–9 yr. and 13–14 yr. in the ROM of hip joint measured in standing position (Figure 8). For groups of boys significant differences were found in the ROM of the hip and total trunk forward flexion in sitting position, whereas spine flexion ROM difference was not significant (Figure 9) (Table I, II; Paper III).

Figure 8. Age related significant difference between girls groups at the age of 8–9 and 13–14 yr. in the ROM of hip joint measured in standing position

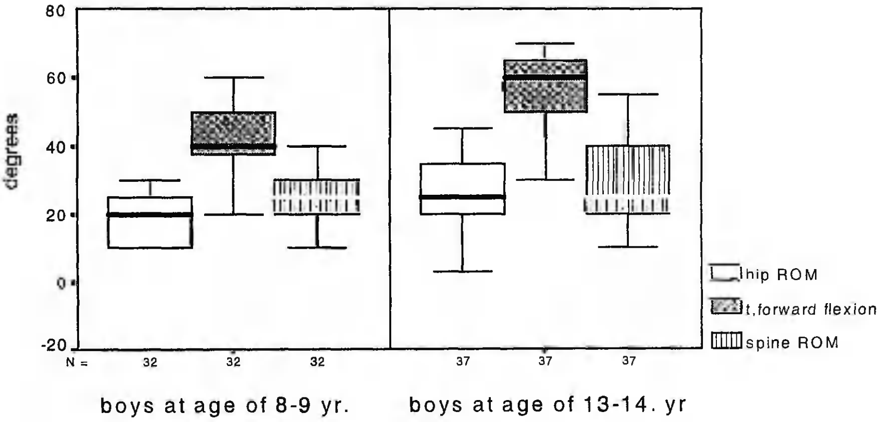


Figure 9. Age related significant difference between boys groups at the age of 8–9 and 13–14 yr. in the flexibility measurements in sitting position

The Pearson product-moment coefficient of correlation between trunk forward flexion and the components of it (hip and spine flexion ROM) measured by the gravity goniometer is presented in Table III (Paper III). The total trunk forward flexion measured in standing and sitting positions was more strongly correlated with the ROM of the spine flexion than with the ROM of the hip flexion in all groups of boys. The conversed relation was followed in all groups of girls in the standing position.

No significant difference was found between the scores of male and female groups except for the ROM of the ankle, although the group mean test score of the female group in each measure had a tendency to be higher (Table I, Paper II).

Gender differences appeared in the flexibility measurements of the total trunk forward flexion in both positions and the spine flexion ROM difference in sitting position for children groups at the age of 8–9 yr. (Figure 10). In the older groups sex related difference was followed only in total trunk forward flexion measured by gravity goniometer in standing position (Figure 11) and by the sit-and-reach test (Table II; Paper III).

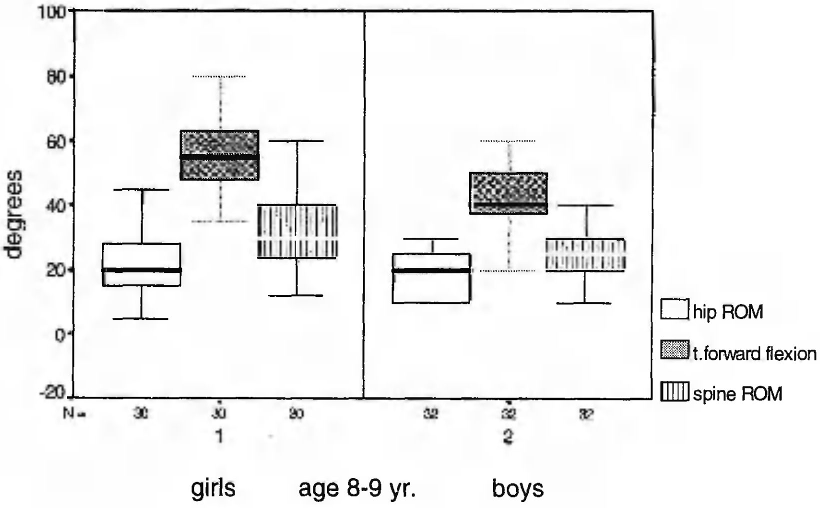


Figure 10. Gender differences in the flexibility measurements of the total trunk forward flexion in sitting position for children groups at the age of 8–9 yr

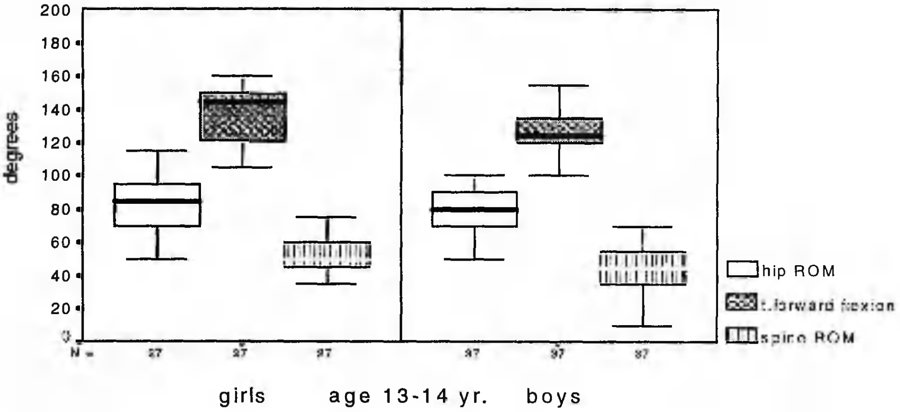


Figure 11. Gender differences in the flexibility measurement of the total trunk forward flexion in standing position for children groups at the age of 13–14 yr

5.2.2. Differences between untrained girls and rhythmic gymnasts at age of 8–9 years

The comparison of untrained girls and gymnasts at the same age revealed significant differences between flexibility measurements in both positions, except the ROM of spine flexion (Figures 12, 13).

The correlation coefficient of trunk forward flexion with the hip and spine ROM in sitting position for untrained and trained girls are presented in Figure 14.

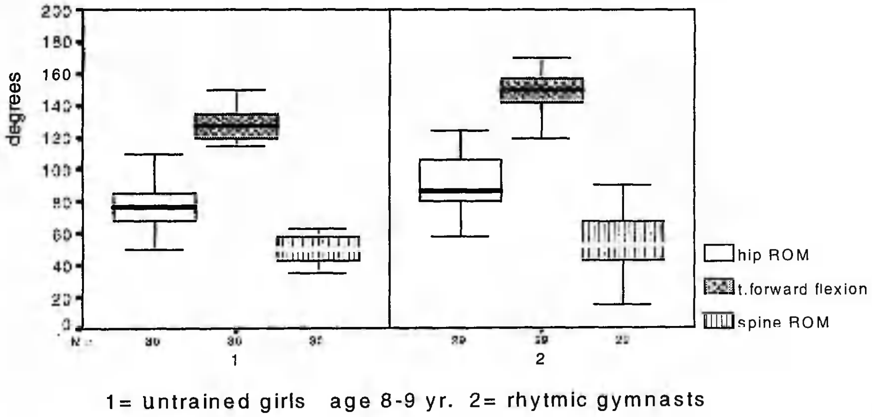
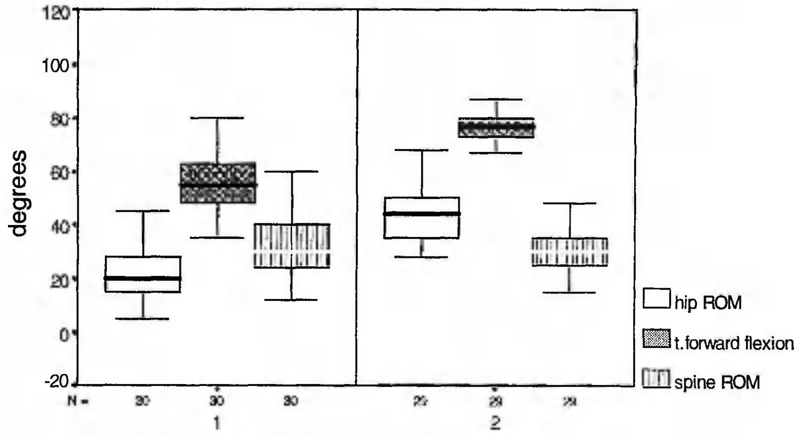


Figure 12. Flexibility measurements of untrained and trained girls in standing position



1= untrained girls age 8-9 yr. 2= rhythmic gymnasts

Figure 13. Flexibility measurements of untrained and trained girls in sitting position

Sitting position

Note. The bold numbers are the correlation coefficients of untrained girls.

Figure 14. The correlation coefficient of trunk forward flexion with the hip and spine ROM in sitting position for untrained and trained girls

6. DISCUSSION

6.1. The evaluation of the constructed instrument for measuring the knee extension ROM

The knee extension arc is limited, and any error might, therefore be magnified. The constructed linear instrument used in this study showed in a previously arranged pilot study high intertester reliability (r=.95) with intertester error 1.46 (mm). This measurement procedure doesn't need to determine the anatomical landmarks, and the management procedure takes a little time. A relatively poor intertester reliability intraclass correlation coefficient r=.63–.70 for different types of goniometer measurements of passive knee extension ROM was found by Rothstein *et al.*, (1983). A little higher value r=.86 has been reported by Watkins *et al.*, (1991). The reasons for it, as noted by the authors, may be the difficulties in determining the anatomical landmarks in patients and that the knee extension itself may be highly labile and therefore hard to quantify. Fredriksen *et al.*, (1997) have studied the intertester reliability of the measurement of the passive knee extension ROM by another technique (the subject in supine position with hip stabilized in 120 degrees of flexion and the knee was passively extended by a standardized force by one of the tester) and found Pearson correlation coefficient between test retest scores to be of r=.99. However, a total of 28 test-retests was performed on eight and six different days and the limited number of subjects (one male and one female) could influence on the results of reliability.

The intratester intrassay error using the constructed instrument was 1.3 mm and the correlation coefficient between the two measurement sessions r=.96 (p<0.001). Several authors (Shelbourne and Johnson, 1994; Axe *et al.*, 1996; De Carlo and Sell, 1997) have reported the results of knee extension ROM using linear measurement, but only one of them have presented the data of measurement reliability with intraclass correlation coefficient r=.94 (Axe *et al.*, 1996). According to the measurement procedure, the examiner held the forefoot with one hand and stabilized the distal segment of the femur on the table with the other hand, while the assistant measured the distance from the posterior border of the heel to the table in centimeters. The exact recording of the distance in this manner is quite questionable, and therefore the obtained result of intraclass correlation coefficient seems to be very high. However, the mean values of the knee extension ROM of the greater (41.8±9.7 mm) and lesser (26.7±9.19 mm) flexibility groups of 22 students of the faculty of physical education recorded in this study (Paper VI) are similar with those obtained by Axe *et al.* (1996) for hyperextension group (35.7 mm) and no-hyperextension group (28.1 mm) among 100 patients at age of 24±9 years.

De Carlo and Sel (1997) using the linear measurement method of Shelbourne and Johnson (1994) measured the passive knee extension ROM among the 889 healthy females and males at the mean age of 14 years. The recorded values are higher about 2 cm than those recorded in the present study for active knee extension ROM in schoolchildren at the age of 13–14. However, these values are also comparative, as the passive ROM of joint is usually higher than active, and with increasing the height of subjects the values of linear measurement increase (see Paper V).

The results of this study (Paper V) indicated the superiority of the linear instrument in assessing knee extension ROM in millimeters, because the coefficient of variance of the measured values was lower for all the subjects than the coefficient of values recorded with the gravity goniometer. Additionally, in the first case, more differences in the knee extension ROM between age and sex groups by Mann-Whitney U-test were brought out (Table 2, Paper V). To assess ROM of knee extension that is relatively small, linear measurement allows more accurate results. A large standard deviation found in the present study and those, reported by Cheng *et al.* (1991) may have been caused by the wide range of knee extension ROM exhibited by individuals. Correlation coefficient between indirect and direct knee extension ROM obtained by the linear measurement instrument and the gravity goniometer was $r=.79$ ($p<.001$). Clapper and Wolf (1988) have found a weak negative relationship ($r=-.33$) between the standard and the electronic goniometer when both were used to measure knee extension ROM. The authors noted that the reason for it was that two different numerical scales have been used for the measurement and explained it with different measurement procedures. They used a standard goniometer to assess knee extension ROM from full extension but with the electronic goniometer from full flexion to extension. Considering the relatively strong correlation ($r=.79$) between the values recorded using two instruments in the present study, the linear instrument may be one of the alternative methods to the commonly used goniometer.

The widespread and commonly used straight leg raise test is advised to measure the hip joint and hamstring flexibility (Ekstrand *et al.*, 1982; Shephard and Berridge, 1990; Alter, 1996). However, it does not allow to evaluate the hip and hamstrings flexibility separately. The method of Suni (1994), for the determination of the knee extension in supine position is not free from the hip flexion influence to knee articulation. In this way, the hip and the knee joints are flexed to 90° at zero point of measurement. The linear measurement of the knee extension characterises more exactly the flexibility of hamstrings when the extremity is in the zero starting position. The results of the knee extension ROM in millimeters and the modified sit-and-reach test scores allowed to evaluate the role of the knee extension ROM in the trunk forward flexion. The results of the modified sit-and-reach test, in which the knee extension ROM was eliminated, decreased by about 2 cm compared with the traditional test in adults. Similar result was obtained in the study of 44 male students (Hein (a), 1996). The difference between traditional and modified sit-and-reach test scores (2.4±1.5 cm) correlated with knee extension ROM ($r=.60$; $p<0.001$). Also, the higher correlation coefficient $r=.50$ ($p<0.05$) between the trunk forward flexion and knee extension ROM in rhythmic gymnasts than in the subjects of the present papers ($r=.37$ and 0.48) was recorded (Hein, 1996).

Obviously, to assess the ROM of the knee extension, which is relatively small, linear measurement allows to give more accurate results. The constructed apparatus is more appropriate for the measurement of the knee extension ROM in mm as the rotation of the tibia on the femur is small and cannot be measured accurately in degrees (Greene and Heckman, 1994). The limitation of the method, common for all indirect methods, is its dependence upon segment length, and comparisons could be made only within or between the subjects with approximately equal segment length (Hubley-Kozey, 1991). The correlation coefficient $r=.27$, ($p<0.05$) between the knee extension ROM and body height confirms this statement (Paper I). The mean calf length of all the schoolchildren ($n=157$) in this study varied only about 10 cm and therefore the correlation, found between the ROM of knee extension and the segment length was weak ($r=.16$, $p<.05$).

These results indicated that the constructed linear instrument for assessing the knee extension ROM is an appropriate tool that is easy to manage and takes little time.

6.2. The validity of the method to determine the spine flexion in trunk forward flexion

Most investigators have studied the spine flexibility relation to the trunk forward flexion in respect of the lumbar region (Jackson and Baker, 1986; Kippers and Parker, 1987; Jackson and Langford, 1989; Hoeger *et al.*, 1990; Hoeger and Hopkins, 1992; Liemohn *et al.*, 1994; Minkler and Patterson, 1994; Patterson *et al.*, 1996). However, there are only a few records, which reflect the relationship between the total back flexibility and trunk forward flexion (Jackson and Baker, 1986). Unfortunately, they measured the total spine flexibility by skin distraction method, and therefore they were not able to evaluate the extent of the spine flexion in total trunk forward flexion. Tully and Stillman (1997) have noted that despite of the widespread use of the trunk forward flexion, the relative contribution from vertebral and hip movement has not been clearly established, largely because of unsatisfactory measurement techniques.

The validity and reliability of skin distraction tests and several types of inclinometers for measuring the lumbar ROM have been documented by a number of investigators (Troup *et al.*, 1968; Macrae and Wright, 1969; van Adrichmen and van der Korst, 1973; Tichauer *et al.*, 1973; Reynolds, 1975; Mayer, 1983; Portek *et al.*, 1983; Mayer *et al.*, 1984; Keeley *et al.*, 1986; Gerhard and Rippstein, 1990). These studies have documented the high correlation between the measurements obtained by inclinometer and x-ray techniques arranging from r=.90 to .97. Also the correlation coefficients between the repeated measurements of different measurement techniques arranging from r=.58 to .99 have been reported.

The comparison of the methods described in literature for measurement the spinal flexibility with the method presented in this study is difficult due to different techniques. However, a certain similarity is followed between the results of the reliable tests for measuring the lumbar ROM by the inclinometer (Keeley *et al.*, 1986) and spine ROM by the gravity goniometer in the present study. Keeley *et al.* (1986) obtained intertester and intratester correlation coefficients r=.74 and .98; ($p<0.001$) when the inclinometer was used to evaluate the ROM of the lumbar spine. The correlation coefficients between the measurements of the two different testers and between the two measurements of one tester to evaluate the spine ROM by the gravity goniometer were r=.75 and .93, respectively. Hilde and Storheim (1997) found the reproducibility of electronic digital inclinometer for measuring spinal mobility in ventral flexion to be, with intertester and intratester correlation coefficients, r=.83 and r=.92 respectively. However, Bland and Altman (1986) have pointed out that correlation analysis is inappropriate as an indicator of agreement between measurements or techniques. The coefficient of variation is a true measure of variability, and it is therefore a more acceptable estimate of the reliability or imprecision of a technique (Friedlander *et al.*, 1991). In the present study, the coefficient of variance between two measurement sessions of one tester was 9.9% and of two testers 12.3%. According to the results of Hilde and Storheim (1997) the coefficients of variance for test-retest measurements of the lumbar ROM flexion were 6.8% and 7.5%, for lateral flexion 10.1% and 13.8%, but for dorsiflexion 21.4% and 27.6%, respectively, measured with the electronic digital inclinometer. The coefficients of variance were calculated by the same formula as in this study. The authors estimated the measurement techniques, which test-retest values did not exceed the coefficient of variance 14% to be acceptable. A lower intratester and intertester coefficient of variance (6.8%; 7.5%) for measurement the lumbar ROM obtained by the electronic digital inclinometer than with the gravity goniometer for spine ROM (9.9%; 12.3%) may be due to the different qualification of testers explored in these studies. In the study of Hilde and Storheim (1997) the testers were skilled therapists, whereas the testers of the present study have undergone only a short measurement training before testing. Therefore, it allows to suppose that an expensive instrument is only a little more reliable than a simple and inexpensive gravity goniometer for measuring the spinal mobility, especially in respect of one tester. Clapper and Wolf (1988), who compared the standard goniometer with an electronic computerized goniometer for assessment the ROM of lower extremity found that the assessment of lower extremity joint ROM with a goniometer yielded significantly greater confidence levels (*i.e*, fewer degrees of variance for each measurements) than an electronic computerized goniometer for all motion expect hip abduction and hip lateral rotation.

In this study, the spine flexibility was determined as the difference between the results of total trunk forward flexion and hip flexion measured by the gravity goniometer. Then, for the evaluation of the results of the spine flexibility be true, the hip flexion measurement must be adequate, too. The statistically significant correlation between the two different methods (hip flexion measurement during the forward bending with straight vertebral column and hip flexion measurement in supine position) confirmed it. Additional evidence for this fact is the coincidence of the results in hip flexion of this study with those obtained by Entyre and Lee (1988) in the similar population. The group mean test score of ROM in the hip joint obtained by Etnyre and Lee (1988) in 49 men and 25 women (mean age 20, from a university population) lying supine with the hip flexed maximally and knee fully extended were 81° and 87°, respectively. The according results in this study were 81.0° and 88.1° measured by the gravity goniometer (Table I. Paper II). The above-mentioned data and the results of the repeatability of the test (subsection "Methods") reveal the validity of the method used to determine the extent of the spine as a component of trunk forward flexion.

The range of motion of the spine can be measured reliably with the above-mentioned methods besides expensive radiographic techniques. The recording of radiographic motion of the joints on film (cineradiography) is useful in the analysis of spinal motion, but the high level of exposure to radiation makes it unsuitable for routine use. In addition, modern high technology, such as magnetic resonance imaging and computerized tomography, are not traditionally used for measuring the range of motion. Computerized tomography scanning is technically complicated, and magnetic resonance imaging requires the subject to remain motionless for a long time (Roozmon *et al.,* 1993). In contrast to these, computer-assisted video method described by Tully and Stillman (1997) has some advantages as it allows to measure static postural angles as well as dynamic movements.

However, using the gravity goniometer attached to the subject, in accordance with the measurement guidelines to determine the spine and hip ROM separately in trunk forward flexion is free from disadvantages typical for inclinometer, which are associated with surface anatomy problems, identifying the reference point of measuring, in accurately positioning the instrument over the required bony landmarks, and in holding the instrument in position as the subject bends forward. Considering the above-mentioned statements and that a gravity goniometer is not expensive and simple to manage, it may be used for evaluating spine and hip ROM in trunk forward flexion by sport instructors and rehabilitation specialists.

6.3. The evaluation of the method for measuring the spine and the hip flexion in the trunk forward flexion among the different population

The data of the present study on flexibility in the total spine is difficult to compare due to the method used. However, some coincidence is followed with earlier arranged measurements by the authors (Jackson and Baker, 1986; Jackson and Langford, 1989; Liemonh *et al.*, 1994; Minkler and Patterson, 1994), who have studied the sit-and-reach test relation to the lumbar spine flexion. A reason for it is that the spine is most flexible in lumbar region and therefore its ROM reflects spinal mobility to quite a large extent. Although, it is not reasonable to underestimate the role of upper segments of the vertebral column in total trunk forward performance. Several authors (Jackson and Langford, 1987; Minkler and Patterson, 1994; Liemohn *et al.*, 1994) have reported that trunk forward flexion measured by the sit-and-reach test is not a criterion related to the validity for measuring the lumbar spine flexion. Liemohn *et al.*, (1994) who measured the low back flexibility by inclinometer test described by Mayer *et al.* (1984) found a weak correlation (r=.29 and r=.40) in males and females respectively, between sit-and-reach test and ROM of the lumbar spine flexion. A similar relation was reported by Minkler and Patterson (1994) when they determined the low back flexibility by the skin distraction method (modified Schober test), but for the females' group have the correlation coefficient r=.25 and for the males' group r=.40. The latter-mentioned results have been confirmed by the findings of the present study. The correlation coefficients were similar (r=.28 and r=.48) in girls (n=57) and boys (n=69) respectively between spinal flexion and trunk forward flexion in a standing position. An explanation for the poor relation in females may be that lumbar spine ROM, as reported by Batti'e *et al.* (1987) at the age of 20–29 year old age group was less for women than for men.

Trunk forward flexion from the standing position is produced by the moment of the upper body weight and controlled by eccentric contraction of the erector spinae, gluteus maximus and medius, and hamstring muscles. A different condition exists for the sitting position, where less active muscle control is required to maintain this posture. The total trunk forward flexion in sitting position has higher values than in standing position in all the observed groups (Table I, Paper II; Table I, II, Paper III). To compare these values, it is important to mention that the trunk and lower extremities are posed in angle 90° in sitting position. ROM of the spinal flexion decreases about 20 degrees. This can be explained by the different length of muscles which depend on the configuration of body segments. In the sitting position the muscles which are engaged in stabilization of the spine are more contracted due to the body segment configuration and permit a little range of motion. Dvorak *et al.* (1991) have noted that maximal lumbar flexion cannot be achieved when the subject is sitting. However, the influence of the spine flexion on total trunk forward flexion in sitting position is higher (r=.61–.79 correlation coefficients in observed nonathletes groups) than in standing position. The higher correlation coefficients between these variables were also found in adults (Table II, Paper II). This finding may be a reasonable explanation for results of the authors who reported that lumbar range of the spine as measured in standing position bore little relation to the outcome of the trunk forward flexion in sitting position (sit-and-reach test). Therefore, it is assumed to be more adequate to measure the ROM of the spine in sitting position, to clarify its role in total forward performance measured by sit-and-reach test.

The used method of the present study allowed to determine the extent of the hip and spinal flexion ROM in total trunk forward flexion. On the base of the presented data (Table I, Paper II; Table I, II, Paper III) the calculated percentage of the different components showed that trunk forward flexibility is approximately 60% attributable to the hip joint flexion and 40% to spine flexion in standing position. In sitting position, the share of the hip joint ROM in total trunk forward flexion increases approximately to 80% and spinal flexion decreases to 20%. In spite of the relatively higher correlation between the spine flexion ROM and trunk forward flexion, this calculation gives preference to use standing position for trunk forward flexion as it consists more spine flexion ROM, and therefore may be more informative to estimate the spinal mobility than the sitting position. Age related difference between the observed untrained girls was not statistically significant, although the more flexible trend was followed in older girls at the age of 13–14 years. Differences in trunk forward flexion between untrained girls and gymnasts at age of 8–9 years was significant and it mainly depended on the increased hip ROM flexion, as no changes in the spine ROM flexion were followed. It is noteworthy that the ROM of the spine remained stable in the both sex groups at different ages. Most studies conducted with older population have shown that increased age results in a greater loss of motion of the spine than of the peripheral joints. In general, increasing age is associated with a decrease in cervical, thoracic and lumbar motion (Moll and Wright, 1971; Einkauf *et al.*, 1983; Dvorak *et al.*, 1992; Dopf *et al.*, 1994). According to the results of the present study, this statement is not valid for the younger population at the age of 8–14 years. No significant differences in ROM of the spine flexibility between the observed age groups were found. Also, no significant correlation between lumbar ROM and age was found by Ensik *et al.* (1996). However, a small number of subjects (n=29) with chronic low back pain was studied. Some authors (Moll and Wright, 1971; Thomas *et al.*, 1988) have reported the increasing of the trunk forward flexion among the teenagers up to 18 years, but the results of Steen Bekkers (1993) revealed a decreasing process. The results of this study support the increasing of the trunk forward flexion among the teenagers. The mean values of the hip joint and spine ROM of all children groups allow to assume that the improvement of the flexibility is possible via the enhancing procedure of the hip joint. The comparison of the components of the trunk forward flexion of the untrained girls with the same values of the gymnasts also indicates the fact that high results in trunk forward flexion are caused by the increased ROM of hip joint.

To sum up, with the help of this method, it is possible to determine simultaneously the ROM in the hip and back forward flexion during the trunk forward performance. The results of this study indicated the differences in the component of the range of motion of the hip flexion, whereas the total spine flexion remained stable in all the observed groups at the age of 8–14 years. The information received on the basis of determining the ROM of each joint in trunk forward flexion may be of use in improvement procedure of flexibility. It may contribute to the right selection of young athletes. Preference should be given to the children who inherently have an extensive ROM of spine flexion, as the improvement of trunk forward flexibility occurs mainly in hip joint.

CONCLUSIONS

1. The constructed instrument for measuring the knee extension range of motion, together with the modified sit-and-reach test scores allows us to evaluate the extent of knee extension range of motion in the trunk forward flexion.

2. The method to measure forward flexion with a straight spine and total trunk forward flexion by the gravity goniometer allows us to estimate the components of spine and hip flexion in trunk forward flexion separately. According to the results of the present study the trunk forward flexibility is 60% attributable to the hip joint and 40% to spine flexion.

3. Age-and training-related differences in girls' groups are apparent in hip joint range of motion, but not in spine range of motion.

4. Gender differences in trunk forward flexion among schoolchildren at the age of 8–9 years are apparent in spine flexibility.

5. The reliability and validity of the elaborated methods for assessing the range of motion of different joints allow the rehabilitation professionals to use it in the treatment procedure of injured joint as well as the sport instructors in improvement projects of flexibility.

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LIIGESTE LIIKUVUSE MÄÄRAMINE ETTEPAINUTUSEL

Kokkuvõte

Liigeste liikuvuse mõõtmise vahendeid ja meetodeid hakati välja töötama käesoleva sajandi kahekümnendatel aastatel (Dorinson ja Wagner, 1948). Sellest ajast alates on jätkunud nende täiustamine, et suurendada mõõtmistulemuste täpsust.

Liigeste liikuvus on tähtis nii kindlal spordialal kindlate liigutuste sooritamisel (Sigerseth ja Haliski, 1950; Leigthon, 1957; Kirby *et al.*, 1981; Alter, 1996) kui ka tervise seisundit iseloomustavate kehaliste võimete testide seisukohast (Corbin ja Noble, 1980; Shephard *et al.*, 1990). Üheks kasutatavamaks painduvustestiks on ettepainutustest, mis iseloomustab kompleksselt paljude liigeste (lülisammas, puusaliiges) liikuvust ja alajäsemete tagumise rühma lihaste venitatavust (Wells ja Dillon, 1952; de Vries, 1978; Shephard *et al.*, 1990). Ettepainutustest on koolinoorte ja täiskasvanute EUROFITi testide kompleksis (Adams, *et al.*, 1993; Oja and Tuxworth, 1996). Ettepainutustest, selle seos üksikute liigeste liikuvusega, lihaste venitatavusega, antropomeetriliste näitajatega on olnud paljude uuringute objektiks (Wells ja Dillon, 1952; Broer Galles, 1958; de Vries, 1978; Jackson ja Baker, 1986; Jackson ja Langford, 1989; Hoeger *et al.*, 1990; Shephard *et al.*, 1990; Hopkins ja Hoeger, 1992; Cornbeet ja Woolsey, 1996).

Vaatamata mitmesugustele ettepainutustestiga uuritud seostele puuduvad andmed, mis iseloomustaksid üksikute liigeste liikuvust ettepainutusel. Üksikute liigeste liikuvuse määramine ettepainutuse sooritamisel võimaldaks hinnata nende osatähtsust painutuse tulemuses. Ettepainutuse suurendamiseks oleks eelkõige otstarbekas selgitada liiges, kus liikuvus on rohkem piiratud.

Käesolevas töös on välja töötatud kaks meetodit liigeste liikuvuse mõõtmiseks ettepainutuse sooritamisel.

Esimene meetod, mis põhineb liigeste liikuvuse mõõtmisel Leightoni (1955, 1957) gravitatsioonigoniomeetriga, võimaldab mõõta selja ja puusaliigese liikuvuse ulatust ettepainutusel.

Teine meetod, mis rajaneb autori konstrueeritud spetsiaalsel mõõteaparaadil, võimaldab mõõta põlveliigese sirutust ja koos modifitseeritud ettepainutustestiga selgitada selle mõju ettepainutusele.

Uurimistöö eesmärgid

1. Välja töötada aparaat põlveliigese sirutuse mõõtmiseks pikkusühikutes ning uurida põlveliigese sirutuse osa ettepainutuse sooritamisel.

2. Välja töötada selja liikuvuse mõõtmise meetod ettepainutusel.
3. Hinnata 8–14-aastaste koolinoorte selja ja puusaliigese liikuvust ning võrrelda neid iluvõimlejate vastavate näitajatega.

Uuritavad ja metoodika

Kokku uuriti 330 vaatlusalust, kellest 209 olid koolinoored ja 121 üliõpilast. Mõõdetud vaatlusalustel ei olnud vigastustest tingitud liigeste liikuvuse piiranguid.

Põlveliigese liikuvust sirutusel mõõdeti spetsiaalselt konstrueeritud aparaadiga, mille usaldatavust kontrolliti eelnevalt vastava uuringuga. Testi korratavuse kontrollil oli mõõtja ja mõõtjate registreeritud mõõtmistulemuste vaheline korrelatsioonikoefitsient vastavalt r=.95 ja .96. Mõõtmisviga ei ületanud 1,9 mm. Eri mõõtjate registreeritud mõõtmistulemuste variatsioooni koefitsient ei ületanud 7%. Selja painduvuse ulatuse määramise testi korral olid mõõtja ja mõõtjate registreeritud mõõtmistulemuste seosed vastavalt r=.93 ja .75 ning variatsioonikoefitsiendid 9,9% ja 12,3%.

Konstrueeritud aparaadiga (joonis 3) registreeriti põlveliigese liikuvus sirutusel (mm), mõõdetuna kanna kõrgusega horisontaaltasapinnast pärast sirutuse sooritamist (joonis 4).

Selja liikuvuse ulatust ettepainutusel määrati gravitatsioonigoniomeetriga mõõdetud ettepainutuse ja puusaliigese painutuse ulatuse vahena.

Uurimistöö tulemused

Töö tulemuste põhjal selgus põlveliigese sirutuse mõju ettepainutuse tulemusele. Põlveliigese sirutuse ulatuse ja ettepainutustesti tulemuse vaheline korrelatsioonikoefitsient r=.40 – .48 (p<.05). Katsed üliõpilastega näitasid, et põlveliigese sirutuse elimineerimisel modifitseeritud ettepainutustestiga vähenesid ettepainutuse tulemused üliõpilastel keskmiselt 2 cm. Neidude ja noormeeste ning 13–14-aastaste tütarlaste ja poeglaste põlveliigese sirutuse ulatuses statistiliselt olulisi erinevusi ei täheldatud.

Selja ja puusaliigese liikuvusele avaldab mõju kehaosade paiknemine üksteise suhtes. Traditsioonilise ettepainutustesti ja gravitatsioonigoniomeetriga mõõdetud ettepainutuse tulemused olid isteasendis suuremad kui algseisust mõõdetuna, kuid statistiliselt olulisi erinevusi ei leitud.

Gravitatsioonigoniomeetriga isteasendis mõõdetud puusaliigese liikuvus painutusel oli kõigil vaatlusalustel suurem kui algasendist mõõdetud. Selja liikuvuse ulatus aga vähenes isteasendis, võrreldes algseisust mõõdetud tulemustega.

Gravitatsioonigoniomeetri kasutamisega selja ja puusaliigese liikuvuse mõõtmisel ettepainutusel selgus, et ettepainutuse tulemusest 60% moodustab puusaliigese liikuvus ja 40% selja liikuvus.

Puusaliigese liikuvus, mõõdetuna algseisust, oli 13–14-aastastel tütarlastel 86,1°±18,6°, mis on statistiliselt oluliselt suurem kui 8–9-aastastel tütarlastel (77,2°±15,7°). Poeglastel olid vastavad näitajad statistiliselt erinevad isteasendis. Selja liikuvuses ei täheldatud tütarlaste ja poeglaste eri vanuserühmades erinevusi.

8–9-aastastel tütarlastel ja poeglastel olid statistiliselt olulised erinevused selja liikuvuses isteasendis, puusaliigeses erinevused puudusid. Traditsioonilise ettepainutustesti tulemused olid tütarlaste vanusegruppides statistiliselt oluliselt suuremad kui poeglaste vastavates gruppides. Selja liikuvuses täheldati statistiliselt olulist erinevust tütarlaste ja poeglaste nooremate vanusegruppide vahel.

Spordiga mittetegelevate 8–9-aastaste tütarlaste liigeste liikuvuse ulatus ettepainutusel erines statistiliselt oluliselt samavanuste iluvõimlejate omast, välja arvatud selja liikuvuse ulatus, mõõdetuna nii alg- kui ka isteasendist.

Arvestades töös kasutatud meetodite korratavust ja eri meetoditega mõõdetud puusaliigese liikuvuse seoseid ning kokkulangevust teiste uurijate vastavate näitajatega, võib töös esitatud meetodeid kasutada üksikute liigeste liikuvuse ulatuse mõõtmiseks ettepainutusel. Nende meetodite kasutamisel on võimalik saada lisainformatsiooni ettepainutusele mõju avaldavatest liigeste liikuvusest eraldi, mida on otstarbekas arvestada nii ettepainutuse suurendamisel kui ka taastusravi efektiivsuse hindamisel.

ACKNOWLEDGEMENTS

I wish to thank:

Professor Toivo Jürimäe for the encouragement to continue scientific work and for helps in preparation the papers.

Associate Professor Arved Vain for my first steps of research works on the field of sport sciences.

Associate Professor, Dean of the Faculty of Exercise and Sport Sciences, Mati Pääsuke for advices in forming the thesis.

Professor Ene Tiit for the consultations in statistical analysis.

My wife, Associate Professor, Helle Hein for moral support in finishing this thesis. Also I am much obliged to her for help in management with different computer programs.

My son Lauri for drawing the illustrations of the thesis.

Mrs. Jeanne Lillo for the English language spelling of the thesis.

PUBLICATIONS

Hein, V.
Knee extension range of motion: limits to sit-and-reach test.
Biology of Sport 1995, 12(3): 189–193.

Biology of Sport Vol. 12, N°3, 1995

KNEE EXTENSION RANGE OF MOTION: LIMITS TO THE SIT-AND-REACH TEST

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The knee extension range of motion was measured in 60 adults (22 men and 38 women) and in 54 children (23 boys and 31 girls) with the use of a self-constructed instrument, which enabled linear measurements. The range of motion of the knee extension was determined in a modified sit-and-reach test in which movements in the knee joint were eliminated. Significantly higher results were recorded in adults than in children. In adults, the test scores decreased by about 2 cm, due to restricting the range of motion. No such decreases were found in children. Correlation coefficient between the range of motion in the knee joint and the results of the sit-and-reach test or with body height, computed for all subjects, were 0.37 and 0.27, respectively. ***(Biol Sport 12:189-193, 1995)***

Key words: Knee - Range of motion - Sit-and-reach test

Introduction

Extensive cross-sectional data on sit-and-reach test scores in male and female subjects of various ages have been reported by many authors [1,4,14,15,17]. Some investigators studied the influence of flexibility of lower back and hip on the results of this test or its modifications [2,3,5,6,7,9,11]. A few reports exist about the relation of the range of the motion in lower limb joints to sit-and-reach test. Sharpe *et al.* [13] reported significantly lower scores (by about 4 cm) when test was performed with ankle dorsiflexion compared to plantaflexion. Kirby [8] and Suni [16] published methods for measuring knee extension, which is a complex movement due to a large number of muscles and tendons of the lower extremity crossing the knee joint. No data exist, however, how the range of motion (ROM) of the knee joint extension affects measurements of sit-and-reach test scores.

The aim of this study was to work out a simple method for measuring the knee extension ROM and to evaluate its effect on the results of the sit-and-reach test modified so as to restrict the ROM in the knee joint.

Material and Methods

Subjects: 114 subjects, aged 11 to 22 years, participated in the study. None of them experienced any injury which might limit movements in that joint. Physical characteristics of the subjects are presented in Table 1.

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Table 1
Physical characteristics of subjects (means ±SD)

Characteristics	Men n=22	Women n=38	Boys n=23	Girls n=31
Age (years)	19.8±2.0	20.5±2.4	13.6±1.8	13.1±1.2
Body mass (kg)	76.3±10.3	61.0±7.5	52.4±13.2	48.6±11.9
Body height (cm)	182.9±5.5	170.6±5.4	164.5±10.6	159.1±8.3

Knee extension: A special instrument was constructed to measure the knee extension (Fig. 1). The design enabled recording the range of motion (ROM) of the knee extension on a linear scale with an accuracy of 1 mm. The measurement plate was placed in a special box fixed to the edge of the measurement table on the same level. The subject remained in sitting position, feet extended and heels placed on the measurement plate. The knee extension ROM was read from the scale and represented the distance between the heel support (measurement plate in zero position) and maximally uplifted heels.

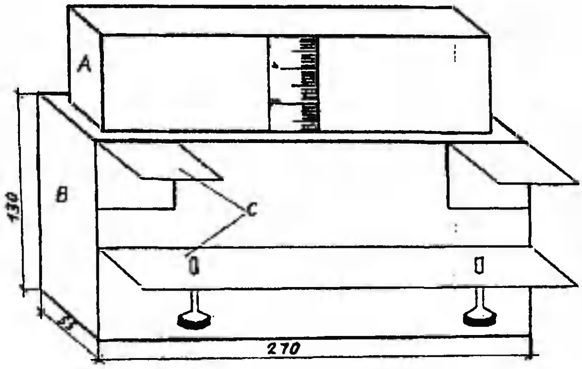

Fig. 1
Instrument for measuring the knee extension mean range of motion
A - Measurement plate; B - Box containing the measurement plate guide; C - Fixing holder

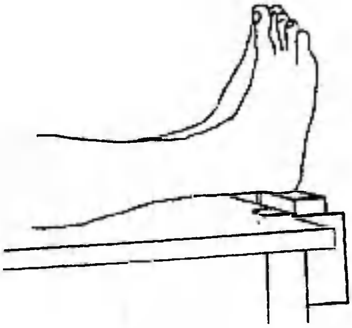

Fig. 2
Positioning subject's feet during the measurement

Reliability of measurements: A pilot study, aimed to estimate the reliability of the knee extension measurement procedure and to determine the within- and between-observer errors, was conducted on 15 subjects. The formula of Malina *et al.* [10] was used to estimate

$$s_d = \sqrt{\frac{\Sigma d_i^2}{2n}}$$

the overall measurement error (in mm), where d_i is the difference between the two measurements on the i-*th* subject. The between-observer error was 1.5, the means ±SD of the two measurement sessions being 30.6±1.7 and 29.9±1.7 and the results of those two sessions being highly correlated ($r=0.95$; $P<0.001$). The corresponding results for the, within-assay error were 1.3, 29,9±1.7 and 30.7±1.7, $r=0.96$, respectively. The within-observer, between-assay error equal to 1.9 was determined from two measurement sessions, one week apart, the means ±SD of the two measurement sessions being 31.3±2.0 and 32.7±1.8, $r=0.95$ ($P<0.001$).

Sit-and-reach test: The subject placed the soles of both feet against the testing box, 0.32 m high. The zero-point of the measurement was taken as the edge of the box. The subject was to reach and hold on for two seconds, feet together and knees fully extending, the range being measured to the nearest half centimeter.

Modified sit-and-reach test: The knee joint extension ROM was previously eliminated by special plates, whose thickness was equal to the ROM of the knee extension, fitted under the heels after the knee extension has been performed. Stabilizing straps were placed around the thighs to prevent associated motions and then the subject performed the traditional forward flexion.

Procedure: All measurements were taken in the same conditions (ambient temperature, time of day). Warm-up exercise consisted of two trials for each measurement procedure. Body height and mass were recorded prior to testing flexibility.

Statistics. Statgraphics program was used to analyze the data. Pearson's correlation coefficients between test scores were computed and regression models constructed. Comparisons were made by the multiple range test. The results were considered significant at $P \leq 0.05$.

Results

Mean values (±SD) of the ROM in observed groups are presented in Table 2. No differences in flexibility were found between male and female groups. Significant differences were found in all observed values between adult and children groups.

Table 2
Mean range of movement (±SD) recorded in male and female groups

Movement	Men (n=22)	Women (n=38)	Boys (n=23)	Girls (n=31)
Knee extension ROM (mm)	34.4±11.3	37.2±15.6	23.3±11.2^{a}	24.0±10.8^{b}
Sit-and-reach (cm)	13.2±7.0	15.1±7.4	4.2±5.6^{a}	9.3±5.9^{b,c}
Modified sit-and-reach	11.2±7.4	13.0±7.0	4.2±5.6^{a}	9.1±5.7^{b,c}
Difference	2.2±1.4	2.0±1.2	0.3±1.3^{a}	0.2±1.7^{b}

Significanly different from the respective value: ^{a} - in men, ^{b} - in women, ^{c} - in boys (all $P<0.05$)

The results of the sit-and-reach test and the ROM of the knee joint were correlated with one another in children (in boys and girls alike; r=0.40) but not in adults. Higher differences between the conventional and modified sit-and-reach test scores were found in adult groups, with no significant differences between men and women (2.04±1.26), than in children. Significant, albeit low correlations computed for all subjects (n=114), were found between the ROM in the knee joint and the results of the sit-and-reach test (r= 0.37) or body height (r= 0.27).

Discussion

The result of the pilot study revealed a high reliability of the constructed instrument. It proved simpler in use and enabled taking measurements faster compared with other methods [8,16]. The method of Suni [16], for determining the knee extension ROM in supine position, with the hip and knee flexed to 90°, is not free from the influence of the hip flexion on knee articulation.

In the present study, significantly higher values (over 10 mm) of the knee extension ROM were found in adults than in children. Moreover, the results recorded in adults, indicated the influence of the knee extension ROM on the sit-and-reach test scores. The results of the modified sit-and-reach test, where the knee extension ROM was eliminated, decreased by about 2 cm compared to the traditional test. Two-fold higher values were recorded by Sharpe *et al.* [13] for the influence of the ankle joint displacement on the results of a modified sit-and-reach test.

Although no differences between scores of the traditional and modified sit-and-reach tests were found in schoolchildren, a significant correlation between the knee extension ROM and sit-and-reach test scores was found (r=0.40, P<0.05). No significant correlation was found in adults. This may be due to the influence of the lower limb length on measurement results, as the body height correlated with the knee extension ROM (all subjects combined, n=114) or to the age-related elasticity of muscles and tendons in the groups studied. Further studies on this subject are thus necessary.

Another question concerns evaluation of the knee extension ROM from the point of view of hyperextension, i.e. possible borderline between the hyperextension and the normal one. Determining this may help predicting knee joint injuries.

In conclusion, the constructed instrument enables measuring the extension ROM in the knee joint and receiving additional information regarding limits of the sit-and-reach test scores. The results obtained may also be useful in conducting an enhanced procedure for determining flexibility.

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Accepted for publication 19.06.1995

II

Hein, V., Jürimäe, T.
Measurements and evaluation of the trunk forward flexibility.
Sports Medicine, Training and Rehabilitation 1996, 7(1): 1–6.

Sports Med., Training and Rehab., 1996, Vol. 7, pp. 1-6
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Amsterdam B.V. Published in The Netherlands by
Harwood Academic Publishers GmbH
Printed in Malaysia

MEASUREMENT AND EVALUATION OF TRUNK FORWARD FLEXIBILITY

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(Received October 10, 1994; accepted August 15, 1995)

Forward trunk flexibility in 39 students (24 men and 15 women) in a physical education faculty was studied using different body positions and testing methods. The test scores of a gravity goniometer and a linear measurement were compared. Trunk flexibility was estimated from components of mobility of the ankle, hip, and vertebral column in different body segment configurations. The flexibility of the vertebral column was calculated from the difference between the measurement of trunk forward flexion and hip flexion. Trunk forward flexion was higher measured in the sitting position than in the standing position measured by both methods. It was established that trunk forward flexibility was attributable to a composite of 60% hip flexion and 40% vertebral column flexibility. The determination of the range of the motion of each joint in trunk forward flexion can be useful in training or rehabilitation procedures.

KEYWORDS: flexion, hip joint, vertebral column, range of motion

Flexibility is commonly accepted as an important component for improving performance during physical exercise and as an important component of overall physical fitness (Corbin and Noble, 1980; Shephard *et al.*, 1990). Several studies have documented the normal range of joint motion for different age groups (Ahlback and Lindahl, 1964; Allander *et al.*, 1974; Boone and Azen, 1979; Einkauf *et al.*, 1987) and athlete groups (Kirby *et al.*, 1981; Leigthon, 1957; Sigerseth and Haliski, 1950). The most frequently used method for evaluating trunk flexibility is the sit and reach test. This test is quite general because components of ankle flexibility, hip flexibility, vertebral column flexibility, and arm and leg length may all contribute to the result. Hubley-Kozey (1991) proposed assessing flexibility from the angular measurement between adjacent body segments. A number of studies have been made on the range of motion (ROM) in hip and ankle joint. Forward bending is a combination of movements at several joints, making it difficult to determine what is actually being measured. For example, Leger and Cantin (1983) showed that the Cureton, Wells, and Dillon sit and rest tests were not interchangeable and thus were not measures of the same variable.

It is well known that the ROM is influenced by muscles, tendons, ligaments, and bone structure. Johns and Wright (1962) evaluated the relative contribution of tissue components to joint stiffness. The torque required to move the bones of a joint in its midrange was 47% attributable to the joint capsule, 41% to passive motion of muscles, 10% to tendons, and 2% to skin. Tendons contributed a greater proportion at the extreme ROM. Little information exists, however, on how body segment configurations influence measurement of

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hamstring muscle tightness determined by a test of trunk forward flexibility. Sharpe *et al.* (1994) compared the sit and reach test score performed both with ankle dorsiflexion and plantar flexion and reported that it was less with ankle dorsiflexion by approximately 4 cm. Extensive cross-sectional data on trunk forward flexion at various ages have now been obtained from the Canada Fitness Survey (Shephard, 1983, 1986), but it is unclear to what extent the ROM of different joints such as vertebral column and the hip are reflected in the total trunk forward flexion measurement.

The aim of this investigation was to contribute to the understanding of the constituents of the trunk forward flexion measurement and to describe a simple method of estimating the flexibility of the vertebral column. Test scores of the ROM of different joints in total trunk forward flexion allow determination of those joints with insufficient motion and this will be useful information to take into account in any attempt to enhance a person's flexibility.

MATERIAL AND METHODS

Subjects

Thirty-nine students aged 18 to 20 years (24 men and 15 women) from the faculty of physical education participated in the study. They were physically active and no injury prevented their performing the flexibility tests. Informed consent was obtained from each subject beforehand.

Flexibility Measurements

Indirect (linear measurement) and direct (gravity goniometer) methods without the application of external force on a joint were used. A flexibility measurement was taken in the standing, sitting, and supine positions. Forward flexion was measured by a gravity goniometer at two points in the standing and sitting positions. The instrument was fastened to one side of the chest (midaxillary line) at nipple height. A subject was instructed first to bend forward with a straight vertebral column (the first point), which allowed determination of the ROM in the hip joint. A subject then performed a full forward bend (the second point). The difference between the two measures was taken as the flexibility of the vertebral column (vertebral flexion = trunk flexion – hip flexion). For comparison, the ROM in the hip joint measurement in the supine position described by Hubley-Kozey (1991) using the Leighton flexometer was made. The ROM of the ankle joint was measured using the same guideline and Leighton flexometer. Linear measurements were obtained by having the subjects reach and hold for 2 seconds a maximum distance with the feet together and knees fully extended.

All measurements were conducted under the same conditions of temperature, time, type of warm-up exercise, and investigator. The reliability and accuracy of goniometer measurement have been proved by several authors (Boone *et al.*, 1978; Hubley-Kozey, 1991).

Statistics

Standard SYSTAT (statistical package) methods were used to estimate the mean, standard deviation, paired *t* tests, Pearson product-moment coefficients of the correlation between test scores. Statistical significance was defined as $p \leq 0.05$.

RESULTS

The mean and standard deviation of results for several joint movements are presented in Table I. No significant difference was found between the scores of male and female groups except for the ROM of the ankle joint, although the group mean test score of the female group in each measure had a tendency to be higher. Vertebral flexion in the sitting position was more than two times lower than in the standing position. To compare hip flexion and trunk flexion in the standing position with that in the sitting position, the configuration of two body segments (the trunk and lower extremities) must be taken into account. The ROM in the hip joint and trunk is better in the sitting position than in the standing position. For example, trunk flexion in the standing position (137.0 ± 13.5°) is less than that measured in the sitting position (58.3° + 90° = 148.3°) Similar results were obtained from linear measurement of stand and reach (0.132 ± 0.068 m) and in sit and reach tests (0.145 ± 0.076 m). However, the hip ROM and vertebral ROM percent contributions to total trunk flexion were approximately 60% and 40%, respectively, in both positions. The Pearson product-moment coefficient of correlation between test scores is presented in Table II. The coefficient of correlation between the linear and goniometer test scores allowed evaluation of the reliability of the methods used for measuring trunk forward flexion. Test-retest scores recorded in the sitting position had a slightly greater correlation between the repeated measured values than in the standing position. The correlation coefficient between the test-retest scores of hip flexion measured in the standing and sitting positions by linear measurement and gravity goniometer (r = 0.41 and r = 0.43, respectively) was similar to the correlation coefficient between the two methods obtained for the hip flexion ROM measurement in the supine position (r = 0.55)

TABLE I
Flexibility of several joints of students*

Movement	All Subjects (n = 39)	Man (n = 24)	Woman (n = 15)
Standing position			
Hip flexion	83.8 ± 14.2	81.0 ± 13.6	88.1 ± 14.5
Trunk flexion	137.0 ± 13.5	137.1 ± 15.0	136.9 ± 11.0
Vertebral flexion	53.3 ± 15.6	56.1 ± 16.6	48.8 ± 13.0
Sitting position			
Hip flexion	35.3 ± 10.8	32.3 ± 10.8	39.9 ± 9.4
Trunk flexion	58.3 ± 15.7	58.4 ± 13.3	58.2 ± 19.1
Vertebral flexion	24.4 ± 10.0	25.8 ± 10.9	22.2 ± 8.2
Ankle plantar			
Dorsiflexion	24.3 ± 10.3	27.4 ± 11.2	19.3 ± 6.5†
Flexion	52.6 ± 10.5	47.3 ± 9.1	61.1 ± 6.1†
Supine position			
Hip flexion	106.7 ± 14.6	100.7 ± 13.5	116.3 ± 10.9
Stand and reach	0.132 ± 0.068	0.125 ± 0.075	0.144 ± 0.056
Sit and reach	0.145 ± 0.076	0.139 ± 8.3	0.153 ± 0.067

* Numbers are mean and standard deviation and are degrees except for stand and reach, sit and reach, which are in meters.

† Group mean difference between male and female groups is statistically significant ($p \leq 0.05$).

TABLE II

Pearson product moment coefficient of correlation between test scores

	1	2	3	4	5	6	7	8	9	10	11	12
Standing position												
1. Hip flexion	1.000											
2. Trunk flexion	0.368*	1.000										
3. Vertebral flexion	–0.394†	0.529†	1.000									
Sitting position												
4. Hip flexion	0.624†	0.518†	–0.121	1.000								
5. Trunk flexion	0.328*	0.877†	0.460†	0.638†	1.000							
6. Vertebral flexion	–0.253	0.552†	0.709†	–0.255	0.579†	1.000						
7. Ankle flexion	–0.001	0.208	0.180	0.056	0.054	–0.008	1.000					
8. Ankle extension	0.114	0.061	–0.051	0.401†	0.196	–0.165	–0.538†	1.000				
9. Ankle range of motion	0.097	0.290	0.163	0.433†	0.261	–0.134	0.470†	0.442†	1.000			
10. Sit and reach	0.407†	0.671†	0.210	0.562†	0.662†	0.229	0.190	0.246	0.465†	1.008		
11. Stand and reach	0.432†	0.693†	0.205	0.566†	0.716†	0.229	0.174	0.190	0.395†	0.950†	1.000	
12. Hip flexion in supine position	0.325*	0.245	–0.084	0.489†	0.345*	–0.085	–0.165	0.490†	0.321*	0.550†	0.549†	1.000

* $p \leq 0.05$; n = 39.
† $p \leq 0.01$.

DISCUSSION

Current data on flexibility in the hip joint is difficult to compare due to the different methods used and subject variability. According to the results of Ekstrand and Gillquist (1982), passive ROM in hip joint for soccer players ranged from 80.8 ± 7.1° and that of Sigerseth and Haliski (1950) to 93.2° for football players. The group mean test score of ROM in the hip joint obtained by Etnyre and Lee (1988) in 49 men and 25 women (mean age, 20 years, from a university population) lying supine with the hip flexed maximally and knee fully extended were, respectively, 81° and 87°. The same ROM measured by Shephard *et al.* (1990) in subjects performing the movement with a comfortably flexed knee was 107.9 ± 1.2° for men and 115.6 ± 9.5° for women. This confirms the dependence of the ROM on joint configuration due to the degree of alignment of the body segments. However, it is interesting to mention the coincidence of results of the present study of the ROM in the hip joint in the standing position (Table I) and the results reported by Etnyre and Lee (1988). This may be due to the method and instruction disallowing subject flexion of the knee during the measurement procedure.

The total ROM in the ankle joint in men and in women correlated significantly with both linear measurements (stand and reach and sit and reach) (Table II), which is in agreement with the statement about the influence of plantar flexion/dorsiflexion comparative flexibility on the sit and reach test measurement reported by Sharpe *et al.* (1994). These investigators found a significance relationship between the sit and reach test measurement with dorsiflexion and hamstring flexibility. The correlation coefficient between the measurements obtained in the present investigation by gravity goniometer and linear measurement are higher in the sitting position than in the standing position. This is attributable to the average value of the ROM at the hip joint and in total trunk forward flexion (Table I). The more extensive ROM of the hip joint in the sitting position (35.3° + 90°) compared with the standing position (83.8 ± 14.2°) may be explained by the different length of the extensor and flexor muscles of a joint that depends on the position held by the limbs. In the sitting position the muscles engaged to stabilize the standing position are less contracted and submit to a greater forward ROM. The converse condition exists for the ROM allowed in the vertebral column. In the sitting position the ROM of the vertebral column decreases to 24.4 ± 10° from 53.3 ± 15.6° attained in the standing position. This allows an effective hip flexion performance but hinders the ROM in the vertebral column. It is significant to note the increased total trunk forward flexion in the sitting position. However, the results indicate a potential complication of this result caused by movement at several joints and to a complication caused by an increased action of muscles that resist the limb ROM.

Comparison of the measurement units recorded by the gravity goniometer and by linear measurement in both positions showed that the different measurement units were linearly related to each other—10° equaling 1.0 cm. (Table I).

From the present observations, a greater ROM in total trunk flexion is attributable to an increased hip joint flexibility (60%). This fact is vital to enhancing trunk flexibility. It indicates that to improve forward bending an increased flexion primarily in the hip joint is required. To attempt to increase forward flexibility by manipulation of the vertebral column in some way is unproductive and is not acceptable, as it may induce spinal injury. If one were to give more credence to the result of one measurement than the other, it is important to note that the gravity goniometer gives more information about trunk forward flexion than does the linear measurement.

In summary, the results of this study show the effect of the body's angular position on forward flexibility. In the sitting position the test score is highest. Trunk forward flexibility is 60% attributable to the hip joint flexion and 40% to vertebral column flexibility. The difference in angle between these two indicated points, in degrees, during forward bending may be calculated to estimate the functional flexion characteristic of the vertebral column.

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III

Hein, V.
A method to evaluate spine and hip range of motion
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Medicina Dello Sport 1996, 49(4): 379–385.

Editoriale

MED SPORT 1996;49:379-85

A method to evaluate spine and hip range of motion in trunk forward flexion and normal values for children at age of 8-14 years

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The purpose of this study was to evaluate a simple method for assessing the consistence of spinal mobility and hip joint in trunk forward flexion and to determine normal values for young children at the age of 8-14 yrs. The components of trunk forward flexibility in case of 57 girls and 69 boys of ordinary schools and 29 rhythmic gymnasts, trained 1-2 yrs. in a sports club at the age of 8-9 yrs. were studied using gravity goniometer. The flexibility of the spine was calculated from the difference between the measurement of trunk forward flexion and hip flexion in different body positions. It was established that trunk forward flexion was attributable to a composite of 60% hip flexion and 40% spine flexion in standing position. In sitting position the percentage of the spine flexibility decreased to 20%. The total trunk forward flexion measured in standing ano sitting positions was more strongly correlated with the ROM of the spine flexion than with the ROM of the hip flexion in all groups of boys. The conversed relation was followed in girls' groups in the standing position, except the athletes' group. The age related analysis of the results indicated to the differences in the component of the hip flexion ROM, whereas the total spine flexion remained stable in all observed groups. The information received on the basis of determining the ROM of each joint in trunk forward flexion will be useful to take into account in the enhance or rehabilitation procedure of flexibility. It may also help to perform a right selection of young athletes proceeding from the results of flexibility test scores acceptable to certain athletic events.

Key words: Flexion - Hip joint - Spine - Range of motion - Sit-and-reach test.

Flexibility is an important component of physical fitness. Trunk forward flexion measured by the sit and reach test is included to several fitness test batteries, as it provides a simple measure of flexibility in the hip, spine and hamstring muscles.[1]

Trunk flexibility may also have health implications for back problems.[2] Therefore, several authors [3-7] have investigated the relation between low back flexibility and low back pain.

Numerous techniques have been developed to assess spinal flexibility. Skin distraction tests for total spinal flexibility [8] and for lumbar spine [9] [10] have been obtained. The authors of the modified Shober test [10] found high correlation (r=0.97) between skin distraction and radiographic measurements of lumbar spine flexion. Stokes *et al.*[11], who investigated the surface measurements of total lumbar spinal motion and its distribution by vertebral level, reported that surface measurements based on changes in back curvature are complicated since the back surface has a variable relationship

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This study was financially supported by Estonian Science Foundation (Grant NR. 1914).

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with spine shape and an accurate measurement of curvature is very difficult. They found correlation coefficient of r=0.58 between surface and radiographic measures. In addition, several devices, such as inclinometers and spondylometers have been developed for spinal flexibility measurements.[12-14] Although the range of motion (ROM) in lumbar region is most extensive of the vertebral column, the investigators [3-5] [15] have found that lumbar ROM as measured through the modified Schober method [10] bore little relation to the outcome of the sit and reach test. These findings indicated that different tests of trunk forward flexion (sit-and-reach or fingertip-to-floor) are not adequate expressions of spinal flexibility. Biering-Sorenson [16] have noted, that such measures likely reflect mobility at the hips rather than at the spine. However, during the trunk forward flexion an increased spine curvature is followed and consistence of it in anterior flexion is beyond doubt.

Based on a review of the literature, it is still unclear to what extent the ROM of spine contributes to the total trunk forward flexion. The above-mentioned methods for assessing the spinal flexibility do not allow the quantification of its role in the trunk forward flexion. The detection of he consistence of trunk forward flexion allows to receive more information about the flexibility fitness. It is specially important for athletes such as gymnasts requiring good flexibility. Also, it may be useful to estimate the effectiveness of the treatment in rehabilitation procedure.

Therefore, the purpose of this study was to evaluate a simple method for assessing the consistence of spinal mobility and hip joint in trunk forward flexion and to determine normal values for young children and to compare these with results obtained in young rhythmic gymnastic athletes.

Materials and methods

Subjects

A hundred and fifty five school children (69 boys and 86 girls) at the age of 8-14 yrs. were subjects of this study. Twenty-nine of them participated 1-2 years in a special training of rhythmic gymnastic. Informed consent was obtained from each subject beforehand. Students were excluded if they had suffered from any disorder of the spine or lower limbs.

Flexibility measurements.—Indirect (linear measurement) and direct (gravity goniometer) methods without the application of external force on a joint were used. A flexibility measurement was taken in the standing and sitting position. Forward flexion was measured by a gravity goniometer at two points in the standing and sitting position in order to compare of the configuration of body segments influence on the components of trunk forward flexion.

The gravity goniometer, according to the guideline reported by Hubley-Kozey [17] was fastened to one side of the chest (midaxillary line) at nipple height and needle placed to zero. A subject was informed to first bend forward with a straight vertebral column (the first point) which allowed determine the range of motion in the hip joint. The subject then performed a full forward bend (the second point). The difference between the two measures was taken as the flexibility of spine (spine flexion=trunk flexion - hip flexion). For comparison the linear measurements were obtained by having the subjects reach and hold for two seconds a maximum distances with the feet together and knees fully extended.

All measurements were conducted under the same conditions of temperature, time, type of warm-up exercise and investigator.

Reliability of measurement.—A pilot study, aimed to estimate the reliability of the spinal flexibility measurement procedure by the gravity goniometer was conducted on 10 subjects. The intraobserver and interobserver testing was arranged. Intraobserver reliability was determined by 2 measurement sessions with one-week interval. Correlation coefficient between two tests scores of spinal flexibility was

TABLE I.—*Sample means, standard deviations, 0.95 confidence-intervals (CI) for the girls' groups and differences by the Mann-Whitney U-test procedure.*

Parameters	Girls 8-9 yrs. (n=30)		Girls 13-14 yrs. (n=27)		Gymnasts Girls 8-9 yrs. (n=29)	
	X±SD	CI	X±SD	CI	X±SD	CI
Standing position						
hip flexion	77.2°±15.7	71.3-83.1	86.1°±18.6**	78.8-93.5	92.6°±17.6*	85.9-99.2
total trunk flexion	128.4°±12.4	123.8-133.0	137.6°±17.2	130.7-144.4	148.4°±12.2*	143.8-153.0
spine flexion	51.2°±11.8	46.8-55.6	51.5°±15.9	45.2-57.8	56.0°±17.1	49.5-62.5
Sitting position						
hip flexion	22.4°±8.7	19.2-25.7	21.9°±11.9	17.1-26.6	44.4°±10.9*	40.3-48.6
total trunk flexion	54.2°±13.6	49.2-59.3	52.0°±14.16	46.4-57.6	74.6°±11.4*	70.2-78.9
spine flexion	31.8°±12.9	27.0-36.6	30.2°±12.7	25.2-35.2	30.1°±8.9	26.8-33.5
Sit-and-reach (cm)	10.3±4.8	8.5-12.1	10.5±4.7	8.7-12.4	15.3°±3.6*	13.9-16.6

*) Denotes the differences between athletes and nonathletes groups at age of 8-9 yrs; **) Denotes the differences between the groups at age of 8-9 yrs. and 13-14 yrs.

TABLE II.—*Sample means, standard deviations, 0.95 confidence-intervals (CI) for the boys' groups and differences by the Mann-Whitney U-test procedure.*

Parameters	Boys 8-9 yrs. (n=32)		Boys 13-14 yrs. (n=37)	
	X±SD	CI	X±SD	CI
Standing position				
hip flexion	72.7°±20.7	65.2-80.1	80.1°±15.2	75.0-85.2
total trunk flexion	121.7°±16.5**	115.8-127.7	125.4°±16.2**	120.0-130.8
spine flexion	49.1°±21.1	41.4-56.7	45.3°±17.1	39.6-51.0
Sitting position				
hip flexion	18.4°±6.8	16.0-20.9	26.5°±10.3	23.0-29.9*
total trunk flexion	43.6°±9.9**	40.0-47.2	54.5°±13.3	50.0-58.9*
spine flexion	25.2°±8.9**	21.9-28.4	30.0°±13.4	23.5-32.5
Sit-and-reach (cm)	7.0±2.8**	6.1-8.0	5.2±5.3**	3.4-7.0*

*) Denotes the differences between two groups; **) Denotes the differences between the boys and girls groups at the according age (data for girls groups are presented in Table I).

r=0.93. Interobserver reliability was determined by 2 measurement session with 5 min interval. The corresponding correlation coefficient was r=0.75.

Data analysis

The appropriate procedures in the Statgraphics package were used. The results were expressed by the mean±SD. Z value was used to estimate the means of the range of motion at 95% levels of confidence interval. Pearson product moment correlation between test scores were established. The Mann-Whitney U test was used to determine the significant differences between age and sex groups. The $p<0.05$ levels was selected as the criteria of statistical significance.

Results

To obtain normative data for the components of the trunk forward flexion in the young children's population, the means and standard deviation of them were determined. Using these values, estimates of the true population means for girls and boys at the age of 8-14 were derived (Tables I, II). These are the 0.95 confidence intervals (CI) for the population

TABLE III.—*Correlation coefficients between trunk forward flexion measured by gravity goniometer and the components of trunk forward flexion.*

Parameters	Gymnasts 8-9 yrs. n=29	Girls 8-9 yrs. n=30	Girls 13-14 yrs. n=27	Girls 8-14 yrs. n=57	Boys 8-9 yrs. n=32	Boys 13-14 yrs. n=37	Boys 8-14 yrs. n=69
Standing position							
hip flexion	0.40*	0.67***	0.61***	0.66***	0.37*	0.41**	0.40***
spine flexion	0.30	0.15	0.37*	0.28*	0.42*	0.58***	0.48***
Sitting position							
hip flexion	0.68***	0.40*	0.54**	0.47**	0.48**	0.38*	0.51***
spine flexion	0.44*	0.79***	0.61***	0.70***	0.75***	0.70***	0.69***

*) Significant, $p<0.05$; **) Significant, $p<0.01$; ***) Significant, $p<0.001$.

means, that is there is a 95% chance that the true population means lie within the intervals calculated.

Age related significant difference was followed between girls' groups at the age of 8-9 yrs. and 13-14 yrs. in the ROM of hip joint measured in standing position. The comparison of girls' nonathletes and athletes at the same age revealed significant differences between flexibility measurements except the ROM of spine flexion. Age related difference for boys' groups was found for flexibility measurements of the hip and total trunk forward flexion in sitting position, whereas spine flexion ROM difference was not significant.

Sex related differences appeared in the flexibility measurements of the total trunk forward flexion in both positions and the spine flexion ROM difference in sitting position for children groups at the age of 8-9 yrs. In the older groups sex related difference was followed only in total trunk forward flexion measured by gravity goniometer in standing position and by the sit and reach test.

The calculation of the percent contribution of the hip and spine ROM to the total trunk forward flexion in the standing position for all groups showed that approximately 60% belongs to the hip joint ROM and 40% to the spine ROM. In sitting position the percent of the spine ROM flexion decreased to 20%.

The Pearson product-moment coefficient of correlation between trunk forward flexion and the components of it (hip and spine flexion ROM) measured by the gravity goniometer is presented in Table III. The total trunk forward flexion measured in standing and sitting positions was more strongly correlated with the ROM of the spine flexion than with the ROM of the hip flexion in all groups of boys. The conversed relation was followed in all groups of girls in the standing position, except the athletes girls' group, where the hip flexion ROM had higher correlation with total trunk forward flexion. The correlation coefficient of trunk forward flexion with the hip ROM was higher than with spine flexion for athletes girls' group in sitting position.

Discussion and conclusions

The data of the present study on flexibility in the total spine is difficult to compare due to the method used. However, some coincidence is followed with earlier arranged measurements by the authors,[3, 4, 18, 19] who studied the sit and reach test relation to the lumbar spine flexion. A reason for it is that spine is most flexible in lumbar region and therefore its ROM reflects spinal mobility to quite large extent. Although, it is not reasonable to underestimate the role of upper segments of vertebral column in total trunk forward performance. Several authors [4, 18, 19] have reported that trunk forward flexion measured by the sit-and-reach test is not criterion related validity for measuring the lumbar spine flexion, Liemohn *et al.*[18] who measured the low back flexibility by inclinometer test described by Mayer [12] found weak correlation (r=0.29 and r=0.40) in males and females, respectively between sit and reach test and ROM of the lumbar spine flexion. The similar relation was reported by Minkler and Patterson [18] when they determined the low back flexibility by the skin distraction method (modified Schober [9] test), but for the females group have correlation coefficient r=0.25 and for males group r=0.40. The findings of the present study confirmed the latter mentioned results as the correlation coefficients were similar (r=0.28 and r=0.48) in girls (n=57) and boys (n=69) respectively between spinal flexion and trunk forward flexion in standing position. An explanation for the poor relation in females may be that lumbar spine ROM, as reported by Batti'e [15] at the age of 20-29 year old age group was less for women than for men.

Trunk forward flexion from standing position is produced by moment of the upper body weight and controlled by eccentric contraction of the erector spinae, gluteus maximus and medius, and hamstring muscles. Different condition exists for the sitting position, where less active muscle control is required to maintain this posture. The total trunk forward flexion (Tables I, II) has higher values than in standing position (to compare these values it is important to mention that the trunk and lower extremities are posed in angle 90º in sitting position). ROM of the spinal flexion is decreased about 20 degrees. This can be explained by the different length of muscles which depend on the configuration of body segments. In the sitting position the muscles which are engaged in stabilization of the spine are more contracted due to the body segment configuration and permit a little range of motion. However, the influence of the spine flexion on total trunk forward flexion in sitting position is higher (r=0.61-0.79 correlation coefficients in observed nonathletes groups) than in standing position. Also this finding may be a reasonable explanation for results of the authors who reported that lumbar range of the spine as measured in standing position bore little relation to the outcome of the trunk forward flexion in sitting position (sit-and-reach test). Therefore it is assumed to be more adequate to measure the ROM of the spine in sitting position to clarify its role in total forward performance measured by sit and reach test.

The used method of the present study allowed to determine the share of the hip and spinal flexion ROM in total trunk forward flexion. On the base of the data presented in Table I and II calculated percentage of the different components showed that trunk forward flexibility is approximately 60% attributable to the hip joint flexion and 40% to spine flexion in standing position. In sitting position the share of the hip joint ROM in total trunk forward flexion increases approximately to 80% and spinal flexion decreases to 20%. In spite of the relatively higher correlation between the spine flexion ROM and trunk forward flexion this calculation gives preference to use standing position for trunk forward flexion as it consists more spine flexion ROM and therefore may be more informative to estimate the spinal mobility than the sitting position.

Age related difference between observed nonathletes girls' groups was not statistically significant, although the more flexible trend was followed in girls' groups at the age of 13-14 yrs. Differences between nonathletes girls' groups and gymnastic girls' group in trunk forward flexion was significant and it mainly depended on the increased hip ROM flexion, as no changes in the spine ROM flexion were followed. It is noteworthy that the ROM of the spine was remained stable in the both sex groups at different ages. Most studies conducted with older population have shown that increased age results in a greater loss of motion of the spine than of the peripheral joints. In general, increasing age is associated with a decrease in cervical, thoracic and lumbar motion.[22-26]

According to the results of the present study this statement is not valid for the younger population at the age of 8-14 yrs. No significant differences in ROM of the spinal mobility between the observed age groups were found. Some authors have [26] reported the increasing of the trunk forward flexion among the teenagers up to 18 yrs., but the results of Bekker [27] revealed a decreasing process. The results of this study support the increasing of the trunk forward flexion among the teenagers. The mean values of the hip joint and spine ROM of all groups allow to assume that the improvement of the flexibility is possible via the enhancing procedure of the hip joint. The comparison of the components of the trunk forward flexion of the nonathletes girls' groups with the gymnastics girls' group indicates also to the fact that high results in trunk forward flexion had taken place due to the increased hip flexion caused by the training procedure.

In summary, the used method of the investigation allowed to determine simultaneously the range of motion in the hip and back forward flexion during the trunk forward performance. The results of this study indicated the differences in the component of the range of motion of the hip flexion, whereas the total spine flexion remained stable in all observed groups at the age of 8-14 yrs. The information received on the basis of determining the ROM of each joint in trunk forward flexion may be useful in improvement procedure of flexibility. It may also help to perform right selection of young athletes. Preference should to give to the children, who have inherently an extensive ROM of spine flexion, as the improvement of trunk forward flexibility occurs mainly in hip joint.

Acknowledgements.—The author thank the teacher of the physical education and administration of schools of Tartu for permission to arrange the measurement procedure.

Riassunto

Un metodo per valutare il campo motorio della colonna vertebrale e dell'anca nella flessione del tronco in avanti e i valori normali per bambini di età compresa tra 8 e 14 anni.

Lo scopo del presente studio è stato quello di elaborare una metodologia semplice per la valutazione dell'entità della mobilità della colonna vertebrale e della giuntura dell'anca nella flessione del tronco in avanti e di determinare i valori normali per i bambini di età compresa tra 8 e 14 anni. Usando il goniometro e gravità sono stati studiati i componenti della flessibilità del tronco in avanti in 57 bambine e 69 bambini dei normali corsi scolastici e in 29 ginnasti ritmici allenati per 1-2 anni presso associazioni sportive all'età di 8-9 anni. È stata calcolata la flessibilità della colonna vertebrale in base alla differenza tra le misure relative alla flessione del tronco in avanti e alla flessione dell'anca eseguite in differenti posizioni del corpo. Si è stabilito che nella posizione in piedi la flessione del tronco in avanti è attribuibile per il 60% alla flessione dell'anca e per il 40% alla flessione della colonna vertebrale. Nella posizione da seduti la flessibilità della colonna vertebrale si riduceva al 20%. Per tutti i gruppi di bambini la flessione totale del tronco in avanti nelle posizioni in piedi e seduti era correlata più al campo motorio della flessione della colonna vertebrale che a quello della flessione dell'anca, mentre, a pane il gruppo di atleti, per i gruppi di bambine nella posizione da sedute si è verificato l'opposto. L'analisi dei risultati realizzata in funzione dell'età ha indicato delle differenze nel campo motorio della flessione dell'anca, mentre la flessione totale della colonna vertebrale è rimasta stabile per tutti i gruppi in osservazione. Le informazioni ottenute in base alla determinazione del campo motorio di ogni giuntura nella flessione del tronco in avanti saranno utili nei procedimenti riabilitativi o nei trattamenti finalizzati al miglioramento della flessibilità, come pure nella selezione dei giovani atleti in base al punteggio delle prove di flessibilità richieste da determinati eventi agonistici.

Parole chiave: Flessione - Giunture dell'anca - Colonna vertebrale - Campo motorio - Prova di allungamento da seduti.

Resumen

Un método para valorar el radio de movimiento de la columna vertebral y de la cadera en la flexión del tronco hacia adelante y los valores normales para niños en edades comprendidas entre 8 y 14 años.

El objetivo de este estudio es valorar un metodo sencillo para apreciar la consistencia de la movilidad de la columna vertebral y de la articulación coxofemoral en la flexión del tronco hacia adelante y determinar los valores normales para los niños en una edad comprendida entre los 8 y los 14 años. Se estudiaron los componentes de la flexibilidad del tronco en la flexión hacia adelante en el caso de 57 niñas y 69 niños de colegios de enseñanza obligatoria y 29 gimnastas rítmicos, que habían entrenado durante 1 ó 2 años en clubs deportivos a los 8 ó 9 años de edad, utilizando un goniómetro de gravedad. La flexibilidad de la columna vertebral se calculó a partir de la diferencia entre la medición de la flexión del tronco hacia adelante y de la flexión de la cadera en varias posturas corporales. Se determinó que la flexión del tronco hacia adelante puede atribuirse en un 60% a la flexión de la cadera y en un 40% a la flexión de la columna vertebral estando de pie. Sentados, el porcentaje de la flexibilidad de la columna se redujo un 20%. La flexión total del tronco hacia adelante medida de pie y sentados estaba relacionada más con el radio de movimiento de la flexión de la columna vertebral que con el radio de movimiento de la flexión de la cadera en todos los grupos de chicos. Se hizo la relación inversa en los grupos de chicas en posición erguida, excepto en los grupos de atletas. El análisis de los resultados realizado en función de la edad indicaba la diferencia en el componente del radio de movimiento de la flexión de la cadera, mientras que la flexión total de la columna vertebral permanecía estable en todos los grupos observados. Convendrá tener en cuenta la información recibida sobre la base de determinar el radio del movimiento de cada articulación en la flexión del tronco hacia adelante en el aumento o rehabilitación de la flexibilidad. Esta información también puede ayudar a realizar una selección correcta de los jóvenes atletas en función de los resultados de puntuación conseguidos en las pruebas de flexibilidad y que son aceptables para ciertos deportes.

Palabras clave: Flexión - Articulación coxofemoral - Columna vertebral - Radio de movimiento - Tests de flexiones hacia adelante sentados en el suelo.

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Hein, V.
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In: *Armstrong, N., Kirby, B., Welsman, J. ed. Children and Exercise XIX*,
London, E & Spon; 1997: 331–334.

EXTENSION AND HYPEREXTENSION OF THE KNEE JOINT AMONG YOUNG CHILDREN

Knee joint mobility of children

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Keywords: Extension, hyperextension, knee joint

Introduction

A distinction is made between the terms "extension" and "hyperextension". Extension is used when the motion opposite to flexion, at the zero starting position, is a natural motion. As the motion opposite to flexion at the zero starting position is an unnatural one, it is referred to as hyperextension[1]. However, the problem is how to determine which range of motion (ROM) is unnatural and which is natural, specially in joints with restricted extension ROM as the knee joint.

Young children typically have some degree of knee extension. Wynne-Davies[2], in a study of 3000 Edinburgh children, noted that 15% of the 3-year-old children could extend their knee beyond 10°, but this degree of extension was observed in <1% at age 6 y. Cheng et al.[3] reported a greater degree of knee extension in a study of 2360 Chinese children, but again, extension decreased as the children became older, averaging 16° ± 9 at age 3 y compared to a mean of 7° ± 9 by age 10 y. Daniel and Anderson[4] have evaluated the knee extension ROM for the same age group at 3° or lower as normal and 3-5° as nearly normal. The value higher than 6° was observed as abnormal. From this point most of the children at age of 10 y according to the results reported by Cheng et al.[3] have hypermobility of the knee joint.

Goniometry is a technique commonly used in physical therapy for assessing the limitation of a patient's joint motion. The reliability of goniometer measurements has been found by Boone et al.[5] to be with intratester variation of 4°. According to the results of Rothstein et al.[6] intertester reliability of goniometer measurements of passive motion of knee extension is low (r = 0.63 to 0.70). A little bit higher reliability values (r = 0.85) for measurements of active motion of knee extension have been recorded by Clapper and Wolf[7]. The measurement of knee extension ROM using the

Children and Exercise XIX. Edited by Neil Armstrong, Brian Kirby and Joanne Welsman.
Published in 1997 by E & FN Spon, 2–6 Boundary Row, London, SE1 8HN.
ISBN 0 419 22100 X.

linear measurement method by the special constructed instrument[8] showed higher intratester and intertester reliability r = 0.95 and r = 0.96, respectively. Axe et al.[9] measured the hyperextension of the knee joint, when the patient was in a supine position, the knee maximally extended, and the foot in a neutral position. The distance from the posterior border of the heel to the table in centimeters after the knee extension performance was recorded. Repeated testing of the knee hyperextension of 20 injured and healthy knees demonstrated an intraclass correlation coefficient of r = 0.94. The results of this study[9] demonstrated that individuals with anterior cruciate ligament injuries whose knees hyperextended 3 cm or more sustained significantly more joint damage at the time of injury than in those whose knees hyperextended less than 3 cm. So, hypermobility may be the risk factor for knee injuries.

The purpose of this study was to evaluate using the linear measurement procedure the knee extension ROM from the point of hyperextension, i.e. possible borderline between the hyperextension and the normal one among young children.

Methods

A hundred and fifty seven children at the age of 8-14 y participated in this investigation. Informed consent was obtained from each subject beforehand. No subjects had limitation of knee joint movement due to injury.

The knee extension ROM was measured using the special instrument constructed in Tartu University[8]. The design enabled recording the ROM of knee extension on a linear scale with an accuracy of 1 mm. The measurement plate was placed into a special box, fixed to the edge of the measurement table, on the same level. The subject was in sitting position, feet extended and heels on the measurement plate. The up-movement of the measurement plate during the knee extension performance takes place due to the pressure of the springs constructed inside the instrument. The knee extension ROM was read from the scale on the uplift measurement plate and expressed the distance between the heel support (measurement plate in zero position) and maximally uplifted heels. The fixing screw enabled the height of the measurement plate at the end of the knee extension performance to be fixed.

Calf length was measured as the projected length, which was vertical distance from the proximal surface of the tibia to the sole of the foot, according to the method of Martin et al.[10].

All measurements were taken in the same conditions: temperature, time, warm-up exercises including two initial practice attempts for each measurement procedure. No external force was used in any measurements.

The appropriate procedures in the Statgraphics package were used. The results were expressed by the mean ± SD. Z value was used to estimate the means of the range of motion at 95% levels of confidence interval. Pearson product moment correlations between test scores were established. The Mann-Whitney U test was used to determine the significant differences between age and sex groups. The $p < 0.05$ level was selected as the criteria of statistical significance.

Table 1. Knee extension ROM and calf length of young children

Age (y)	Girls 8-9 n=30	 11-12 n=29	 13-14 n=27	Boys 8-9 n=25	 11-12 n=17	 13-14 n=29
Calf length (mm)	419.7±21.4	502.1±45.1	511.5±24.2	423.0±13.8	493.5±24.9	523.4±28.4
ROM (mm)	12.6 ± 6.8	13.5 ± 9.2	15.2 ± 11.8	9.2 ± 2.9	14.2 ± 10.5	14.3 ± 7.1
95% CI	10-15	10-17	11-20	8-10	9-20	12-17

Values are mean ± SD and 95% confidence interval (CI)

Results

The values of the range of motion of knee extension recorded by the constructed instrument in mm and the calf length of the observed age and sex groups are presented in table 1.

A weak relationship between calf length and knee extension ROM in mm of all the subjects was $r = 0.16$ ($p < 0.05$). Age related changes in knee extension ROM occurred only in boys groups, where statistically significant differences were followed by the group at the age of 8-9 y and older groups.

Discussion

The limitation of linear measurement is its dependence on segment length[11]. The mean calf length of all the subjects ($n = 157$) in this study varied only about 10 cm and therefore the correlation found between the ROM of knee extension and segment length was weak ($r = 0.16$, $p < 0.05$). Comparison of knee extension ROM in mm of young children with previous literature is difficult as the ROM has previously been determined in degrees. However, the values of calf length in mm and ROM of knee extension in mm allow the calculation of theoretical angle in degrees and to compare to some extent these with the results obtained previously by other authors. The calculation of knee extension ROM in degrees by the formula tan α of the rectangular triangle, where one of the two sides of the triangle was the distance from the bottom of the upraised heels to the initial position of the measurement plate and the other calf length, gives the angle about 1° 38′. It is 5 times lower than the values recorded by Cheng[3] but consistent to some extent with values offered by Danile and Anderson[4], who have evaluated the knee extension ROM at 3° or lower as normal at this age.

The upper limits of 95% confidence interval for all groups did not exceed the value of 20 mm. Therefore the value of knee extension ROM over 20 mm may be observed as hyperextension among children at age of 8-14 y. On the basis of these values the calculated angle of the hyperextension of knee is equal to the 2° 24′. It is inconsistent with values stated by Danile and Anderson[4]. They reported the knee extension ROM higher than 6° as abnormal. From this statement most of the children at age of

10 y according to the results reported by Cheng et al.[3] would have hypermobility of the knee joint. The investigation of Axe et al.[9] showed that subjects at age of 24 ± 9 years with knee extension ROM over 30 mm had sustained significantly more joint damage at the time of injury than those whose knees hyperextended less than 30 mm. The greater values in the adult group may be explained by their greater calf length. On the basis of this study knee extension ROM greater than 20 mm may be assumed to be a risk factor of knee joint injury for children at age of 8-14 y.

Conclusion

The values over 20 mm of knee extension ROM for young children at age of 8-14 y may be observed as hypermobility of the knee joint.

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Journal of Sport Rehabilitation 1998, 7(1): 61–68.

Journal of Sport Rehabilitation, 1998, 7, 61-68

Comparison of a New Linear Instrument and the Gravity Goniometer for Assessing Knee Extension ROM Among Children

Vello Hein

The purpose of this study was to compare knee extension range of motion (ROM) as measured by a newly constructed linear instrument and by a gravity goniometer among children ages 8–14 years and to establish normative values for these children. The linear instrument recorded the distance in millimeters from the border of an uplifted heel to the measurement table. Coefficients of variation for knee extension were lower when linear measurement was used than with the gravity goniometer. The Pearson product moment correlation coefficient between the two methods of knee extension ROM was $r = .79$ ($p < .001$). Mean knee extension ROM was 13.2 ± 8.5 mm, or 2.8 ± 1.9°. Results of this study indicated that the constructed instrument was appropriate for assessing knee extension ROM and may be considered for use by rehabilitation specialists.

Two methods of assessing joint motion—direct (angular measurement) and indirect (linear measurement of distances between segments or from an external object)—have been used throughout the medical profession to assess dysfunction, determine rehabilitation progress, and evaluate treatment effectiveness. However, many clinicians prefer angular measurement techniques because they do not depend on the length of body segments.

The objective assessment of ROM depends on both reliability and validity of the measurements. The reliability of goniometric measurements has been documented by several authors (3, 5, 6). Boone et al. (1) determined that reliability was greater for upper extremity motion than for lower extremity motion. Rothstein et al. (14) found low intertester reliability of goniometric measurements of passive knee extension ($r = .63–.70$). Slightly higher reliability values ($r = .85$) for measurements of active knee extension were recorded by Clapper and Wolf (3). Boone et al. (1) found the reliability of goniometric measurements to have an intratester variation of 4°. They noted that joint motion should differ by at least 5° before a

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true increase or decrease in joint motion may be recorded. Knee extension ROM is relatively small, ranging from 16 ± 9° at age 3 to 7 ± 9° at age 10 (2). Roaas (13) recorded –2 ± 3° for healthy adult males, whereas Watkins et al. (15), studying 43 adults age 18–80 years, recorded a knee extension ROM of –12 ± 14°. Based on the results of Boone et al. (1), goniometric measurement of knee extension ROM may be unreliable in regard to assessing treatment effectiveness.

To date, no studies have compared the values of direct and indirect ROM measurement methods. Only a few articles have provided information about the different types of goniometer used to measure knee extension ROM. Clapper and Wolf (3) did not find that the electronic goniometer was more accurate than the standard goniometer. Watkins et al. (15), in comparing visual estimation and goniometric measurement of knee extension, concluded that visual estimates of knee passive ROM added slightly more error to the clinicians' measurements than those taken with a goniometer.

Therefore, the aim of this study was to determine knee extension ROM using a linear measurement instrument and to compare these values with (a) goniometric measurements and (b) theoretically calculated values among children ages 8–14 years.

Method

Subjects

One hundred and fifty-seven children 8–14 years of age participated in this investigation. Some of their physical characteristics are shown in Table 1. Informed consent was obtained from each subject beforehand. No subject had limitation of knee joint movement due to injury.

Table 1 Subject Characteristics

	Height (cm)		Calf length (mm)	
Age group (years)	*M*	*SD*	*M*	*SD*
Girls				
8–9 (*n* = 30)	134.5	5.7	419.7	21.4
11–12 (*n* = 29)	156.5	7.5	502.1	45.1
13–14 (*n* = 27)	163.0	6.2	511.5	24.2
Boys				
8–9 (*n* = 25)	133.8	4.8	423.0	13.8
11–12 (*n* = 17)	154.2	6.6	493.5	24.9
13–14 (*n* = 29)	161.2	8.3	523.4	28.4

Procedure

Linear Measurement. A special instrument was constructed to measure knee extension (8) (Figure 1). The design enabled knee extension ROM to be recorded on a linear scale with an accuracy of 1 mm. The measurement plate was placed into a special box, fixed to the edge of the measurement table. The subject was seated with the knees extended and the feet in a neutral position with heels on the measurement plate. The distal segment of the femur was stabilized with a Velcro band on the measurement table. Knee extension ROM was read from the scale and expressed as the distance between the heel support (measurement plate in zero position) and maximally uplifted heels. The upward movement of measurement plate A, during the knee extension performance, was due to the pressure of springs constructed inside the instrument. The fixing screw D enabled the height of the measurement plate to be fixed at the end of the knee extension performance.

To estimate the reliability of the knee extension measurement procedure, intra- and interobserver testing was arranged in a previous study (8) on 15 students of physical education between the ages of 18 and 19. An analytic equation by Malina et al. (10) was used to estimate the technical error of measurements in millimeters. There was a calculated intertester error of 1.46 mm, and the Pearson product moment coefficient of correlation between two sessions was $r = .95$ ($p < 0.001$). The corresponding result for intratester intrassay error was 1.26 and $r = .96$ ($p < .001$). Intratester interassay error of 1.85 was determined during two measurement sessions separated by 1 week, and the correlation coefficient between sessions was $r = .95$ ($p < .001$).

Angular Measurement. A gravity goniometer was used to determine the angle of the knee extension (ROM). The goniometer was fastened according to the guidelines reported by Hubley-Kozey (9). The reliability and accuracy of goniometer measurement have been demonstrated by several authors (1, 3, 5, 6, 14, 15).

Theoretically Calculated Angle of the Knee Extension. Calf length was measured as projected length, which was the vertical distance from the proximal surface of the tibia to the sole of the foot in the sitting position with 90° between the thigh and calf, according to the method of Martin et al. (11). Calf length was evaluated as one of the two small sides of a right triangle. The other side of the

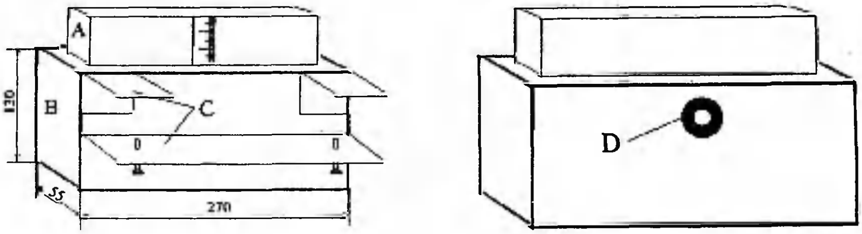

Figure 1 — Instrument for measuring knee extension ROM. A = measurement plate, B = box containing the measurement plate guide, C = fixing holder, D = fixing screw.

right triangle formed the distance from the bottom of the upraised heels to the initial position of the measurement plate. According to the tan α formula, the angle was calculated and observed as the theoretical calculation of the knee extension ROM in degrees (Figure 2).

All measurements were taken in the same conditions: temperature, time, and warm-up exercises (including two initial practice attempts for each measurement procedure). No external force was used in any measurement. Body height and calf length were recorded before knee extension ROM was tested.

Data Analysis

The appropriate procedures in the Statgraphics package were used. The results were expressed as mean ± *SD*. The *Z* value was used to estimate the mean of ROM at the 95% level of confidence interval. Pearson product moment correlations between test scores were established. The Mann-Whitney *U* test was used to determine significant differences between age and sex groups. The $p < .05$ level was selected as the criterion of statistical significance.

Results and Discussion

The values for knee extension ROM recorded by a newly constructed instrument in millimeters and by a gravity goniometer, and the differences of those values between age and sex groups, are presented in Table 2. Coefficients of variance of the values of knee extension were low using linear measurement for all groups except girls age 13–14 years. The Pearson product moment correlation coefficient between the two different methods of assessing knee extension ROM was $r = .79$ ($p < .001$). There was a weak relationship between calf length and knee extension ROM in millimeters of all the subjects ($r = .16$, $p < .05$). Table 3 shows the range limits of knee extension ROM of the observed age and sex groups at the 95% level of confidence. In most of the observed groups, the range of limits increased as age increased.

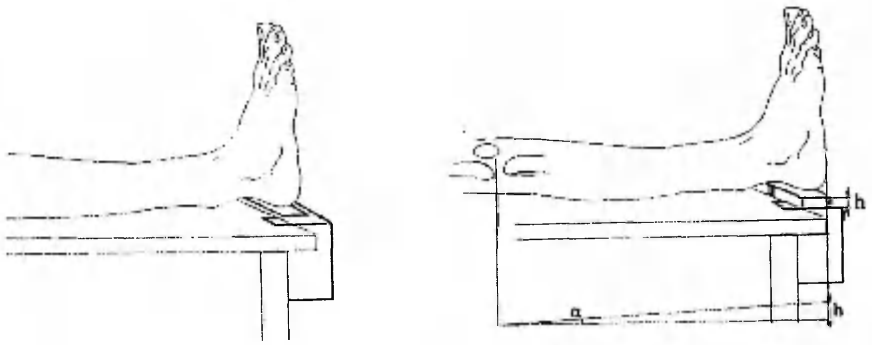

Figure 2 — Positioning a subject's feet during the measurement of knee extension range of motion in millimeters.

Table 2 Means, Standard Deviations, and Coefficients of Variance Obtained by Linear Measurement, Gravity Goniometer Measurement, and Calculated Angle of the Knee Extension ROM

	Linear measurement (mm)			Gravity goniometer measurement (°)			Calculated angle (°)		
Age group (years)	*M*	*SD*	CV%	*M*	*SD*	CV%	*M*	*SD*	CV%
Girls									
8–9 (*n* = 30)	12.6^a	6.8	54.2	2.6	1.8	68.2	1.7^a	0.95	55.0
11–12 (*n* = 29)	13.5^a	9.2	68.4	2.4	2.1	86.8	1.5	1.0	68.5
13–14 (*n* = 27)	15.2	11.8	77.2	3.4^b	2.2	63.4	1.7	1.3	76.2
Boys									
8–9 (*n* = 25)	9.2	2.9	31.2	2.5	0.92	36.4	1.2	0.3	30.9
11–12 (*n* = 17)	14.2^a	10.5	74.1	3.0	2.4	79.9	1.6	1.2	72.7
13–14 (*n* = 29)	14.3^a	7.1	49.7	2.9	1.9	63.1	1.5^a	0.7	48.5
Total (*n* = 157)	13.2	8.5	64.6	2.8	1.9	68.1	1.6	1.0	61.9

Significantly different from the respective value ^{a}in boys age 8–9 years, ^{b}in girls age 11–12 years, by Mann-Whitney *U* test.

Table 3 95% Confidence Interval for Knee Extension ROM in Millimeters

Age group (years)	Knee extension (mm)
Girls	
8–9	10–15
11–12	10–17
13–14	11–20
Boys	
8–9	8–10
11–12	9–20
13–14	12–17

Results of this study reveal that knee extension arc was limited and, therefore, any error might be magnified. In a pilot study (8), the same linear instrument as used in the present study demonstrated a high intertester reliability (r = .95) with low intertester error (1.46 mm). This measurement procedure didn't require determination of anatomical landmarks, and the procedure took little time. Rothstein et al. (14) found a relatively poor intertester reliability intraclass correlation coefficient (r = .63–.70) for different types of goniometric measurements of passive knee extension ROM. A slightly higher value (r = .86) was reported by Watkins et al. (15), who noted that this may have been due to difficulties in determining the anatomical landmarks in patients and that the knee extension itself may be highly labile and therefore hard to quantify.

The results of the present study indicated the superiority of the linear instrument in assessing knee extension ROM in millimeters, because the coefficient of variance of the measured values was lower for all the subjects than the coefficient of values recorded with the gravity goniometer. Additionally, differences in knee extension ROM between age and sex groups were demonstrated. To assess ROM of knee extension that is relatively small, linear measurement appears to provide more accurate results. The large standard deviation found in the present study, and those reported by Cheng et al. (2), may have been caused by the wide range of knee extension ROM exhibited by individuals. The correlation coefficient between indirect and direct knee extension ROM obtained by the linear measurement instrument and a gravity goniometer was r = .79 (p < .001). Clapper and Wolf (3) found a weak negative relationship (r = –.33) between the standard and the electronic goniometer when using both to measure knee extension ROM. The authors noted that this was because two different numerical scales were used for the measurement as well as different measurement procedures. They used a standard goniometer to assess knee extension ROM from full extension but used an electronic goniometer from full flexion to extension. Considering the relatively strong correlation (r = .79) between the values recorded using two instruments in the present study, the linear instrument may be an alternative method to the commonly used goniometer.

The limitation of linear measurement is its dependence upon segment length (9). The calf length of all the subjects ($N = 157$) in this study varied only about 10 cm, and therefore the correlation between knee extension ROM and segment length was weak ($r = .16$, $p < .05$). Measuring both calf length and knee extension ROM in millimeters allowed the theoretical angle to be calculated in degrees and compared with the results obtained by a gravity goniometer. The calculated angle of the knee extension ROM was lower in all groups than the angle recorded with the goniometer. The discrepancy may be due to the measured calf length being not exactly equal to the distance from the point of rotation of the knee joint to the point of support at the heel, which was used as the value of one side of the triangle.

The linear instrument recorded age-related changes in knee ROM for the boys in this study. Statistically significant differences were found between the 8- to 9-year-old boys and the older boys. The higher values of knee extension ROM in the older groups than in the younger may be explained by their increased calf length. In addition, sex differences appeared in the 8- to 9-year-olds. These findings are consistent with those of several authors (7, 9, 12) who reported higher flexibility in females than males. The specific physical exercises typically undertaken by boys and girls may have influenced knee extension ROM during the observed period, an influence that has also been reported by Reid et al. (12).

For subjects age 11 to 12 years, knee extension ROM as measured with a gravity goniometer (3 ± 2.4°) was lower than the results recorded by Cheng (2) (7 ± 9°). However, the recorded mean ROM (2.8 ± 1.9°) of knee extension was similar to values reported by Daniel and Anderson (4), who judged a knee extension ROM of 3° or lower to be normal, 3–5° nearly normal, and higher than 6° abnormal. Considering this and the correlation found in the present study between the direct and indirect methods, knee extension values in millimeters at a 95% confidence interval for age and sex groups (Table 3) may be regarded as normal.

Conclusions

Results of this study indicated that the constructed linear instrument for assessing knee extension ROM was an appropriate tool and may be considered for use by rehabilitation professionals to evaluate the effectiveness of knee treatment procedures. The linear instrument is an alternative to the goniometer that is easy to manage and requires little time. Knee extension ROM recorded in millimeters may be a more sensitive measure to compare injured and uninjured knees after surgery and rehabilitation.

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Acknowledgments

This study was financially supported by the Estonian Science Foundation (Grant No. 1914). I thank the physical education teachers and administration of the Tartu schools for permission to conduct the measurement procedure.

VI

Hein, V., Vain, A.
Joint mobility and the oscillation characteristics of muscle.
Scandinavian Journal of Medicine & Science in Sports 1998, 8(1): 7–13.

Scand J Med Sci Sports 1998: 8: 00–00
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Scandinavian Journal of
MEDICINE & SCIENCE
IN SPORTS
ISSN 0905-7188

Joint mobility and the oscillation characteristics of muscle

Hein V, Vain A. Joint mobility and the oscillation characteristics of muscle.
Scand J Med Sci Sports 1998: 8: 00–00. © Munksgaard, 1998

The aim of this study was to investigate which muscle characteristics of oscillation of the lower extremities have influence on trunk forward flexion and knee extension. The frequency and the decrement of damped oscillation of the muscles m. rectus femoris, m. biceps femoris, m. semitendinosus and t. semimembranosus in relaxed, contracted or stretched states were recorded by the myometer among the 22 first-year male students of the department of physical education. The subjects were divided twice into two groups according to: 1) the values of the trunk forward flexion, and 2) the values of the knee extension range of motion. The oscillation frequency of m. rectus femoris of the groups with high trunk forward flexion and high knee extension range of motion was lower than in groups with less range of motion. The similarity was followed in the decrement of m. semitendinosus. The difference between the decrements of the relaxed and stretched state of m. semitendinosus and the decrement of the relaxed state of the same muscle tendon correlated with the knee extension range of motion ($r=0.46$ and $r=0.48$, $P<0.05$). The relationship between the decrement of the relaxed state of m. biceps femons and the range of motion was $r=-0.51$ ($P<0.01$). The results of this study showed that the characteristics of the damped oscillation as indirect parameters of viscoelastic properties of the muscles were related to the joint mobility.

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Key words: viscoelastic properties of the muscle; flexion; extension; knee joint; damped oscillation

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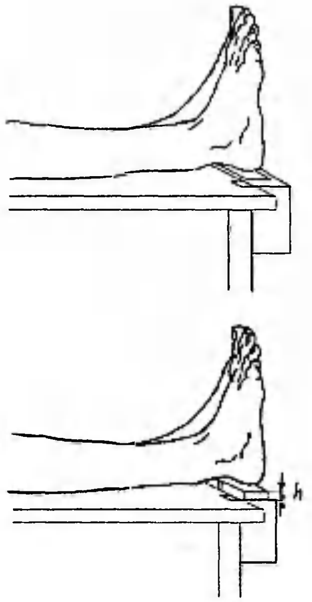
Accepted for publication 11 November 1997

Flexibility is considered to be one of the most important functional parameters to characterize the neuromusculoskeletal system's responsibility for complicated coordination movement. The skeletal muscles have at minimum three basic functions to perform: the generation, dissipation and recuperation of mechanical energy. It is well known that in every elementary movement of a human being at least two antagonistic muscle groups are involved. When one of them shortens in the contraction process, the other group of antagonistic muscle is stretched out at a certain velocity. Depending on its damping properties (the ability to dissipate the mechanical energy) and tonicity, this muscle group resists the force moment created by their antagonists (1). The torque required to move the bones of a joint in its mid-range is 47% attributable to the joint capsule, 41% to passive motion of muscles, 10% to tendons, and 2% to skin (2). Thus, the range of motion (ROM) of the joint depends on the ability of the muscle-tendon unit to elongate within the physical limits of the joint. The mechanical behavior and structure of the muscle-tendon unit has been presented by Chapman (3). The passive resistance is a result of the elastic properties primarily of the connective noncontractile elements within the muscle. As the muscle elongates, the perimeter decreases and tension increases along the muscle, thus providing resistance to excessive lengthening. It is known that the collagen fibers situated in the envelopes (endo-, peri- and epimyseum) pass over directly into tendons. These envelopes also ensure the constancy of muscle volume in the muscle elongation or contraction process. The tension evoked in the envelopes of muscles, as a result of stretching, depends on the magnitude of the resistance force of the elastic structures of the muscle (the S2 part of the myosin filament cross-bridge, titin filaments etc.) and resists the changing of its shape by external forces. Additionally, the resistance force is influenced by the stretching velocity. This part of the resistance force depends directly on oscillation decrement of the muscle (4, 5). Taylor et al. (6) have shown that the decreased peak tension and the increased muscle length obtained during stretching were attributable to changes in the viscoelastic properties. Fung (7) noted that biological tissues are all viscoelastic and one of the simplest ways to determine the viscoelastic properties experimentally is to subject the material to oscillation. Several authors (8, 9) have measured stiffness as one of the viscoelastic properties using the method of the damped oscillation frequency of the muscles. Significant relations have been observed between muscle stiffness and the range of motion of the joints, which is directly related to the ability of the muscle to lengthen (9, 10). However, no data exist on how the characteristics of the damped oscillation (CDO) of the muscles, involved in the trunk forward flexion performance, affect the result of the flexibility test. One of the reasons for this may be the lack of suitable equipment and noninvasive methods to determine quantitatively the frequency and decrement of damped oscillations, which reflect the viscoelastic properties of certain skeletal muscles.

The most frequently used measurement of forward flexibility is the sit-and-reach test, based on the assumption that it gives a composite accounting of hip, spine and hamstring flexibility (11). Some investigators have studied the influence of the flexibility of the lower back and hip on the results of this test or its modification (12–18). Less attention is given to the relation of the ROM in lower limb joints as one of the components of the sit-and-reach test (19, 20). Two major muscle groups – quadriceps and hamstrings, which cross the knee joint – are involved in the extension and flexion of the lower extremities, and their viscoelastic properties will determine to some extent the ROM in the joints.



POSITIONING SUBJECT'S FEET DURING THE

MEASUREMENT THE KNEE EXTENSION

Fig. 1. Measurement procedure of the knee extension ROM.

The objectives of this study were: 1) to record the oscillation characteristics of the muscles involved in the trunk forward flexion and in the knee extension; and 2) to determine which muscles are most responsible for flexibility performance in respect of the oscillation characteristics.

Subjects and methods

Subjects

Twenty-two first-year male students of the department of physical education participated in this investigation. Their mean age, height and weight was 19.0±1.5 yr, 182±16 cm and 74±9 kg, respectively. Informed consent was obtained from each subject beforehand. No subjects had limitation of joint movement due to injury.

Measurements of flexibility

Sit-and-reach

The subject placed the soles of both feet against the testing box, 0.3 m in height. The zero-point of measurement was taken at the edge of the box. The linear measurement to the nearest half centimeter was obtained by having the subject reach and hold for 2 s with feet together and knees fully extended, which corresponded to a stretching maneuver.

Knee extension

A special instrument was constructed to measure knee extension (20). The measurement procedure is presented in Fig. 1. The design enabled the recording of the ROM of knee extension on a linear scale with an accuracy of 1 mm. The measurement plate was placed in a special box on the same level and fixed to the edge of the measurement table. The subject was in a sitting position, with feet extended and heels on the measurement plate. The knee extension ROM was read from the scale and expressed as the distance (h) between the heel support (measurement plate in zero position) and maximally uplifted heels performed by the active force of the subject. The reliability of measurement procedures and the construction of the instrument have been reported previously (20).

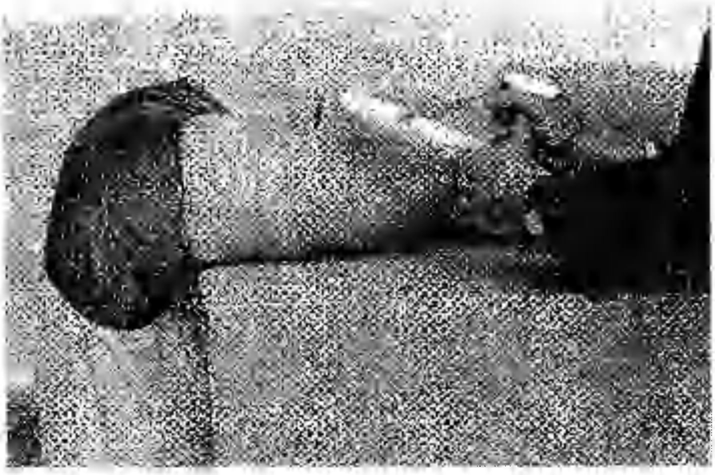


Fig. 2. Measurement of damped oscillation by myometer; contact-end with wheel in contact with muscle.

Measurement of the oscillation characteristics of muscle

A myometer, designed and constructed by Vain and Humal (1, 21) at the University of Tartu (Estonia), was used to measure the oscillation frequency and decrement of the muscle tissue. The instrument consists of a rocking lever, mounted on a fulcrum in the tool and carrying an acceleration transducer, a contact-end with a wheel and an armature set between the poles of an electromagnet (Fig. 2). Because the lever is unbalanced, the weight of the acceleration transducer presses the wheel at the contact-end against the muscle to be tested with a low force of about 0.3–0.4 N. This enables the recording of oscillation characteristics on a restricted area of the muscle. To perform the measurement, the electromagnet is supplied with an impulse of 11 ms duration from a single-impulse generator. The armature is pulled up by the electromagnet and produces a short mechanical impulse that rotates the lever and, as a result, the testing end performs an impact against the tissue. Due to elastic behavior of the biological tissue, the testing end together with constancy volume of the underlying tissues will perform damped oscillation (Fig. 3). These oscillations are registered by the acceleration transducer, and that which is registered characterizes muscle's ability to dissipate the mechanical energy in muscle properties. The freqency of the oscillation (Y) reflects the stiffness of the muscle and the logarithmic decrement of decay (θ) characterizes muscle's ability to dissipate the mechanical energy in muscle structure. The difference between the oscillation frequencies of the contracted and relaxed state ($\Delta Y = Y$ contracted$-Y$ relaxed) characterizes muscle's ability to generate force (1). The difference between logarithmic decrement of damped oscillation of the relaxed and contracted state ($\Delta\theta = \theta$ relaxed$-\theta$ contracted) characterizes the resistance force of muscle against stretching. When $\Delta\theta > 0$, then the resistance force of muscle is low, and in the case of $\Delta\theta < 0$, then the resistance force of muscle is high.

The frequency and decrement of damped oscillation of the m. rectus femoris, m. biceps femoris, m. semitendinosus and t. semimembranosus were recorded in relaxed and stretched or contracted states. The measurement points on the above-mentioned muscles and tendon are indicated on Fig. 4. The maximal voluntary force of the subject was applied to obtain the contraction state of the muscle. The

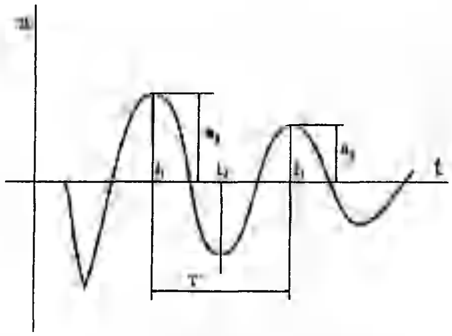


Fig. 3. Graph of damped oscillation by myometer. Smooth graph in active field calculated from actual measurement. T= period, a_1 and a_3=amplitude of damped oscillation. Frequency $Y = 1/T$ Hz, decrement of damped oscillation $\theta = \ln(a_1/a_3)$.

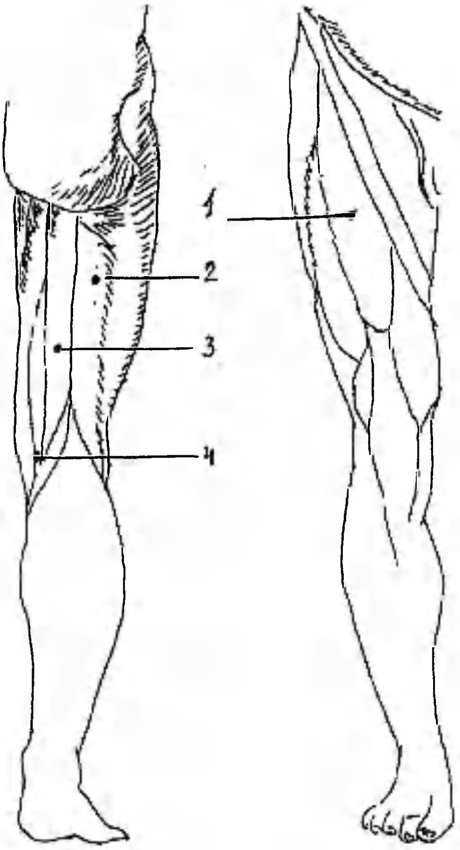


Fig. 4. Positions of the acceleration transducer of myometer during the oscillation characteristics measurement procedure: 1 – m. rectus femoris, 2 – m. biceps femoris, 3 – m. semintendinosus, 4 – tendo semimembranosus.

contraction state of the m. rectus femoris was recorded during the performance of the knee extension on the constructed instrument when the heels were maximally lifted up by the maximal voluntary force of the subjec (Fig. 1). The stretched state of the hamstrings was measured when the subject was lying on the measurement table, with the upper and the lower body forming an angle of 90° (the upper body was hanging over the edge of the table). The relaxed state of the posterior muscles in prone and m. rectus femoris in supine positions were measured.

Procedure

All measurements were taken in the same conditions: temperature, time, and warm-up exercises. No external forces were used in any measurements. Body height and weight were recorded prior to testing flexibility and the CDO of the muscles. To compare the influence of the CDO of the muscles on the range of motion in joints, the subjects were divided twice into a greater and a lesser flexibility group, in the first case on the basis of the knee extension ROM and in the second on the basis of the sit-and-reach test score. The borderline between the lesser and greater knee extension ROM was evaluated as 33 mm and for the sit-and-reach test as 11 cm, according to the mean values of the subjects.

Statistics

A Statgraphics program was used to analyze the data. Pearson product moment correlations between test scores were established and a multiple regression model was constructed by stepwise selection for trunk forward flexion. The Mann-Whitney U test was used to determine the significance of the difference of the CDO between the two groups with greater and lesser range of motion. The $P<0.05$ level was selected as the criterion of statistical significance.

Results

The calculated mean values of the sit-and-reach test of the greater and lesser flexibility groups were 16.83±4.40 (cm) and 4.50±3.52 (cm) respectively. On the basis of the results of knee extension ROM, the mean values of the greater and lesser flexibility groups were 41.8±9.7 (mm) and 26.75±9.1 (mm). The correlation coefficient between the sit-and-reach test and the knee extension ROM was 0.48 ($P<0.05$).

The oscillation frequency and decrement of the observed muscles and the comparison of the groups with greater and lesser range of motion in the knee extension ROM and in the trunk forward flexion are given in Table 1. The trunk forward flexion was significantly correlated with the difference between the oscillation frequency of the contracted and relaxed states of m. rectus femoris ($r=-0.57$, $P<0.01$) and with the oscillation frequency of the same muscle in its contracted state ($r=-0.43$, $P<0.05$). The relationships between trunk forward flexion and the oscillation frequency of the relaxed m. semitendinosus and the decrement of the stretched t. semimembranosus were accordingly $r=-0.51$) $P<0.01$) and $r=-0.46$ ($P<0.05$).

The knee extension ROM was primarily related to the decrements of damped oscillation of the m. biceps femoris and the m. semitendinosus. Correlation coefficient between the ROM in the knee joint and difference of the decrements of the relaxed and stretched state of the m. semitendinosus ($\Delta\theta$) or with the relaxed state of the same muscle tendon (0) were $r=0.46$

Table 1. Comparison of the oscillation characteristics of muscles between groups with lesser and greater flexibility in respect of the range of motion of knee extension and trunk forward flexion

Muscles and groups	Y relaxed state	Y contracted	ΔY	θ relaxed state	θ contracted	Δθ
m. rectus femoris $n=22$	13.21±1.05	19.31±2.39	6.09±1.88	1.32±0.30	0.79±0.18	0.52±0.36
1	13.45±1.19	20.32±2.57	6.87±1.64	1.29±0.28	0.77±0.25	0.52±0.39
2	13.02±0.94	18.47±1.95*	5.44±1.88*	1.35±0.33	0.82±0.10	0.53±0.37
3	13.12±1.22	20.30±2.49	7.14±1.49	1.34±0.32	0.73±0.19	0.61±0.36
4	13.27±0.91	18.48±2.05*	5.22±1.76**	1.30±0.30	0.85±0.16*	0.45±0.37
m. biceps femoris $n=22$	13.22±1.19	14.29±1.50	1.07±1.34	1.39±0.31	1.16±0.21	0.24±0.34
1	13.35±1.30	14.34±1.70	0.99±1.33	1.45±0.23	1.15±0.22	0.30±0.22
2	13.11±1.14	14.24±1.38	1.14±1.40	1.35±0.37	1.16±0.21	0.18±0.43
3	13.45±1.31	14.68±1.74	1.23±1.78	1.42±0.22	1.09±0.21	0.33±0.23
4	13.02±1.10	13.95±1.24	0.93±0.88	1.37±0.38	1.21±0.21	0.16±0.42*
t. semimembranosus $n=22$	19.05±2.89	23.31±3.19	4.26±2.39	0.97±0.28	0.78±0.20	0.18±0.29
1	19.08±2.87	23.17±3.47	4.09±2.55	1.02±0.26	0.82±0.23	0.21±0.27
2	19.03±3.03	23.43±3.08	4.40±2.37	0.93±0.30	0.77±0.19	0.17±0.33
3	19.50±2.47	22.83±3.55	3.33±2.05	1.00±0.26	0.88±0.23	0.12±0.28
4	18.68±3.25	23.71±2.95	5.04±2.47	0.95±0.30	0.72±0.15**	0.24±0.31
m. semitendinosus $n=22$	13.88±1.12	16.48±1.45	2.60±1.46	1.41±0.35	1.16±0.15	0.26±0.41
1	14.12±1.12	16.76±1.50	2.64±1.16	1.34±0.23	1.42±0.13	0.20±0.24
2	13.68±1.13	16.26±1.44	2.57±1.72	1.47±0.42	1.17±0.18	0.31±0.52
3	14.43±1.21	16.73±1.38	2.30±1.86	1.29±0.27	1.11±0.12	0.18±0.28
4	13.42±0.82**	16.27±1.54	2.86±1.04	1.50±0.39	1.19±0.17	0.32±0.49

1. Knee extension ROM <33 [mm] $n=10$. 2. Knee extension ROM >33 [mml $n=12$. 3. Sit-and-reach test score <110 [mm] $n=10$. 4. Sit-and-reach test score >110 [mm] $n=12$. Y relaxed – oscillation frequency of the relaxed muscle. Y contracted – oscillation frequency of the contracted muscle. θ relaxed – logarithmic decrement of the relaxed muscle. θ contracted – logarithmic decrement of the contracted muscle. ΔY=Y contracted−Y relaxed, Δθ=θ relaxed−θ contracted. Statistical difference in Mann-Whitney U test: $^{**}P<0.05$, $^{*}P<0.1$.

and 0.48 ($P<0.05$), respectively. The relationship between the decrement of the relaxed state of the m. biceps femoris and the ROM of the knee extension was $r=-0.51$ ($P<0.01$).

The stepwise multiple regression equation was conducted with trunk forward flexion (sit-and-reach test) – k, being predicted by the characteristics of oscillation frequency of the muscles:

$$k=61.6-12.89x_1-2.24x_2-1.54x_3, \text{ where}$$

x_1 is the logarithmic decrement of the stretched t. semimembranosus, x_2 is the oscillation frequency of the relaxed m. semitendinosus, and x_3 is the difference between the oscillation frequency of the contracted and relaxed m. rectus femoris. The regression equation for the sit-and-reach test prediction indicated the essential role of the decrement of damped oscillation of the stretched t. semimembranosus and the characteristics of oscillation frequency of the m. semitendinosus and m. rectus femoris. R-square was equal to 0.57, and the significant level of all variables was $P<0.05$.

Discussion

The results of this study showed the influence of the CDO on joint mobility. These findings are in agreement with the results of Wilson et al. (8), who reported a significant correlation ($r=-0.54$, $P<0.05$) between stiffness of the musculature and static flexibility, although the methods used were different. In our study, the correlation coefficient between the oscillation frequency (stiffness) of the relaxed m. semitendinosus and the sit-and-reach test score was $r=-0.56$, $P<0.05$. The method used by Wilson et al. (8) allowed the recording of the damped oscillation frequency of the muscle group via the force platform. During the measurement procedure the subject maintained a quasi-static muscular action in a position specific to the bench-press movement. Wilson et al. (8) noted that the fundamental oscillation pattern of the registered deltoid/pectoralis musculature was distorted, and those distortions appeared to be due to oscillations from the bar-benched system and to physiological muscle tremor. However, this interference was eliminated by transforming the data by Fourier analysis, removing the high-frequency contamination and reconstructing the frequency-limited wave-form. In our study, the oscillation frequency was recorded directly from the biological tissues of the subject and therefore is free from the influence of such distortion on measurement results.

The oscillation frequency was registered when the muscle group was briefly (150–200 ms) loaded with external force in the order of 100 N. The technical parameters of the myometer used in this study enabled us to record the damped oscillation of one particular muscle as the applied external force was only about 0.3–0.4 N with a duration of 11 ms. Additionally, it was easy to calculate the decrement of damped oscillation of muscle. In the case of a small decrement value the muscle is more elastic. Larger decrement values indicate greater dissipation of the mechanical energy in muscle structure. The findings of this study supported this statement. The group with higher sit-and-reach test scores has a significantly smaller value of the decrement of t. semimembranosus in the stretched state than the group with less flexibility (Table 1). The tendon where the decrement does not reach a high value during the elongation is more extensible and permits more ROM.

The essential part in the trunk forward flexion occurs due to the ROM in the hip joint (13, 15, 16). Therefore, the stretched state of the hamstring was recorded when the subject was in the lying position with an angle of 90° in the hip joint. The differences between the oscillation frequencies in the relaxed state and in the stretched state ($\Delta\Upsilon$) of t. semimembranosus and m. semitendinosus (4.26 ± 2.39 and 2.60 ± 1.46) were higher than the corresponding values for m. biceps femurs (1.07 ± 1.34). This allows us to make an assumption that during the trunk forward flexion more tension evokes in such muscle-tendon units as the medial hamstrings, where the elastic elements are more resistant to the changing shape of the muscle. A similar conclusion can be drawn from the decrement values of the damped oscillation of the hamstring (Table 1). The most significant role belongs to the t. semimembranosus, where decrement of the contracted state was in correlation with the sit-and-reach test score ($r = -0.46$, $P < 0.05$).

The multiple regression model, using stepwise variable selection procedure, evaluated the contribution of the CDO of the observed muscles to trunk forward flexion. According to the results of this study, it appeared that the decrement of the stretched t. semimembranosus and the oscillation frequency of the relaxed m. semitendinosus were the best predictors of trunk forward flexion. The value of the independent variable of the stretched t. semimembranosus in regression equation allowed the assumption that the decreased decrement (that is the increased ability of muscle to dissipate the mechanical energy in muscle structure) increased the trunk forward flexion.

The ΔY and Y in the contracted state of the m. rectus femoris in the greater flexibility group in respect of the sit-and-reach test in comparison with the lesser flexible group were significantly smaller (Table 1). This suggests that the hamstring, as the antagonist of the m. rectus femoris, is more extensible when the oscillation frequency of the m. rectus femoris is not large. In addition, this suggestion is supported by the negative value of the independent variable of the m. rectus femoris in the regression equation.

The oscillation frequency of the contracted state (Υ) and the difference between relaxed state and contracted state ($\Delta\Upsilon$) of the m. rectus femoris in the group with lesser knee extension in comparison with the group with greater knee extension ROM were significantly larger. It indicates the knee ROM dependence on the characteristics which reflect the muscle stiffness. The small values of oscillation frequencies of the m. rectus femoris induce more extensibility of the hamstring and permit more ROM in the knee joint. The situation was reversed for the decrement values of the hamstring. The decrements of their relaxed and contracted state have a tendency to be small in the group with greater knee extension ROM and, therefore, do not restrict the contraction of m. rectus femoris to perform the knee extension. This speculation is supported by the relationship between the knee extension ROM and the decrement of the relaxed m. biceps femoris ($r = -0.5$, $P < 0.01$).

The present study of the influence of the CDO of the muscles on trunk forward flexion and knee extension involved physically active trained subjects. Further research is needed to confirm (or oppose) the findings at different ages and at different levels of the physically active population. Exact knowledge of the dependence of the oscillation characteristics of the muscle-tendon unit on the range of the joint motion is of great importance for better understanding of the flexibility mechanism and for improving the stretching procedure.

Conclusions

The results of this study showed that from the CDO of the muscles, the decrement of the contracted t. semimembranosus, the oscillation frequency of the relaxed m. semitendinosus, and the characteristics reflecting the stiffness properties of m. rectus femoris were most responsible for limiting trunk forward flexion. The knee extension range of motion was related to the decrements of damped oscillation of m. biceps femoris and m. semitendinosus.

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Education

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1973	Pedagogical Institute of Tallinn Qualification of the teacher of the physical education
1977–1981	postgraduate student of Tartu State University
1992	Master degree of Sport Sciences (MSc)

Special courses

2nd international workshop on the assessment of health related fitness" Finland, Tampere, UKK Institute, March, 5–10, 1995

5-th International course for physical education teachers, Hungary, Budapest. July, 24–31, 1994

25-th International course on teaching sports, Austria, Graz, July 22–30, 1995

Study visit to De Monfort University, Bedford and to Gloucestershire Institute of Higher Education, Cheltenham in England, March, 9–17, 1996

Study visit to Umea University, Sweden, January 13–27,1997

Professional employment

1973–1983	gymnastics coach of Tartu Sports School
1983–1993	teacher of the secondary school and assistant headmaster of the primary school in Tartu
1993	lecturer of Institute of Sport Pedagogy, University of Tartu

Research training

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1973–1983	Tartu LNSK sportvõimlemistreener
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1993	Tartu Ülikooli spordipedagoogika instituudi lektor

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Osavõtt seminar-kursusest “2nd international workshop on the assessment of health related fitness” Soomes Tamperes 5.–10. märtsil 1995

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Erialane täiendus Umeå Ülikoolis 13.–27. jaanuaril 1997

Teadustegevus

Koolilaste painduvuse määramise metoodika ja standardiseerimine.

DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

1. Lennart Raudsepp. Physical activity, somatic characteristics, fitness and motor skill development in prepubertal children. Tartu, 1994. 138 p.

TARTU ÜLIKOOL
UNIVERSITAS TARTUENSIS
1632

ISSN 1406–1058
ISBN 9985–56–322–0