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Section: Biomechanics

Influences of strength-, stretching- and circulatory exercises on flexibility parameters of the human hamstrings

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Abstract

The purpose of this study was to compare the effect of resistance training, static and ballistic stretching and stationary cycling on the range of motion (ROM) and end ROM torque of hip joint flexion, resting tension of the hamstrings and stretch-induced electromyographic (EMG) activity of the hamstrings. Four separate experimental groups performed either 15 min resistance training of the hamstrings (n = 12), 15 min static stretching of the hamstrings (n = 14), 15 min ballistic stretching of the hamstrings (n = 16), or 15 min stationary cycling (n = 12). A control group (n = 15) remained resting for 15 min. ROM was increased after static and ballistic stretching and after stationary cycling. ROM remained unchanged in the resistance training group as well as in the control group. End ROM torque showed a significant increase after static and ballistic stretching. Static and ballistic stretching and stationary cycling decreased EMG activity significantly. Resting tension was decreased only after stationary cycling ($p < 0.1$). The constancy of the muscle resting tension suggests that merely the subjects' tolerance to higher stretching strain brings about the enlargement of ROM after short-term stretching exercises. The enlargement of ROM after stationary cycling could have been caused by the poor decrease of resting tension.

Key words: EMG, flexibility, hamstrings, resistance training, resting tension, stretching torque, stretch training

Introduction

Flexibility is an important attribute of a healthy as well as of a physically fit muscle. Therefore stretching exercises are an essential part of preparation for subsequent sporting activities. In muscular therapy, exercises to improve the flexibility of the muscle are applied to treat hypertensed and short muscles or myogelosis. Moreover stretching exercises are applied after strength training programs in order to prevent muscle contractures supposed to be a consequence of resistance training. In general the following effects are attributed to stretching: precaution against developing short muscles (3); lowering of muscular resting tension (1,15,21); prevention of muscle tightness (15); increase of joint's range of motion (ROM; 6,9,10,13,22,24); prophylaxis against injuries (6,24), and due to these stretching effects a general increase of muscular performance (2,6,25,28).

Experimental verification of those effects, however, has so far only been obtained successfully for the enlargement of the joint’s ROM. This effect of stretching could be demonstrated not only after long-term stretching programs lasting several days or even some weeks (6,9,10,24) but also after short-term stretching programs of 5 - 50 min duration: Such short-term effects are described by Cornelius & Hinson (4), Moore & Hutton (19), and Osternig et al. (22) who obtained an increase of ROM in hip joint flexion. Möller et al. (18) reported a stretch-induced increase of ROM in different movements of the lower extremity, and Hubley et al. (13) found increased ROM after short-term stretching exersises of hip flexion and hip extension stretching. Only Toft et al. (26) reported a decreased passive tension in ankle dorsiflexion after short-term stretching of the soleus muscle and Madding et al. (15) found a reduced stretching resistance after a 15 s passive stretch of the thigh adductor muscle. The rest of the above mentioned effects attributed to stretching are merely deduced from the observation that flexibility is increased after stretching exercises. The effect of short-term resistance training on a muscle’s flexibility has not yet been proved experimentally.

Further more, it is supposed that stretching exercises and resistance training could have adverse effects on the muscular stretching parameters. According to this hypothesis a muscle should display an increased resting tension (26) and a decreased flexibility after resistance training. Because of this, it is usually recommended to stretch a muscle after each resistance training workout in order to counteract the shortening effect of strength training.

Besides stretching exercises a warming-up program mainly includes exercises to improve endurance - for example running, sprinting and jumping. These exercises are expected to increase the blood circulation of the muscle and thereby improve its elastic properties (13).

In order to become qualified to arrange appropriate training programs or to prescribe suitable rehabilitative measures, it is necessary not only to know the effects of stretching on ROM, but also to learn about the effect of stretching and other kinds of muscle training on muscle resting tension and relaxation capacity. Therefore, the purpose of this study was to compare the influence of short-term stretching programs with the influence of short-term resistance training and short-term stationary cycling on range of motion, resting tension and stretch-induced electromyographic acivity of the hamstrings.

Materials and Methods

Subjects. In the investigation, 69 healthy male volunteers aged 20 to 34 participated with written informed consent. All were students of physical education or junior assistants. None of them had previously taken part in a specific stretching program different from normal routine. None of them had taken part in a performance training of such kinds of sports which require increased hip joint flexibility. A random assignment of the subjects to one of the four treatment groups or to the control group was guaranteed.

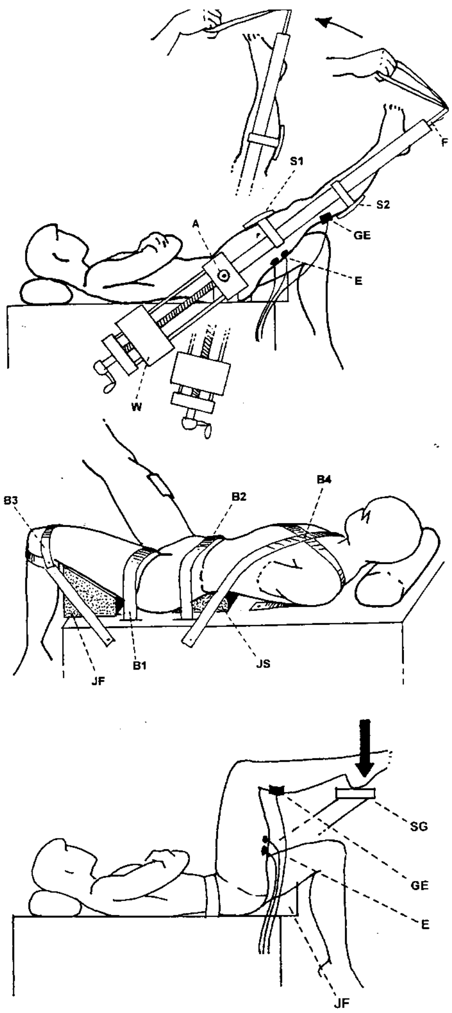

Figure 1 Experimental station. *Above*: Stretching balance beam for investigation of length-resting tension relationship of the hamstrings. A: Axis of rotation with goniometer. E: Surface electrodes. F: Strain gauge. GE: Ground electrode. S_1, S_2: Adjustable leg supporting planes of the balance beam. W: Movable weight. *Middle*: Subject fixed onto the experimental station. JF: Thigh-supporting jack. JS: Sacrum-supporting jack. B_1-B_4. Fastening belts. *Below:* Position for performing maximal isometric voluntary contractions. SG: Strain gauge

Mechanical set-up. In order to determine the stretching parameters of the hamstrings in the course of straight leg raising tests an experimental station was constructed. On the right hand side of the experimental station (shown in Fig. 1) a balance beam was fixed, onto which the right leg of the subject - lying in supine position - was laid and fastened against passive knee flexion. To neutralise the gravitational force of the subject’s leg, an adjustable counterweight at the opposite end of the beam could be moved by a crankshaft until the balance beam was in a state of equilibrium.

To quantify the angle of hip flexion, a goniometer (Dinopot-HQ5, accuracy of measurement = 0.15°) was fixed at the balance beam's axis of rotation and calibrated by means of a spirit-level. A strain gauge (carrier frequency amplifier: KWS 3073 Hottinger-Baldwin) was installed at the end of the balance beam to pick up the stretching force necessary to perform the hip flexion by means of a canvas loop (Fig. 1). The calibration of the strain gauge was carried out with a standardised weight placed at the end of the balance beam in horizontal position. Surface electrodes (sinter electrodes, pick-up area 6 mm, interelectrode distance 20 mm, ground electrode at the right shank) were attached to the subject's hamstrings to pick up the electrical activity of the hamstrings in the course of the stretching procedure. A custom-made preamplifier (cutting-off frequency: 2 kHz; input/exput-quotient: 0.002) was used to amplify the EMG-signals. The goniometer, the strain gauge as well as the EMG-amplifier were linked to a PC via a 12bit A/D-converter (Fig. 2). All signals were picked up in steps of 1ms each and stored simultaneously.

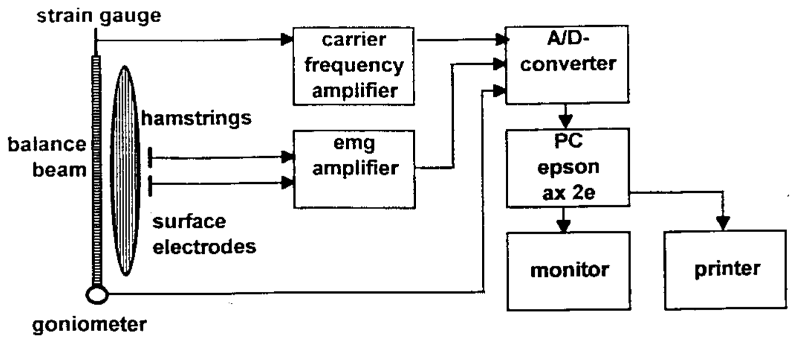

Figure 2 Simplified block diagram of the mechanical set-up.

Treatment programs. After a 5 min warm-up and the pretest the subjects performed one of the four 15 min training programs:

a) **Static stretching** consisted of three sets of different static stretching exercises for the hamstrings. The exercises had to be performed three times each per leg - 15 s holding a stretched position and 20 s of relaxation alternately - with resting intervals of 3 min in between the sets.

b) **Ballistic stretching** included the same three exercises as static stretching. These had to be performed rhythmically for 15 s three times each per leg. Each 15 s stretching period was followed by a 20 s period of relaxation, each set was followed by a resting interval of 3 min.

c) **Resistance training** was performed on a leg flexion machine (custom-built; with exchangeable disc-weights) in five sets of 12 repetitions each (resistance weight 70% of maximal isometric voluntary contraction-force) with 3 min resting periods between the sets.

d) **Stationary cycling** consisted of a 15 min workout on an ergometer, during which subjects had to choose an individually adapted load (peak pulse rate after workout between 140 and 160 Hz).

e) The **control group** rested for a period of 15 min between prettest and posttest.

Experimental protocol. After the subject had been prepared for bipolar surface electromyography in the usual way, the electrodes were attached to the right leg in the middle of the belly of the hamstrings. After a test of the interelectrode resistance which had to be less than 5 kΩ, the subject was placed in a supine position on the experimental station. The transversal hip joint's axis of rotation had to be aligned with the balance beam’s axis of rotation. Afterwards, the subject was strapped on to the experimental station (Fig. 1): An anatomically-shaped supporting jack was placed under the subject’s sacrum (Fig. 1, JS). The supporting jack in conjunction with two belts - one of them running over the anterior superior spines of the ilium (Fig. 1, B2), the other around the proximal part of the left thigh (Fig. 1, B1) - held the subject’s sacrum fixed at an angle of 15° to the horizontal plane and prevented the pelvis from any visible rotation around a transversal axis in the course of the right hip flexion procedure. To prevent the right leg ROM from being limited by the passive tension of the left side hip flexors, a block under the left thigh (Fig. 1, JF) held the left hip joint fixed at an angle of 25° (horizontal thigh with extended hip = 0°). Shoulder belts fitted crosswise (Fig. 1, B4) and a knee belt (Fig.1, B3) prevented the subject from sliding in cranial or caudal direction. The right leg was fixed to the balance beam (knee joint extended, the femur parallel to the balance beam) and balanced by the movable counterweight. The subject was instructed to relax and neither to resist the experimental manoeuvres nor to support the manoeuvres by contracting the hip flexor muscles. After the subject had been asked to give an acoustic sign , when - in the course of the flexing manoeuvre - the sensation in the back of the thigh changed from discomfort to slight pain, a single stretching procedure was carried out. By means of a canvas loop fixed to the strain gauge at the end of the balance beam, the beam was moved to the hip-flexed position in which the sign was given by the subject and was moved back into the initial position (= pretest). After this the subject left the station and performed one of the four training programs or remained inactive for 15 min.

Immediately after the training, the subject was again strapped on to the experimental station for a second time and had to undergo a second stretching procedure (= posttest). Finally the subject had to perform a maximal isometric voluntary contraction: without loosening the belts, the subject’s right leg was taken off the balance beam and the heel was placed on a strain gauge, with both hip joint and knee joint flexed to 90°. In this position, the subject had to press down the heel as hard as possible for nearly 3 s (Fig. 1, below). The EMG of the maximal isometric voluntary contraction served as a reference value for quantifying the EMG activity of the hamstrings in the stretching procedures.

Investigated parameters. The right hip **range of motion** (**ROM**) reflecting the flexibility of the hamstrings was determined by the angle measured at the end of the stretching procedure via the balance beam goniometer (extended hip = 0°).

The **end ROM torque** reflecting the stretch loading capacity of the hamstrings was determined by the torque that had to be generated to reach ROM, i.e. what the subject was willing to tolerate.

The **passive muscle stretching tension** of the hamstrings as a result of both, the elastic resting tension and the viscous resistance against the stretching of the muscle fibers, was defined in this study as the resistance of the voluntary inactive muscle against the stretching procedure. Since the gravitational force of the subject’s leg had been neutralised in advance by means of the above mentioned balance beam (Fig. 1) and the viscous proportion of the stretching tension had been minimized by using a flexing angular-velocity smaller than 30°/s, the resting tension of the hamstrings was identical with the stretching torque that had to be generated to carry out the stretching procedure. The passiv muskular stretching tension was picked up by the strain gauge over the entire stretching procedure in steps of 1 ms each and simultaneously stored with the signals of the goniometer. Whereas in smaller angles (up to 30°) of the hip flexion manoeuvre the moment of inertia influenced the stretching torque, in larger angles involuntary or reflexive contractions of the hamstrings contributed to the stretching resistance. To ensure a satisfactory validity of the muscular resting tension, the stretching torque occurring when the leg passed the 70° angle of hip flexion was chosen as the representative value of resting tension.

Because the hamstrings will answer to the stretching procedure with electrical activity, due to involuntary contractions and/or reflexive activity of the hamstrings, the electrical activity signals of these muscles were recorded during the entire stretching procedure, rectified, integrated and expressed as a percentage of the electromyographic activity obtained during a maximal isometric voluntary contraction of the hamstrings. The degree of the **electromyographic (EMG) activity** reflects the relaxation capacity of the neuro-muscular system, because all subjects were instructed not to resist actively the stretching procedure. Representative electromyographic values were obtained for the last 20° before reaching the extreme position of hip flexion.

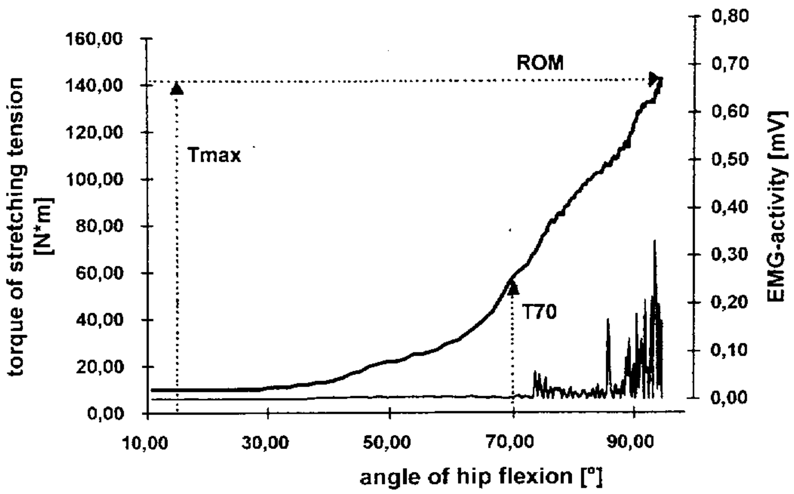

Figure 3 Hip-angle stretching-tension curve (thick line) and full wave rectified EMG of the reflex activity (thin line) of a single stretch procedure of the hamstrings. ROM: Range of motion. Tmax: End ROM torque. T70: Muscle resting tension

A block diagram (Fig. 2) illustrates the system for the recording and analysis of the experimental data, whereas Fig. 3 shows one subject's hip-angle stretch-tension curve and the EMG activity of the hamstrings picked up during a single stretching procedure.

In a pilot study involving 62 subjects, quantification of ROM produced a retest correlation coefficient of $r_{tt} = 0.96$ on condition that two hip-flexing procedures were carried out within a 10 s interval. However, r_{tt} attained 0.91 on ondition that the subject left the experimental station after the pretest and was afterwards replaced on it to carry out the retest. The retest correlation of end ROM torque reached 0.89 (0.86 respectively), and the retest correlation of the resting tension recorded when the balance beam passed the 70° angle attained 0.94 (0.89 respectively). Therefore the reliability of the chosen method was considered acceptable.

Statistics. ANOVA procedure was used to detect differences between the pretest mean values of the treatment groups (control group included). Additionally, ANOVA was employed to compare the mean pretest-posttest differences. In both cases, when significant F-values had been found Duncan's post-hoc procedure was used to determine which mean values were significantly different from each other. Repeated measure ANOVA followed by paired t-tests was used to test the differences between the pretest and posttest mean values within the treatment groups as well as the control group. To examine the reliability, the product moment correlation test was employed.

Results

The descriptive statistics for the pretest and posttest values of the 4 examined parameters (means ± SD) are presented in Table 1. The hip-angle resting-tension curves in Fig. 4 elucidate the pretest-posttest history of ROM, end ROM torque and resting tension.

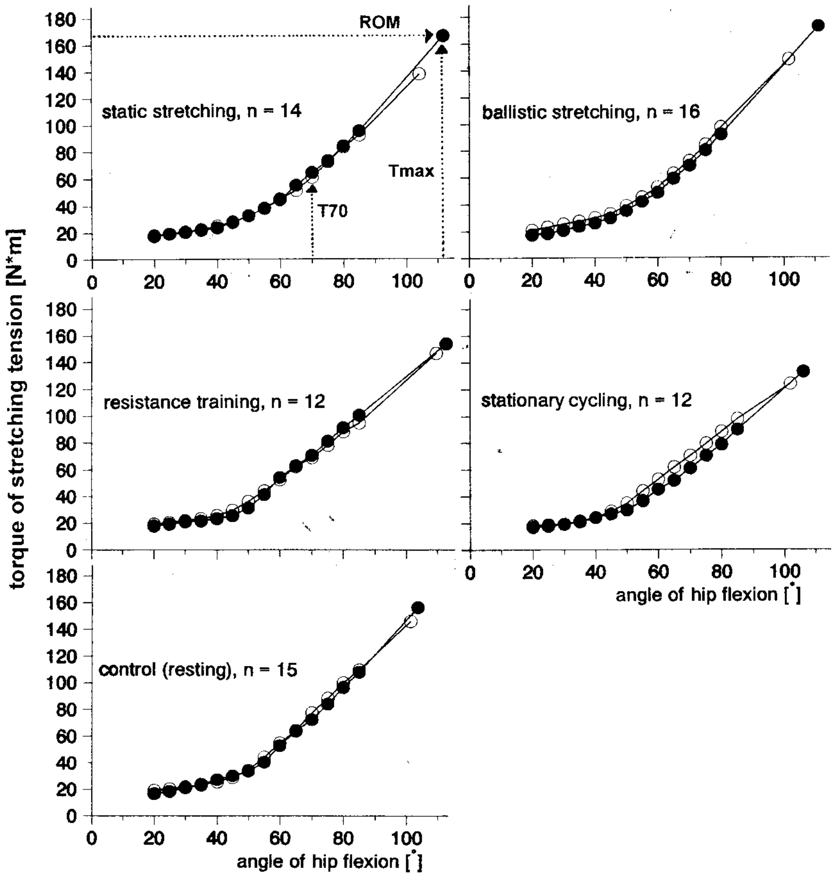

Figure 4 Hip-angle stretching-tension curves of stretch procedures of the hamstrings before (empty circles) and after (filled circles) four different 15 min training sessions and resting. All curves display the means within the treatment group. ROM: Range of motion. Tmax: End ROM torque. T70: Muscle resting tension

Table 1 Range of motion (ROM) and end ROM torque (Tmax) of hip joint flexion and EMG-activity (EMGmax) and resting tension (T70) of the hamstrings before (pretest) and after (posttest) 15 min treatments of resistance training (RT), static stretching (SS), ballistic stretching (BS) and stationary cycling (SC) and in the control group (CO). EMG-activity expressed as a percentage of the EMG activity of maximal voluntary contraction. Means ± SD.

	Parameters	**Pretest**	**Posttest**
RT (n = 12)	ROM [°]	109.3 ±13.6	111.3 ±14.9
	Tmax [N*m]	146.9 ±28.5	154.0 ±47.8
	EMGmax [%]	7.19 ±8.47	5.25 ±5.31
	T70 [N*m]	70.1 ±24.5	71.9 ±21.3
SS (n = 14)	ROM [°]	103.6 ±13.3	111.4 ±15.8 **
	Tmax [N*m]	138.3 ±36.7	166.5 ±47.1 *
	EMGmax [%]	7.82 ±7.36	3.92 ±4.59 **
	T70 [N*m]	62.2 ±30.5	65.9 ±22.2
BS (n = 16)	ROM [°]	104.2 ±11.9	112.6 ±12.4 **
	Tmax [N*m]	148.7 ±36.1	172.1 ±49.9 *
	EMGmax [%]	7.73 ±11.01	4.46 ±6.45 *
	T70 [N*m]	68.9 ±21.7	68.6 ±19.8
SC (n = 12)	ROM [°]	103.1 ±9.4	107.1 ±10.9 **
	Tmax [N*m]	124.0 ±36.9	132.8 ±32.3
	EMGmax [%]	10.22 ±11.04	7.09 ±6.38 (*)
	T70 [N*m]	70.9 ±35.2	62.2 ±23.1 (*)
CO (n = 15)	ROM [°]	102.5 ±12.9	104.4 ±13.1
	Tmax [N*m]	146.8 ±33.7	156.9 ±41.7
	EMGmax [%]	9.99 ±6.35	10.35 ±6.27
	T70 [N*m]	75.4 ±29.9	71.1 ±35.9

Differences to pretest: (*) = $p < 0,1$; * = $p < 0,05$; ** = $p < 0,01$

ANOVA did not show any significant differences of the mean pretest values of the examined parameters between the four treatment groups and the control group (s: Table 2). Repeated measures ANOVA elucidated a significant within subject effect ($F = 30.68$, $p < 0.001$). The follow-up t-test procedures showed that ROM was significantly increased after 15 min treatments of static stretching, ballistic stretching and stationary cycling. End ROM torque only increased significantly with the treatments of static stretching and ballistic stretching whereas the enlargement of this parameter in the resistance-training group and in the stationary-cycling group was not significant. Resting tension was only decreased after stationary cycling ($p < 0.1$), a result illustrated by the length-resting tension curve in Fig. 4. The decrease of the EMG activity reached significant values after static stretching ($p < 0.05$), ballistic stretching ($p < 0.05$) and stationary cycling ($p < 0.1$). All parameters remained unchanged after resistance training and in the control group.

Table 2 Results of ANOVA (F ratio and F probability) comparing the pretest mean values of the examined parameters between the treatment groups and the control group.

Parameters	F ratio	F prob
ROM	0.6145	0.6537
Tmax	1.1284	0.3511
EMGmax	0.3202	0.8634
T70	0.4004	0.8077

The analysis of the pretest-posttest differences produced a significant F-value only for ROM ($F = 2.71$, $p = 0.038$). In detail, Duncan's procedure showed that the pretest-posttest differences of both, the static-stretching group and the ballistic-stretching group, were significantly higher than those of the control group, respectively, and the pretest-posttest differences of the ballistic-stretching group were higher than those of the resistance-training group (Table 3). There were no differences in the effectiveness of either static stretching or ballistic stretching.

Table 3 Pretest-posttest differences (means) of hip flexion range of motion (ROM) caused by 15 min treatments of resistance training (RT), static stretching (SS), ballistic stretching (BS), stationary cycling (SC) and resting (CO).

	Treatment groups				
Parameters	**RT**	**SS**	**BS**	**SC**	**CO**
ROM [°]	-1.95	-7.76 *	-8.41 § *	-3.97	-1.95

Differences to RT: § = $p < 0.05$
Differences to CO: * = $p < 0.05$

Discussion

ROM, end ROM torque. The results of the present study showed an increase of hip flexion ROM in both static and ballistic short-term stretching of the hamstrings. In contrast to several investigators who found a mean pretest hip angle of 70° - 90° in straight leg raising tests (6,18) in the present study, the mean values of the hip angle reached 102° - 109°. We believe that the following factors were responsible for this:

1. Being PE students all subjects were active sportsmen and well trained compared to sedentary persons. All of them more or less regularly used common stretching exercises as a preparation for their personal training or their (everyday) training during university courses (as PE students).

2. The special method of investigating ROM used in this study (the fixation of the contralateral thigh in a hip-flexed position of 25°) implied that the pelvis was less inclined (and the lumbar spine less curved) than in a supine position with extended contralateral hip joint and/or without strapped pelvis, respectively. This may have resulted in greater hip flexion ROM.

The hip-angle stretching tension diagrams in Fig. 4 reflect the relation between the origio-insertio length and the passive stretching tension of the hamstrings. Fig. 4 demonstrates that the ROM/end ROM torque quotient did not change from pretest to posttest. This suggests that higher end ROM torque values tolerated by the subjects (or by the stretched muscles, respectively) bring out higher ROM values, and - in the present study - that the effect of short-term stretching on ROM must be ascribed to the increase of the subject’s tolerance to stretching strain.

Though the posttest ROM of the resistance-training group showed a similarly high mean value as the static-stretching group, in the resistance-training group - as well as in the control group -, no significant change of ROM from pretest to posttest was found. Despite the statistics showed that the higher values of the pretest ROM in the resistance-training group was not significantly different from the other groups we acknowledge that the high pretest ROM in the resistance-training group may have resulted in a type II error which would have been prevented by using parallelized samplings of the treatment groups.

The stationary-cycling group also showed a significant increase of ROM. Since the end ROM torque of the stationary-cycling group had not increased significantly, the enhancement of ROM in this case might be due to a decrease in resting tension which only occurred in the stationary-cycling group and presumably caused a reduced restistance to the stretching procedure. This decrease of resting tension after stationary cycling may be attributed to an improved liquid content of the tissue which reduces the muscle tightness due to an enlargement of the viscous compliance.

Passive muscle stretching tension (i.e. resting tension). In the hip-angle stretch-tension diagram of the static-stretching group and the ballistic-stretching group, respectively, the pretest curves and the posttest curves show an almost congruent shape between the 20° hip angle and the 85° hip angle (Fig. 4). This discloses that the muscle’s resistance to the stretching procedure was not affected by the stretching exercises. Additionally, no significant change in resting tension from pretest to posttest was detected by the statistics for the static-stretching group and the ballistic-stretching group. This result is in contrast to the findings of Madding et al. (15) and Toft et al. (27) and in contrast to the common expectation that stretching may reduce the resting tension (see introductory chapter) and, in this way, may remove muscular tightness. Unlike Madding et al. (15) and Toft et al. (27) we did not test the resting tension during or immediately after the stretching treatments, as our subjects had to go from the training station back to the experimental station to be strapped on it again to perform the posttest. On account of these differences in the experimental protocols, we concluded that if any reduction of the resting tension had occurred as a result of the static stretching and the ballistic stretching treatment, it would have been eliminated due to subjects' muscular activity by the time (approx. 1 min later) they underwent the second stretching procedure. Even when subjects were tested - in a further investigation not yet published - immediately after single stretching procedures and did not have to leave the experimental station, we could not detect any reduction of the resting tension. In experiments with isolated muscle fibres, Ramsey & Street (23) as well as Higuchi et al. (11) showed that after stretches up to 140% - 160% of the resting length a complete reversion to the initial resting tension was established and that only after stretches above 160 % of the resting length the resting tension was reduced. Since in-vivo stretches of the hamstrings only reach a maximum of approximately 140% of the resting length (7), a stretch-induced decrease of the resting tension could not be expected for these muscles. This can be confirmed by our results of a ten-week stretch training program - not yet published - in which the posttest did not reveal any change of resting tension in a group of male subjects. A group of female subjects even presented a significant increase of the resting tension after 10 week stretch training. We suggest that an explanation of the lack of change in the resting tension can be found in the results of Maruyama et al. (16,17) and Higuchi et al. (12) who identified the high elastic stiffness of the connectin filaments (especially the titin filaments) within the sarcomeres as the main source of the resting tension.

Resistance training did not result in any change of the resting tension. Although on may expect a decrease in muscle flexibility after resistance training, we could not find enlarged muscle resistance to the stretching manoeuvre after resistance training. Regarding the experimental protocol, we suggest that if any diminished compliance of the hamstrings had occurred after the resistance training period it would have been removed by the subject's movements from the training station to the experimental station (see above!). Thus the risk of getting hypertensed muscles after resistance training seems to be rather unlikely. Consequently, the recommendation to perform stretching exercises especially after resistance training to avoid shortened muscles can be called into question.

There is controversy in the descriptions of a muscle's reaction to fatiguing contractions. It is claimed that after a phase of contraction the muscle will show an increased flexibility due to a decreased resting tension; this is believed to be caused by post-contraction inhibition of α-motoneurons and/or by reduced motoneuron excitability (5,8). In contrast to this, it was possible to demonstrate an increase of spindle discharges after fatiguing contractions as well as a decrease or even a total absence of discharges of the Golgi tendon organs (14). These results and the findings of Nelson and Hutton (20) of an increased reaction of the spindle receptors to stretching after prolonged contractions suggest that, in a stretchability test after strength training, increased motoneuron excitability and - in consequence of this - increased reflexive EMG activitiy as well as increased stretch tension of the muscle should be expected. However, our tests revealed neither a post-isometric relaxation nor an increase of the passive tension due to fatigue. It is thought that possible effects induced by strength training might have been eliminated on account of muscular activity in between strength training and the stretching test, which would be in line with the findings of Nelson and Hutton (20). Therefore the question whether fatiguing contractions are followed by reduced or enhanced resting tension remains unsolved.

The decrease of resting tension in the stationary-cycling group has been discussed above.

EMG activity. Despite the fact that subjects were asked to remain relaxed and not to resist the stretching procedure, the hamstrings generated electrical activity, in particular in greater hip flexion angles (Fig. 3). This EMG activity is probably due to both the subjects' involuntary reactions to the stretching procedure and/or reflexive contractions promoted by increased spindle afferent discharges. However, in using surface electromyography it was not possible to differentiate involuntary supraspinally triggered contractions from reflexive contractions. Though the stretch in this study (i.e. the lengthening of the hamstrings) was relatively slow (using a selfcomputed model, the lengthening rate was calculated as approximately $60mm * s^{-1} = 0.32\ \Delta l/l * s^{-1}$) we suggest that the EMG activity of the hamstrings was caused - at least in part - by increased discharge of the spindle receptors. This is supported by the results of Nelson and Hutton (20), who found increased firing rates of both, Ia and II afferent units in the course of the dynamic phase of a ramp stretch of $5mm * s^{-1}$ (approximately $0.25\ \Delta l/l * s^{-1}$) as well as in the static phase of the ramp stretch ($\Delta l/l = 0.25$). Since increased spindle afferents increase the excitability of α-motoneurons, the assumption may be made that EMG activity is promoted by stretch-induced spindle afferents.

Only in the posttest of the static-stretching and the ballistic-stretching group the EMG activity was decreased. This reduction may be attributed to the subjects becoming accustomed to the stretching tension and - in consequence of this - to a decrease of the involuntary supraspinally triggered EMG activity. Nevertheless a decreased EMG activity did not lead to a reduction of the muscle's resistance to the stretching procedure as the diagrams in Fig. 4 elucidate as well.

According to the reaction of the neuromuscular system to fatiguing contractions described above, one should expect increased EMG activity after resistance training. This could not be confirmed in this study, because no significant pretest-posttest differences of EMG activity could be established. Post-contraction after-effects had possibly been eliminated by the posttest stretch procedure - which would be in line with the above mentioned results of Nelson & Hutton (20) - provided these after-effects had not already been neutralized beforehand by the muscular activity in between the resistance training program and the posttest (see experimental protocol).

Conclusions. Though athletes are accustomed to avoid increased muscle tightness after resistance training by performing stretching exercises and both athletes and therapists aim to reduce the muscle passive tension by means of stretching, in the present study no sign of any decrease in muscle-resting tension could be found caused by short-term stretching.

Therefore, a stretch training induced increase of flexibility cannot be explained by a reduction of the passive stretching tension but, according to our findings, has to be attributed to an increase of the subject's tolerance to stretching strain. Getting used to stretching strain seems also to be responsible for the observation that subjects believe they have gained longer or more relaxed muscles after a short-term stretching program. Even after short-term resistance training the resting tension turned out to be a relatively stable muscular parameter. Due to the fact that only warm-up exercises like stationary cycling reduced the tension of the passive muscle, a program to improve flexibility should contain stretching exercises as well as exercises to increase the blood circulation in the muscle.

Since the subjects in this study were students without any muscular disease, the present findings can only be applied to healthy muscles. Questions about flexibility and resting tension of weak, immobilised or hypertensed muscles or muscles affected by myogelosis cannot be answered in the present study and require further investigations.

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