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Stretching Exercises: Effect on Passive Extensibility and Stiffness in Short Hamstrings of Healthy Subjects

Jan P. K. Halbertsma, MSc, Ludwig N. H. Göeken, MD, PhD

ABSTRACT. Halbertsma JPK, Göeken LNH. Stretching exercises: effect on passive extensibility and stiffness in short hamstrings of healthy subjects. Arch Phys Med Rehabil 1994;75:976-81.

• Passive muscle stretch tests are common practice in physical therapy and rehabilitation medicine. However, the effects of stretching exercises are not well known. With an instrumental straight-leg-raising set-up the extensibility, stiffness, and electromyographic activity of the hamstring muscles have been experimentally determined and the effects of stretching exercises have been evaluated. Fourteen volunteers, aged 20 to 38 years (mean 27.3) were selected from a young healthy population with the toe-touch test (finger-ground distance greater than 0cm), and a straight-leg-raising angle about 80°. According to usual standards the diagnosis was short hamstrings. One group of seven subjects was treated during 4 weeks with a daily home exercise program aimed at stretching the hamstrings, whereas the untreated group was used as a control. Instrumental straight-leg-raising was performed in the subjects of both groups. The significance of the differences between the mean values was determined with the Student's *t*-test. Comparison of the data obtained before and after the muscle stretching program showed a slight but significant increase in the extensibility of the hamstrings accompanied with a significant increase of the stretching moment tolerated by the passive hamstring muscles. However, the elasticity remained the same. It is concluded that stretching exercises do not make short hamstrings any longer or less stiff, but only influence the stretch tolerance.

In patients with a limited ability to bend forward from the standing position while holding the knees in extension, it is common practice for clinicians to perform the passive straight-leg-raising (SLR) test. The test is called passive muscle stretch test if assessment of hamstring muscle pathology (short hamstrings) is the object, and Lasègue's test if it is aimed at assessing neurogenic pathology. In both cases, the test outcome is interpreted with respect to the following two variables: the maximum angle between the leg and the horizontal plane (lift angle) that can be reached while raising the leg, and the pain that is provoked. The outcome of the test is assessed as normal if the leg can be lifted to a lift angle of 80° or more without provoking pain. If the maximum value of the lift angle is under 80° and pain is aspecific or absent, the cause of the movement restriction is usually attributed to an insufficient elasticity of the hamstrings (short hamstrings) and therapy is directed at stretching these muscles.[1,2]

Studies on the effect of stretching exercises on hamstring extensibility are abundant.[3-11] To determine the effect, in most studies the difference between the maximum lift angles established during SLR before and after a training program has been used as an effect parameter. The results of the studies differ considerably and the pretest-posttest differences measured vary between 3°[10] and 20°.[5] Regarding the results one must keep in mind that the studies all differed in (1) subjects (age, sex, normal, or short hamstrings); (2) type of training program (active or passive stretching, slow or fast stretching, short or long duration); (3) the measuring method (sit and reach test, active or passive SLR, goniometers, tape-measure, camera); and (4) the various definitions describing the effects of the therapy (increase in elongation, flexibility, range of motion (ROM), suppleness, elasticity). Considering the discrepancy in the outcomes of the many studies, it still seems unclear whether or not it is possible to lengthen short hamstrings by performing stretching exercises. Another question regarding the effect of stretching exercises in short hamstring is their mechanism in lengthening the muscles. In most of the studies mentioned, the idea is that the exercises lengthen the hamstrings by changing the elasticity of the muscles. This concept supposes an abnormal or high muscle stiffness. However, in a previous study,[12,13] it was found that short hamstrings are not characterized by an abnormal muscle stiffness, but by a low stretch tolerance. The object of this study was to evaluate the effect of muscle stretching exercises in subjects with the diagnosis short hamstrings using a measuring method that provides information on the elasticity of the muscles.

In the exposition of this article it is important to define some basic terms. Elasticity refers to the property of a structure to elongate when a force is applied, and to return to its original length when the force is taken away. Within elasticity there exist concepts like extensibility and stiffness. Extensibility is here defined as the ability of a muscle to allow elongation, more specifically the ROM over which the limb can be passively moved (the maximum angle). Passive stiffness is here defined as the ratio of the change in passive muscle moment to the change in muscle stretch (Δmoment/Δangle). A high passive stiffness therefore implies a high increase in passive muscle moment per unit angular movement.

From the Department of Rehabilitation Medicine, Department of Human Movement Sciences, University of Groningen, The Netherlands.

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Reprints requests to Jan P. K. Halbertsma, MSc, Department of Rehabilitation Medicine, University Hospital Groningen, Oostersingel 59, 9700 RB Groningen, The Netherlands.

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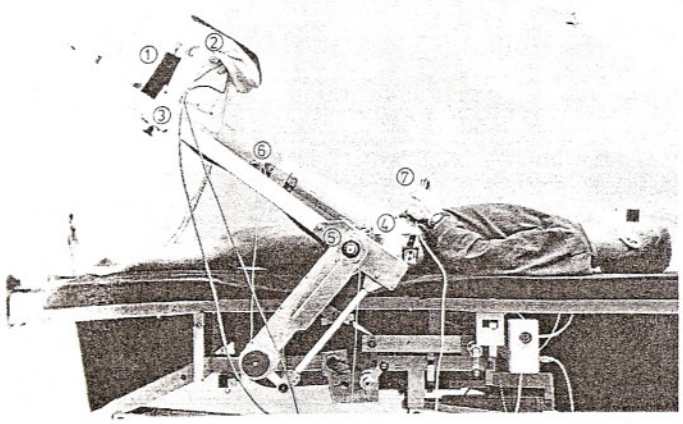

Fig 1—Overview of the instrumental set-up: sling (1), force transducer (2), lift-frame (3), electrogoniometers on hip (4), frame axis (5), knee (6) and pain indicator (7). Surface electrodes on muscles are not visible.

Previously, in the scope of a larger study,[12,13] an instrumental version of the SLR test has been developed, called instrumental straight-leg-raising (ISLR). To measure the necessary variables, in this study an adapted version of ISLR has been used.[14] This measuring method makes it possible to measure the ROM of the leg, the pelvic-femoral angle, the force needed to lift the leg, the first sensation of pain and the electromyogram (EMG) of the hamstring muscles. These variables provide information about the extensibility, stiffness, and EMG activity of the hamstring muscles.

METHODS AND MATERIALS

The ISLR method has been described extensively.[12-16] At this place a brief exposition of the adapted version may suffice, therefore. In the ISLR set-up the subject lies supine on an examination table (fig 1). The leg is placed in a sling at the ankle which is connected through a force transducer to a lift-frame. The lift-frame can be rotated with an angular velocity of 3°/sec by an electromotor. Electrogoniometers are placed on hip, lift-frame axis, and knee. A pain indicator is held in the hand. Surface monitoring electrodes (not visible here) are placed on the designated muscles. A schematic representation of the hip angles involved is presented in fig 2.

Angles

The electrogoniometers record the following angles: The angle of the leg (α) with respect to the horizontal plane, measured with a goniometer on the axis of the lift-frame. The lift-frame axis can be moved to make it coincident with the hip axis. The angle α represents the ROM of the leg. The angle between leg and pelvis (ϕ). Great care was taken to provide a good fixation to the pelvis. The construction of the hip goniometer allowed a considerable nonalignment between hip axis and goniometer axis. The angle ϕ represents the extensibility of the hamstrings. In general angle ϕ is smaller than the ROM of the leg, because of the tilting of the pelvis. The angle of the knee (κ). This angle is used as an indication whether the leg has been kept straight during SLR. All angles are expressed in degrees. The electrogoniometers are low-friction potentiometers[a] (10KΩ; linearity, 0.2%) and have their mechanical axes perpendicular to the sagittal plane.

The amount of extensibility of the hamstrings, relative to their length in the supine position, has been expressed in angular units as the angle ϕ, according to:

$$\phi = \alpha - \psi$$

From figure 2 it will be obvious that when the leg is raised to an angle α, part of this rise will be caused by a rotation between leg and pelvis (angle ϕ) but the other part is caused by a tilting of the pelvis (angle ψ). It should be mentioned that all angles are relative (see measuring procedure).

Moments

The force necessary to lift the leg from the examination table is measured by a force transducer (fig 1). The force transducer[b] (range, 0 to 500N; linearity, 0.02%) is connected perpendicular to the ankle by a sling. The hip moment is equal to the measured force perpendicular to the leg times the length of the leg (distance sling to hip axis). To obtain the passive muscle moment M_e, the moment caused by gravity from the weight of the leg is subtracted. The passive muscle moment M_e (Nm) as a function of the angle ϕ represents the elasticity curve of the hamstring muscles. Within elasticity the passive stiffness is defined as Δmoment/Δangle.

EMG

Bipolar surface EMG electrodes[c] (composition, Ag/AgCl, 10mm diameter) 25mm apart are placed on the semimembranosus, semitendinosus, and the long head of the biceps femoris. The electrode leads are connected to an EMG-amplifier[d] (input impedance, 1MΩ; common mode rejection, 80db; frequency range, 20 to 600Hz). The EMGs are full wave rectified and low-pass filtered (IEMG). It will be clear that to determine the passive stiffness of the hamstrings, it is necessary to obtain information on the electrical activity of the muscles, to see if they are active.

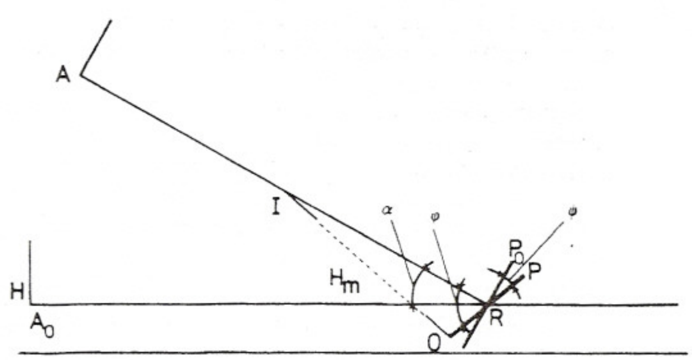

Fig 2—Schematic representation of a sagittal view of the supine subject. R, represents the hip axis; RA, the leg; RP, the pelvis; and HR, the horizontal plane. O and I represent the origin and insertion of the hamstring muscles (H_m) respectively. The initial positions, with the leg lying on the table, are given by RA_0 and RP_0. The angles are defined as follows: $\alpha = \angle$ HRA, lift angle of the leg with respect to the horizontal, $\phi = \angle$ ORA, angle between leg and pelvis, $\psi = \angle$ P_0RP, backward tilt of the pelvis when the leg is raised.

Table 1: Personal Data of the Subjects

N (n)	Sex (M, F)	Age (years)	Height (cm)	Weight (kg)	FGD (cm)	Group (C, S)
E	M	29	176	74	2	C
J	M	38	174	67	8	C
M	M	33	179	84	18	C
O	F	31	178	68	25	C
P	F	32	168	64	10	C
R	F	25	171	68	17	C
S	M	31	182	84	11	C
D	F	21	170	64	24	S
F	M	27	181	78	7	S
G	F	20	171	59	27	S
H	F	22	163	59	10	S
K	M	24	188	83	16	S
L	M	28	184	84	24	S
N	F	21	171	60	18	S

Abbreviations: N, identification; FGD, finger-ground-distance; C, control; S, stretching.

Pain Indicator

A device with an on/off push-button is held in one hand. The subject is asked to activate the push-button at the first sensation of pain during the lifting of the leg. Pain is here defined as a painful feeling of tension (stretch) in the dorsal part of the thigh. The activation of the device, ie, stretch tolerance ϕp is registrated as a function of the extensibility ϕ of the hamstrings.

Data Processing

An Apple II[e] computer is used for storage, processing, and presentation of the measured data. Analog signals are converted with an 8-bit A/D converter (256 levels) at a sampling frequency of 10Hz.

Subjects and Procedure

Via an entry form, students from the Academy of Physical Therapy in Groningen (The Netherlands) were asked to participate in the experiment. To select subjects with short hamstrings and to eliminate possible pathology potential candidates had to meet the following selection criteria: not being able to touch the ground with the fingertips while bending forward from the standing position, holding the knees in extension (finger-ground distance $>$ 0cm); and a history without recent or chronic low back pain and without previous surgery or recent injury of the back, pelvis, or legs. Selected in this way, 18 subjects entered the experiment, 8 men and 10 women, ranging in age from 19 to 38 years (mean 26.5). The subjects were randomly divided into two groups of nine subjects, a stretching group (S) and a control group (C). Unfortunately, during the experiments, four subjects had to be excluded because of illness or sport injuries, finally leaving seven subjects in the stretching group (range 20 to 28 years, mean 23.3), and seven subjects in the control group (range 25-38 years, mean 31.3). The data are reported in Table 1.

Training Program

The subjects of the stretching group performed a training program during 4 weeks aimed at stretching the hamstrings. A 4-week period is chosen because in the therapeutic field there is an evaluation of the patient exercises after the same period of time. In this program the following exercise, based on the principles of Janda,[1] was frequently practiced. While sitting on the ground with straight knees, the subject holds a strip of cloth that is placed around the feet (fig 3). Facilitation is achieved by pressing the heels to the ground and trying to bend the knees. Stretching of the hamstrings is achieved by stretching the knees and bringing the trunk forward by pulling the cloth strip (contract-relax). After an extensive instruction course by a physical therapist and verifying that the subjects understood the performance of the exercise, this exercise was practiced, twice a day for 10 minutes, with one session at 9 hours and one session at 20 hours. During the training program the subjects of the stretching group kept a log to record their activity. The subjects in both groups were also asked to refrain from unusual physical activities during the testing period.

Measuring Procedure

After registration of the personal data, the subject is lying supine on the ISLR set-up, the EMG electrodes are applied, and the EMG signals are checked. Next the foot is placed in the sling and the length and weight of the leg are determined in horizontal position. Then the goniometers are applied and adjusted to zero. Because of the zeroing all angles to be measured are relative. Care is taken for proper alignment of hip axis and lift-frame axis. The subjects are encouraged to relax during the leg raise and instructed to activate the pain indicator at first sensation of pain and to say "stop," when they cannot go any further. Then the lifting of the leg will be stopped. Finally, the recording is made when the lift-frame is raised by the electromotor. The measurement is repeated five times and the values representing the ROM, the extensibility, the first sensation of pain, and the muscle moment of the hamstrings are expressed in mean values. Excitation of the muscles will influence the muscle moment M_e. Therefore, all maximum values of the α, ϕ, and M_e were defined by the beginning of the EMG to determine the passive stiffness. Because the aim was to collect data on muscle elasticity, and not on possible left-right asymmetry, only the left leg was examined. Both premeasurements and postmeasurements for each individual subject were made during the same time of day (between 9 and 10am). This is important as the extensibility may change during the day. Moreover, no warm-up and stretching exercises were performed by the subjects before their measurements with the

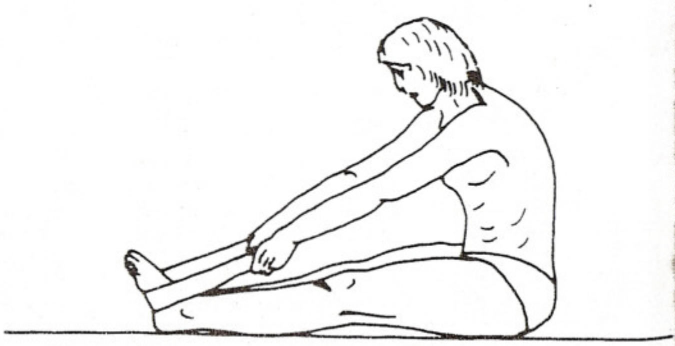

Fig 3—Stretching exercise for the hamstring muscles.

Table 2: Mean Values and Standard Deviations in Subjects of the Control Group in Pretest ($Index_1$) and Posttest Session ($Index_2$)

N	$\alpha_1 \pm$ SD (degrees)	$\phi_1 \pm$ SD (degrees)	$\phi_{p1} \pm$ SD (degrees)	$M_{e1} \pm$ SD (Nm)
F	82.0 ± 1.00	44.7 ± 2.31	38.0 ± 6.93	67.7 ± 7.02
J	65.7 ± 3.21	36.0 ± 1.00	29.0 ± 1.00	30.3 ± 8.62
M	64.3 ± 0.58	36.0 ± 1.00	30.7 ± 1.15	29.7 ± 0.58
O	55.0 ± 1.73	30.7 ± 1.53	26.0 ± 1.00	32.0 ± 1.00
P	76.7 ± 3.06	40.0 ± 1.73	33.0 ± 2.00	32.7 ± 2.08
R	65.3 ± 3.06	33.0 ± 1.73	18.3 ± 3.51	29.0 ± 3.00
S	75.7 ± 0.58	38.0 ± 0.00	17.3 ± 1.53	54.3 ± 2.31
N	**$\alpha_2 \pm$ SD (degrees)**	**$\phi_2 \pm$ SD (degrees)**	**$\phi_{p2} \pm$ SD (degrees)**	**$M_{e2} \pm$ SD (Nm)**
F	81.0 ± 3.61	39.7 ± 4.16	30.3 ± 0.58	71.3 ± 8.02
J	65.7 ± 1.53	36.3 ± 1.53	30.0 ± 1.00	36.7 ± 2.52
M	65.0 ± 2.65	36.3 ± 1.53	33.7 ± 1.53	34.3 ± 2.31
O	56.0 ± 3.61	32.0 ± 3.00	24.0 ± 1.00	20.7 ± 2.31
P	77.7 ± 2.52	39.0 ± 2.00	33.7 ± 1.53	32.0 ± 3.00
R	70.0 ± 3.00	37.3 ± 1.53	26.7 ± 1.15	31.0 ± 3.61
S	74.3 ± 2.52	36.0 ± 1.00	18.3 ± 1.53	52.0 ± 6.24

Abbreviations: α, ROM; ϕ extensibility of the hamstrings; ϕ_p, first detection of pain; M_e, maximum exerted passive muscle moment.

ISLR. The significance of the differences of the mean values were determined with the Student's t-test.

RESULTS

Table 2 and 3 give the mean maximum values and standard deviations of the ROM, extensibility of the hamstrings, first sensation of pain and the elastic moment obtained in the subjects of the control group and the stretching group in the pretest and posttest sessions. It was initially hypothesized that the stretching program would result in changes of the variables in only one direction. Therefore we used a one-tailed test for the stretching group. However, in the control group a two-tailed test was applied.

Table 3: Mean Values and Standard Deviations in Subjects of the Stretching Group in Pretest ($index_1$) and Posttest Session ($index_2$)

N	$\alpha_1 \pm$ SD (degrees)	$\phi_1 \pm$ SD (degrees)	$\phi_{p1} \pm$ SD (degrees)	$M_{e1} \pm$ SD (Nm)
D	73.7 ± 3.51	27.7 ± 4.04	22.0 ± 3.00	32.3 ± 3.51
F	82.0 ± 3.00	45.7 ± 1.53	33.7 ± 1.53	53.3 ± 6.11
G	79.7 ± 1.53	47.3 ± 3.06	35.7 ± 2.52	29.7 ± 3.21
H	82.0 ± 6.56	51.7 ± 2.89	36.7 ± 4.16	41.3 ± 3.51
K	62.0 ± 5.29	26.0 ± 3.00	25.7 ± 3.51	44.3 ± 10.20
L	67.0 ± 4.36	38.0 ± 3.46	28.7 ± 2.52	40.3 ± 5.51
N	77.0 ± 1.73	40.0 ± 1.00	34.0 ± 2.00	46.7 ± 1.53
N	**$\alpha_2 \pm$ SD (degrees)**	**$\phi_2 \pm$ SD (degrees)**	**$\phi_{p2} \pm$ SD (degrees)**	**$M_{e2} \pm$ SD (Nm)**
D	73.0 ± 3.46	36.0 ± 1.00	30.0 ± 2.00	35.0 ± 7.00
F	88.7 ± 2.31	53.7 ± 1.53	53.7 ± 1.53	69.7 ± 4.93
G	84.7 ± 0.58	51.3 ± 1.15	48.0 ± 1.00	33.7 ± 2.08
H	78.3 ± 1.53	45.0 ± 1.73	38.3 ± 2.52	49.0 ± 6.24
K	75.7 ± 3.21	36.3 ± 1.53	35.3 ± 2.31	80.0 ± 7.94
L	75.7 ± 2.52	41.7 ± 0.58	32.0 ± 1.73	62.3 ± 3.79
N	84.7 ± 0.58	48.7 ± 0.58	47.3 ± 1.53	53.7 ± 3.06

Abbreviations: α, ROM; ϕ extensibility of the hamstrings; ϕ_p, first detection of pain; M_e, maximum exerted passive muscle moment.

Table 4: Results of the One-Tailed Paired Samples t-test on Variables of the Stretching Group

VAR	Mean Diff	SD Diff	T	p
α	−5.3	5.85	−2.41	0.026
ϕ	−5.2	5.78	−2.37	0.027
ϕ_p	−9.7	6.25	−4.13	0.003
M_{e75}	−0.2	0.43	−1.30	0.120
M_e	−13.6	11.94	−3.02	0.012

Abbreviations: α, ROM; ϕ, extensibility; ϕ_p first detection of pain; M_e, maximum exerted passive muscle moment; M_{e75}, exerted passive muscle moment.

Comparison of the data of the stretching group before and after the training program (Table 4) with a one-tailed paired samples t-test showed a significant increase in both the ROM, the extensibility of the hamstrings, the first detection of pain and the passive elastic muscle moment ($p < .05$). The elasticity, M_e values at an extensibility of 75% (M_{e75}) showed no significant increase ($p > .05$). The elasticity curves, M_e as a function of angle ϕ in the pretest and posttest sessions were identical (fig 4). Comparison of the data of the control group in pretest and posttest sessions (table 5) with a two-tailed paired samples t-test showed no significant change of the variables mentioned. The elasticity curves were also identical in pretest and posttest sessions.

DISCUSSION

Although the number of trained subjects (N = 7) in this study is quite small, the results show that a home program of stretching exercises has only a modest influence on the range of the leg excursion, certainly from a therapeutical point of view. The greatest increase in ROM as a result of physical therapy has been reported by Markos.[5] Comparing the effect of proprioceptive neuromuscular facilitation (PNF) hold-relax and contract-relax therapy in young female

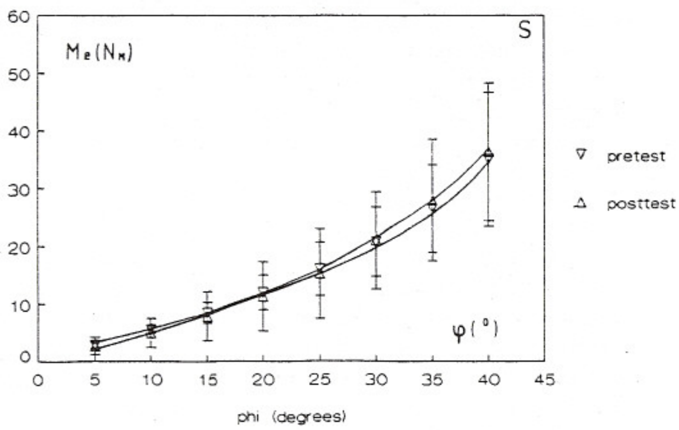

Fig 4—Mean and standard deviation of the passive muscle moment M_e established for the common ϕ tract per 5° of the angle ϕ from the pretest and posttest measurements in 7 subjects of the stretching group (S) and 7 subjects of the control group (C) (∇ pretest, △ posttest).

volunteers suffering from short hamstrings, the author measured a mean increase of 20° in ROM of the leg during active SLR in the subjects treated with hold-relax therapy. In our experiment the mean increase in ROM in the training group was about 5° (Table 4).

There are several options to explain the different outcomes, predominantly regarding differences in both therapy and measuring method. With respect to the therapy it should be mentioned that when prescribing a home exercise program the exact and regular performance of the program is never entirely assured. Moreover, in such a program the amount of stretching force that is exerted on the muscles during exercise is not controlled. With respect to the measuring method it is important to define valid variables. It is necessary to distinguish between an ISLR equipment capable of measuring more variables, and a manual test with a handheld goniometer. Also, keep in mind that the reproducibility of the ROM (angle α) depends on the performance (active or passive) and direction (sagittal plane or abduction, adduction) of the leg movement, possible flexion of the knee, muscle activity which is provoked, but most of all on the maximum moment which is exerted on the hamstrings. This was shown in reproducibility tests by the occurrence of considerable differences for the variables in the measurements of a subject within one test session. The range of the exerted moment M_e varied up to 17Nm. Differences in the angles α and ϕ, 15°, and 8° respectively were measured.[14-16] This significant change in α and ϕ during one test session illustrates the influence of the exerted moment and the muscle activity that is provoked. Therefore, the EMG of the hamstring muscles was used to check for electrical activity during the lifting of the leg to determine the passive stiffness. Excitation of the muscles will influence the value of M_e.[17] Only at the end of the ROM of the leg there was some irregular muscle activity. Thus all maximum values of α, ϕ, and M_e were defined by the beginning of the EMG. These variables were not considered in the Markos study.

Another question is the use of the angle α as a parameter for hamstring extensibility. This practice is not correct because of the pelvic tilt, ie, the extensibility of the back muscles, also contributes to this angle. Therefore, the increase of the pelvic-femoral angle ϕ is a better parameter for hamstring extensibility. In our study the mean increase of angle ϕ in the trained group was about 5° (Table 4).

In theory an increase in extensibility of the hamstrings can be achieved in the following two ways: by a change in the elasticity of the muscles or by an increase in pain tolerance, ie, stretch tolerance. In our study we could not establish a marked change in hamstring elasticity. This was checked for M_e values at an extensibility of 75% (M_{e75}) in pretest and posttest sessions (Table 4). However, the maximum moment that could be applied during the posttest session was markedly increased in the trained subjects. This finding indicates that an increase in extensibility of the hamstrings as a result of stretching exercises is caused by an increase in stretch tolerance of the subjects. There is a significant shift in ϕ_p for the trained subjects in the direction of the maximum extensibility ϕ (Table 4).

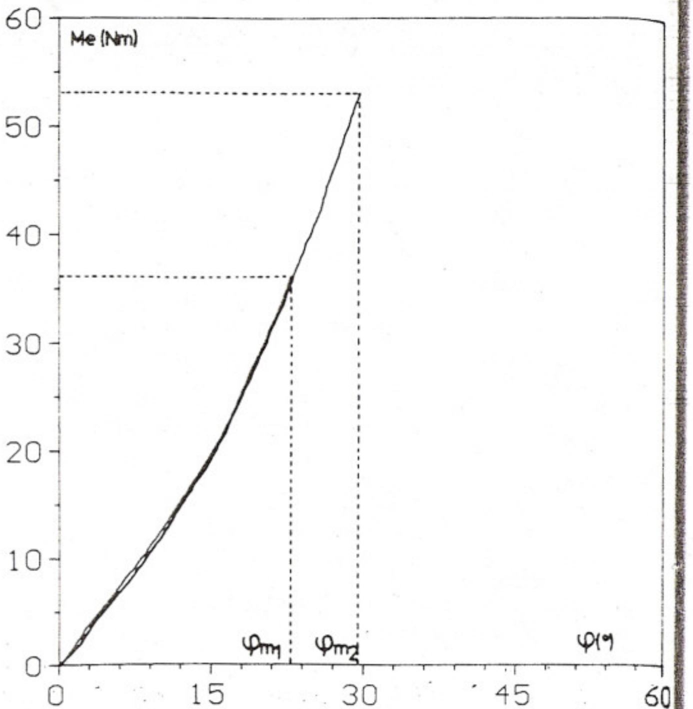

Fig 5—The passive muscle moment M_e as a function of the angle ϕ, established from two measurements in a subject within one test session. This shows that the maximum angle ϕ (ϕ_m) that is achieved depends on the moment that is tolerated.

The extensibility of the hamstrings depends on the exerted moment, whereas the maximum moment that can be exerted in its turn depends on the stretch tolerance of the subject (fig 5). It should be emphasized that it is always the subject who indicates to stop the leg raise. It will be clear that the relation between stretch tolerance and extensibility of the hamstrings makes studies on effect of stretching exercises on hamstring muscle worthless when there is no information about the muscle moment as a function of the extensibility.

Table 5: Results of the Two-Tailed Paired Samples *t*-test on Variables of the Control Group

VAR	Mean Diff	SD Diff	T	*p*
α	−0.7	1.97	−0.95	0.376
ϕ	0.2	2.89	0.22	0.834
ϕ_p	−0.6	4.85	−0.34	0.747
M_{e75}	−0.3	0.52	−1.27	0.250
M_e	−0.3	5.94	−0.15	0.888

Abbreviations: α, ROM; ϕ, extensibility; ϕ_p, first detection of pain; M_e, maximum exerted passive muscle moment; M_{e75}, exerted passive muscle moment at 75% extensibility.

CONCLUSIONS

The results of this study indicate that if there is any effect of stretching exercises on the extensibility of short hamstrings, this effect is only slight and not caused by a change in elasticity but caused by an increase in the stretch tolerance of the subject.

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Suppliers

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b. EBN 8500-1250, Depex type Brosa, Brosa GmbH & Company, Tettnang, Germany.
c. Red Dot, 3M Medical-Surgical Division, St. Paul, MN 55144-1000.
d. Type E7527, Department of Medical Physics, University of Groningen, Bloemsingel 10, 9712 KZ Groningen, The Netherlands.