EFFECTS OF STRETCHING ON LENGTH, RESTING TENSION, AND FLEXIBILITY OF THE HUMAN HAMSTRINGS

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INTRODUCTION: The effects attributed to stretching exercises are a lowering of muscular resting tension (3,4), an increase of the joint's range of motion (ROM; 2), prevention of muscle tightness (3), precaution against developing short muscles (1), and increased muscular performance (8). Experimental verification of these effects, however, has so far only been obtained successfully for the expansion of a joint's ROM. The rest of the mentioned effects are merely deduced from the observation that flexibility is increased after stretching exercises. Therefore, the purpose of this study was to investigate the effects of short-term and long-term stretching training on ROM, resting tension (RT), muscle length (ML) of the human hamstrings, and the relaxation capacity of the neuromuscular system, i.e., the stretch-induced electromyographic activity (EMG) of the human hamstrings.

METHODS: An experimental station was constructed to determine ROM, end ROM torque (ERT), RL, and ML of the hamstrings, recently described in detail (6,7). Hip ROM was determined by the passive straight leg raising test. RT, i.e., passive muscle stretching tension was defined as the mechanically measured resistance of the passive muscle against the stretching test procedure. The stretching torque occurring when the leg passed the 80° angle of hip flexion was chosen as the representative value of RT. ERT was determined by the torque that had to be generated to reach ROM. The degree of the electromyographic (EMG) activity of the hamstrings during a stretch maneuver, expressed as a percentage of the EMG activity obtained during a MVC, reflects the relaxation capacity of the neuro-muscular system. Representative electromyographic values were obtained for the last 20° before reaching the extreme position of hip flexion. ML of the hamstrings was determined as the origio-insertio distance, in which the maximum of isometric voluntary contraction force (MVC) was generated. The following experimental groups were investigated: Short-term stretching group (SG: 14 male students), control group (CG: 15 male students), long-term stretching groups (FLG: 12 female students, and MLG: 13 male students). Short-term stretch training consisted of a 15 min static stretching program. The control group remained resting for 15 min between pretest and posttest. Long-term stretch training included 3 short-term stretching programs per week for 10 weeks.

After the subject had finished a warming-up program and had been prepared for bipolar surface electromyography in the usual way he was strapped onto the experimental station in a supine position. The subject was instructed to relax and neither to resist the experimental maneuvers nor to support the maneuvers by contracting the hip flexor muscles. After the subject were asked to give an acoustic sign when - in the course of the flexing maneuvers - the sensation in the back of the thigh changed from discomfort to slight pain, a single stretching procedure was carried out (= pretest). In SG and CG, the subject left the station and performed a 15 min static stretching program or remained inactive for 15 min, respectively. Immediately after training or after rest the subject was again strapped onto 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 of the hamstrings. In FLG and MLG, the subjects performed 3 short-term stretching programs per week for 10 weeks. Three days after the last training session, the subjects performed the posttest. After both, the pretest and the posttest, the subjects performed a MVC in each of 10 different hip joint angle positions, as described recently (6).

RESULTS: The descriptive statistics for the pretest and posttest values of ROM, ERT, RT, and EMG (means ± SD) are presented in Table 1. The hip-angle resting-tension curves in Fig. 1 elucidate the pretest-posttest history of ROM, ERT, and RT. After the training periods, ROM as well as ERT were significantly increased in SG, FLG and MLG. RT remained unchanged in SG, CG, and MLG, and increased significantly in FLG. EMG decreased significantly in SG and MLG. In FLG and MLG, no symptom of a change of ML could be detected, because the optimal length, i.e., the origio-insertio length of the maximal active force, did not alter from pretest to posttest, as Fig. 2 indicates. In CG, all parameters remained unchanged.

Table 1 Range of motion (ROM) and end ROM torque (ERT) of hip joint flexion and resting tension (RT) and EMG-activity (EMG) of the hamstrings in the pretest and posttest. Means ± SD.

	Parameters	Pretest	Posttest	
SG (n = 14)	ROM [°]	103.6 ± 13.3	111.4 ± 15.8	##
	ERT [N*m]	138.3 ± 36.7	166.5 ± 47.1	#
	RT [N*m]	62.2 ± 30.5	65.9 ± 22.2	
	EMG [%]	7.82 ± 7.36	3.92 ± 4.59	##
CG (n = 15)	ROM [°]	102.5 ± 12.9	104.4 ± 13.1	
	ERT [N*m]	146.8 ± 33.7	156.9 ± 41.7	
	RT [N*m]	75.4 ± 29.9	71.1 ± 35.9	
	EMG [%]	9.99 ± 6.35	10.35 ± 6.27	
MLG (n = 13)	ROM [°]	106.8 ± 19.4	117.9 ± 14.5	##
	ERT [N*m]	156.0 ± 52.1	197.9 ± 50.3	##
	RT [N*m]	63.8 ± 25.4	63.4 ± 25.5	
	EMG [%]	10.99 ± 7.46	4.68 ± 4.71	##
FLG (n = 12)	ROM [°]	108.1 ± 11.3	115.9 ± 13.1	##
	ERT [N*m]	87.5 ± 36.6	116.0 ± 41.3	#
	RT [N*m]	43.2 ± 17.8	48.8 ± 16.9	#
	EMG [%]	2.04 ± 1.28	1.30 ± 1.17	

Differences compared to pretest: # = $p < 0.05$; ## = $p < 0.01$

DISCUSSION: The hip-angle stretching tension diagrams in Fig. 1 reflect the relation between the origio-insertio length (calculated by a PC-model and expressed as the associated angle of hip joint flexion) and the passive stretching tension of the hamstrings. The diagram 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 as well as the effect of long-term stretching on ROM must be ascribed to the increase of the subject's tolerance to stretching strain. 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 caused by short-term stretching or long-term stretching, respectively, could be found. The constancy of RT may be explained by the recent findings (5) that the source of the resting

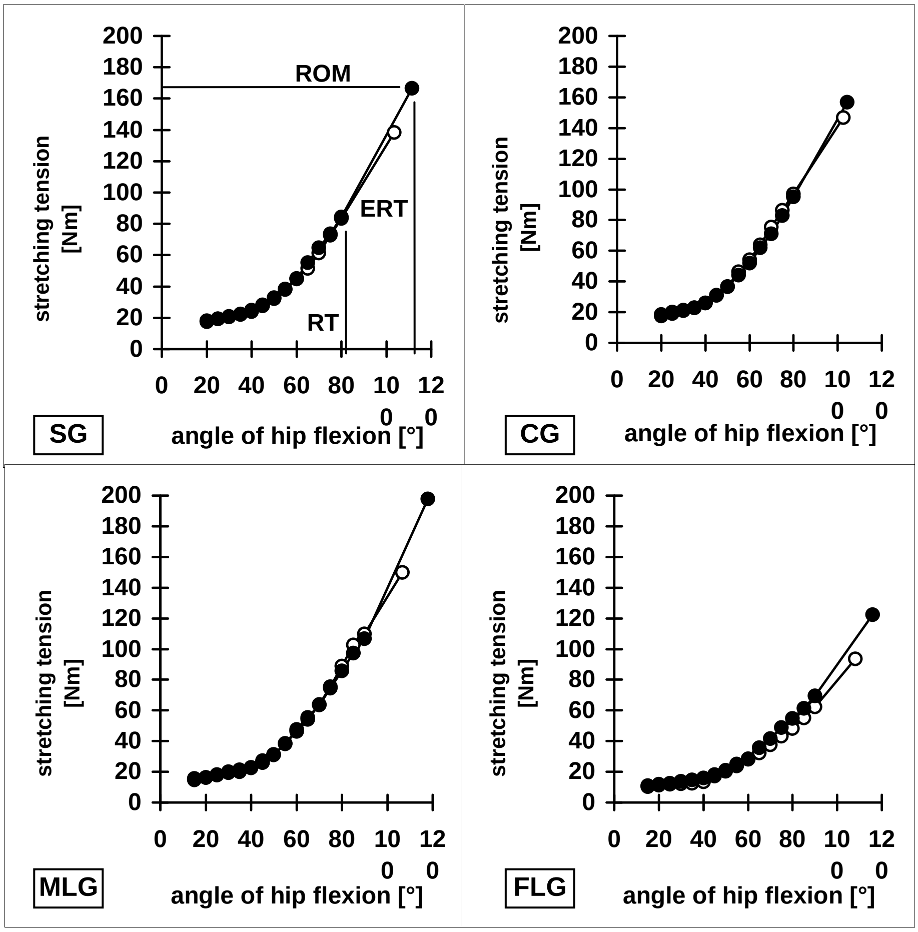

Fig 1 Hip-angle stretching-tension curves of stretch procedures of the hamstrings. Pretest: empty circles. Posttest: filled circles. All curves display the means within the treatment group. ROM: Range of motion. ERT: End ROM torque. RT: Muscle resting tension

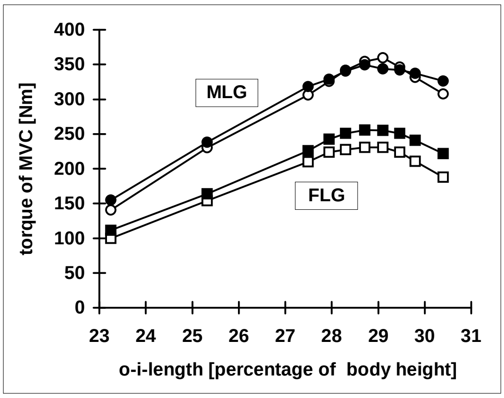

Fig. 2 Length of active-tension curves of the hamstrings before (empty symbols) and after (filled symbols) a 10 week stretching training. MLG: 13 male subjects. FLG: 12 female subjects.

tension can be seen in the high elastic stiffness of the titin filaments within the sarcomeres. The increase of RT in FLG indicates a hypertrophy of the hamstrings, i.e., an increase of the thin and thick filaments and - connected with this - an increase of titin filaments. This hypertrophy may be caused by the mechanical stress placed on the sarcomeres during the stretching exercises of the female subjects. This suggestion can be supported by the significant increase of the hamstrings' MVC in FLG. In the long-term stretching groups, the constancy of ML may be attributed to the functional constraints of the subjects' daily movement behavior, which presumably demands a constant optimal length of the hamstrings. In the posttest of both, SG and MLG, 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 decreased EMG activity did not lead to a reduction of the muscle's resistance to the stretching procedure.The findings lead to the assumption that stretch training effects an enhancement of muscular flexibility, but is not the appropriate means to reduce muscular stiffness or to enlarge muscle length.

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