

HIP JOINT LOAD AND MUSCULAR ACTIVATION DURING RISING EXERCISES

Gunnar Németh, Jan Ekholm, Ulf P. Arborelius,
Kristina Schüldt and Karin Harms-Ringdahl

Kinesiology Group, Department of Anatomy, Karolinska Institute and Department of Physical Medicine and Rehabilitation, Karolinska Hospital, Stockholm, Sweden

ABSTRACT. The load on the hip joint and activation of the gluteus maximus, hamstrings, adductor magnus and rectus femoris muscles during rising exercises including different adaptive adjustments were investigated in nine healthy subjects. The joint load was calculated from forces recorded with a force-measuring platform and pictures on cine-film. Levels of muscular activity were recorded with rectified, low-pass filtered, time-averaged and normalized EMGs. The loading moment about the hip joint was about 45 Nm during the initial part of the rising exercise, decreasing with smaller hip angle. Increase of the backward inclination of the trunk increased the load moment, which was maintained at about the same level during the rising exercise. Two adaptive adjustments lowered the joint load: foot position further backward and reduced resistance from the device. Foot position further forward increased the joint load. The levels of muscular activity in the hip extensors were low to medium and were slightly increased by posterior foot position and increased resistance from the device. Increased backward trunk inclination increased the activity in the final part of the rising exercise.

Key words: Biomechanics, electromyography, EMG, exercise therapy, biological models, physical therapy, rehabilitation

There are several ways of designing exercise therapy (10, 11, 25). Adjustments can be made in order to change the exercise outcome, for example to lower the joint load or to increase the muscular activity. An example of such adjustment is a change of speed of the exercise movement. The positioning of the subject in relation to the device may also be altered, as well as the resistance from the device. The present investigation deals with the load on the hip joint and activation of the hip muscles during rising exercises including different adaptive adjustments.

There are three investigations dealing with the hip during exercise therapy. Pauly (23) found that the gluteus maximus was active during hip exercises such as hip extension with the subjects lying prone. Load moments during hip flexion exercises (2) as well as the muscular activity of the hip (9)

during flexion and extension exercises resisted by a pulley apparatus have been reported. In these latter two studies the subjects were lying in a supine position.

The load on the hip joint has also been mapped during walking, stair-climbing and lifting. The compressive hip force is four times body weight during level walking (22, 26) and during climbing stairs seven times body weight (22) or 113-124 Newton-meters (Nm) (1). Loading moments ranging from 88 to 124 Nm occur during lifting a 13 kg burden from floor to table (21).

Electromyographic studies concerning the hamstrings and the gluteus maximus (9, 12, 17, 19, 21, 24, 28) and the adductor magnus (3, 9, 21) show that these muscles are active during hip extension, for example rising from squatting or crouching positions. The gluteus maximus shows low to moderate activity during lifting (12, 21) and is active during ascending stairs (18, 19).

As far as we know there is no study dealing with the hip joint load and muscular activity during rising exercises, i.e. simultaneous hip and knee extension and ankle flexion. This exercise was chosen because it corresponds to a "physiological" lower leg motion during several activities of daily living, for example rising from sitting or squatting positions or climbing stairs. The following specific questions were analyzed:

1. What is the magnitude of the hip joint load during some common rising exercises?
2. What is the level of muscular activity in the hip extensors?
3. Is there co-contraction activity in the rectus femoris muscle?
4. To what extent are the hip joint load and the muscular activity influenced by adaptive adjustments of the exercise such as (a) altered backward inclination of the trunk, (b) altered foot position, (c)

Table I. Subject's sex, age and anthropometric data

M=male, F=female

Subject no.	Sex	Age (yrs)	Height (m)	Weight (kg)	Segment length	
					Thigh (m)	Lower leg (m)
1	M	24	1.77	68.7	0.425	0.42
2	M	28	1.80	74.4	0.455	0.475
3	M	46	1.87	78.5	0.435	0.42
4	F	25	1.60	49	0.40	0.40
5	F	24	1.65	55.7	0.41	0.40
6	M	29	1.86	80	0.45	0.47
7	F	19	1.70	56	0.425	0.405
8	F	29	1.66	51.1	0.395	0.41
9	F	26	1.60	51.4	0.405	0.37
Means \pm 1 SD		28 \pm 3.7	1.73 \pm 0.05	62.8 \pm 6.3	0.422 \pm 0.011	0.419 \pm 0.017

altered resistance from the training device, and (d) altered motion velocity?

MATERIALS AND METHODS

Two series of experiments were performed and 15 healthy subjects volunteered to participate, 5 of them in a pilot study and 10 in the main study. The experimental parameters in the present main study were designed in the light of pilot study results. Due to technical failure, data from 1 of the 10 subjects participating in the main study could not be used. Age, sex and anthropometric data for the remaining nine subjects are shown in Table I. The subjects were instructed and slightly trained how to perform the exercises. The sequence of the different varieties of the exercise was randomized.

The training device used (Fig. 1) was a thigh exerciser (LIC, Solna, Sweden). The backward inclination of the trunk could be altered by changing the angle of the back support (*a* in Fig. 1). The back support had a movable sled (*b*) weighing 115 Newton (N), against which the subject leaned the trunk. From squatting the subjects rose, thus moving the back support upward. Changes in resistance from the device were made by attaching extra weights to the handles of the movable sled (*c* in Fig. 1) or to a cord (*d*) passing through a pulley at the upper part of the device, in the latter case balancing out most of the resistance from the device. The foot plate (*e* in Fig. 1) allowed three different foot positions.

The influence of the following parameters on joint load and level of muscular activity was studied.

(a) Degree of inclination of back support: 10° and 45° backward inclination.

(b) Foot position: anterior, intermediate and posterior positions of the feet on the footplate.

(c) Three different extra weight applications: reduced resistance from the device (-10 kg), increased device resistance (+10 kg) and no weight attached to the device.

(d) Movement velocity: slow (3 s) and fast (1 s) performance of the rising movement.

Nine combinations of the alterations were studied (parameters in italics indicate the difference from combination no. 1):

- 10° backward inclination of the back support, intermediate foot position, no extra weight attached to the device, slow performance,
- 10°, *posterior foot pos.*, no weight, slow perf,
- 10°, *anterior foot pos.*, no weight, slow perf,
- 10°, intermediate foot pos, no weight, *fast perf.*,
- 10°, intermediate foot pos, -10 kg, slow perf,
- 10°, intermediate foot pos, -10 kg, *fast perf.*,
- 10°, intermediate foot pos, +10 kg, slow perf,
- 45°, intermediate foot pos, no weight, slow perf, and
- 45°, intermediate foot pos, no weight, *fast perf.*

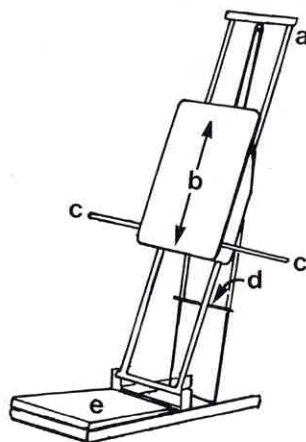


Fig. 1. The training device used for rising exercises. The angle of the back support (*a*) is variable. The subject leaned his back against the movable sled (*b*) and gripped the handles (*c*), and placed his feet on the foot-plate (*e*). Resistance from the device was increased by attaching weights to the handles (*c*), and reduced by attaching weights to the cord (*d*) passing over the pulley.

The different combinations will be called exercise (ex.) 1, 2 etc. Nine subjects performed exercises 1 and 8 in order to obtain a fair idea of the average levels of magnitude of the load moment and levels of muscular activity. To show the intra-individual influence of the other parameters (foot position, extra weight attached to the device and motion velocity) three subjects also performed the other seven exercises (ex. 2-7 and 9). The difference in load moment and muscular activity between the relevant exercise and exercise 1 was calculated for each individual. In this way each of the three subjects served as his own control.

All exercises were recorded using a 16 mm cinecamera (Bolex Paillard), running at 50 frames per second. The film was analyzed with a projector (Analector ANL 4). The load moment and muscular activity were analyzed during the rising movement just after the start and at 60°, 45°, 30°, 15° and 5° flexion. The Analector made it possible to "freeze" the film at these positions and the picture was then traced. In order to synchronize the EMG recordings and the pictures, an optical time-indicator panel paced time marks on all recorders and, in parallel, the light-emitting diode display with a bar representation of time was visible on each film frame. This arrangement made it possible to synchronize the biomechanical calculations and the analysis of the EMG activity levels for each muscle.

A Kistler multicomponent force-measuring platform (9281 A) and charge amplifiers (5006) were used for measuring the floor-to-foot reaction forces. The recordings were made on a UV-recorder (Honeywell Visicorder 1508). The floor-to-foot reaction forces were vertical forces from force sensors anterior (F_{za}) and posterior (F_{zp}) to the feet and horizontal forces in the anteroposterior direction (F_y) (Fig. 2). Each subject's thigh and shank lengths were measured, and the hip, knee and ankle joint centres were marked. The weight and center of gravity for the segments of the lower limb were calculated from Dempster's data (5). The loading moment about one hip joint (M_{load}) was calculated from the recorded reaction forces and the traced pictures:

$$M_{load} = (F_{za} \times dz_a + F_{zp} \times dz_p - F_y \times dy) / 2 - F_t \times d_t - F_{sf} \times d_{sf} \quad (1)$$

where

F_{za} , F_{zp} and F_y are floor-to-foot reaction forces according to Fig. 2,

dz_a , dz_p and dy are the corresponding moment arms to the hip centre,

F_t is force of gravitation for the thigh and F_{sf} for the shank and foot (Fig. 2), and

d_t and d_{sf} are the corresponding moment arms to the hip centre.

The calculated loading moments about the bilateral motion axis (about which flexion and extension occur) had a flexing direction in all exercises. The corresponding muscular moment developed by the hip extensor muscles was thus extending.

Investigated muscles were the gluteus maximus, long head of biceps femoris, semimembranosus/tendinosus, adductor magnus and rectus femoris. Muscle activity was recorded with full-wave rectified low-pass filtered and

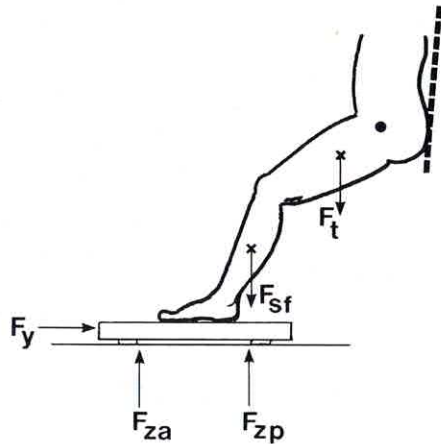
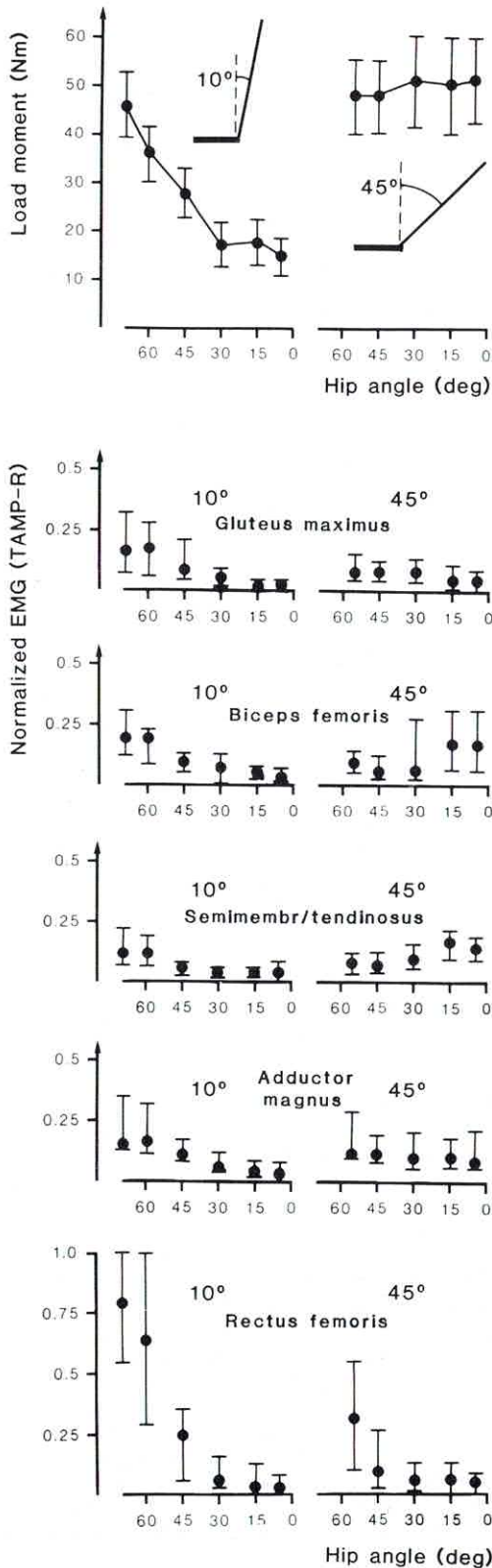


Fig. 2. Drawing illustrating the different floor-to-foot forces (F_{za} , F_{zp} , F_y) and the body-segment gravity force of the thigh (F_t) and of the shank+foot (F_{sf}) acting about the bilateral hip motion axis (filled circle).

time-averaged EMGs (Devices M4, AC8 and Neurolog NL 103, 104) with a time constant of 0.25 s. A UV-recorder (Honeywell Visicorder 1508) and an oscilloscope (Tektronix RM 565) recording the amplified unfiltered direct signals, were used allowing control of possible disturbances hidden in the low-pass filtered EMG. Ag-AgCl electrodes with an inter-electrode centre distance of 0.03 m were attached to the skin on the right side of the body over each muscle belly in the main direction of the muscle fibers. For the thigh muscles the electrodes were placed at half the distance between the knee and hip. For the gluteus maximus they were placed at the middle of the muscular belly and approximately at the level of the tip of the trochanter major.

To compare the levels of EMG activity between different muscles and different individuals a normalization was performed. For each muscle we recorded the EMG activity during an isometric maximum voluntary contraction (IMVC). During IMVC of the rectus femoris and the hamstrings the subject was fixed in a specially designed chair with the knee joint held in a mid-position. All subjects also performed IMVC during hip extension, lying prone on an OB Combi Trainer (LIC, Solna, Sweden) (i.e. quadriceps bench) with the hip and knee held in a mid-position. This maneuver has been described elsewhere (20). In this position the gluteus maximus was activated to the highest level in all subjects and also the hamstrings and adductor magnus in some. The latter muscle was also tested with the subjects supine, performing IMVC during hip adduction with the hip in the neutral position. Recording of the EMG activity during IMVC was made before and after the experiment and the highest obtained value was used as a reference activity level. The normalized EMG is presented as the time-average myoelectric potential ratio (TAMP-R), i.e. the activity recorded during the experiment divided by the reference activity level. The described technique of processing the EMG has been used earlier (6, 7, 8, 21).



RESULTS

A comparison between two different backward inclinations of the trunk during rising is shown in Fig. 3: 10° (left diagrams) and 45° (right diagrams). The rising exercise movement was in both cases performed slowly without extra weight attached to the device (ex. 1 and 8). There was a great difference in joint load moment between the two back inclinations as seen in the two top diagrams. With the back support almost vertical (10°) a loading moment of about 45 Nm occurred at 75° hip flexion. The load moment decreased with smaller hip angles. A minimum of 15 Nm was recorded at 5° hip flexion. While rising with 45° backward inclination of the trunk on the other hand, the initial load moment was about 50 Nm, and this magnitude was approximately maintained (slightly increased) also when the hip angle became small (as in top right diagram of Fig. 3).

The level of muscular activation presented as normalized EMGs (medians with 95% confidence intervals) is shown in the lower diagrams of Fig. 3. The hip extensor muscles were generally activated only up to a moderate level, none being activated more than 0.35 TAMP-R. Median values of the muscular activity were up to 0.2 TAMP-R. Changing the backward inclination of the trunk from 10° to 45° showed a tendency to increase the muscular activity in the hip extensors during the last part of the rising movement. The biceps femoris increased 0.11 TAMP-R units at 15° hip angle and 0.14 TAMP-R units at 5°. The corresponding values for semimembranosus/tendinosus were 0.09 and 0.13 TAMP-R units increase; the adductor magnus 0.05 and 0.08 TAMP-R units increase. During the first part of the rising movement the gluteus maximus was slightly less activated at 45° inclination. The rectus femoris passes on the flexor side of the hip joint but is also a knee extensor and the activity is mainly due to the knee load (27). As seen in Fig. 3 the sagittal hip joint motion during the rising exercise ranged between 75° and 0° hip flexion with 10°

Fig. 3. The mean loading moment of force ± 1 SD about the bilateral hip joint axis (upper diagrams) and the normalized EMG (five lower diagrams) shown as medians with 95% confidence intervals. Diagrams to the left show 10° backward inclination of the trunk and diagrams to the right 45° trunk inclination. The exercise movements were performed with intermediate foot position, no extra weight attached to the device, and slow velocity. $n=9$.

EFFECT ON LOAD MOMENT OF:

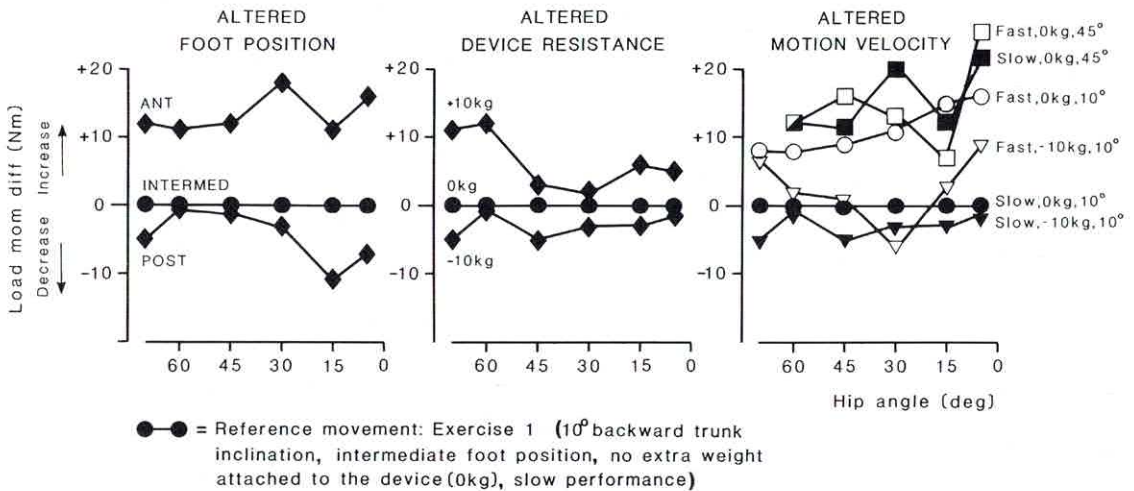


Fig. 4. The effect on load moment of altered foot position, altered resistance from the device and altered motion velocity. Exercise 1 (filled circles, defined below in the

diagram) was used as a reference and the effect of the different altered parameters is given as the mean load moment difference from the reference movement. $n=3$.

backward inclination of the trunk and between 60° and 0° hip flexion in the 45° situation.

Here follows a description of the changes caused by different adjustments undertaken in order to alter the exercise outcome. Figs. 4-7 illustrate only the deviations from the outcome of ex. 1 (ex. 1 is defined in the Methods section and in Fig. 4 and has been used as a reference in the graphs). The changes in hip load moment with altered foot position, extra weight attached to the device (resistance from the device) and altered motion velocity, are summarized in Fig. 4, which shows differences from ex. 1 in mean load moment. With a backward inclination angle of 10°, the hip joint load was increased by more than 10 Nm with a foot position further forward than the regular intermediate one. A similar difference was caused by the fast movement (7-16 Nm). The load was also increased (12-14 Nm) during the initial phase of the rising movement by increased resistance from the exercise device (+10 kg). Reduction of resistance (-10 kg) caused only a slight decrease in the hip load moment. 45° backward inclination and fast performance increased the load moment (10-25 Nm).

Figs. 5-7 illustrate the differences in normalized EMG activity from the reference exercise 1 for each individual.

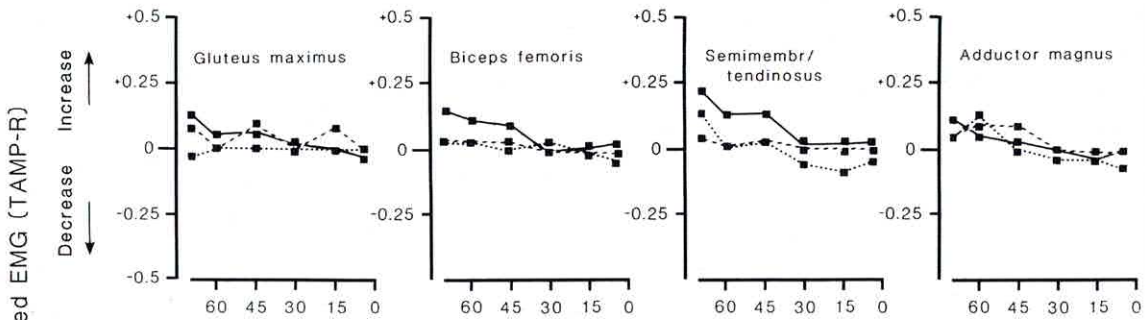
Altered foot position. A foot position further

back than the regular intermediate one is used in fig. 5a (posterior position, ex. 2). During the first phase of the movement, the level of muscular activity increased in the biceps femoris in one subject and in the semimembranosus/tendinosus and gluteus maximus muscles in two subjects. There was a slight increase in the initial activity of the adductor magnus muscle in all subjects. A foot position further forward (anterior position, ex. 3), shown in Fig. 5b, caused no major changes in the EMG activity, except that one subject showed a decrease in the hamstrings and adductor magnus.

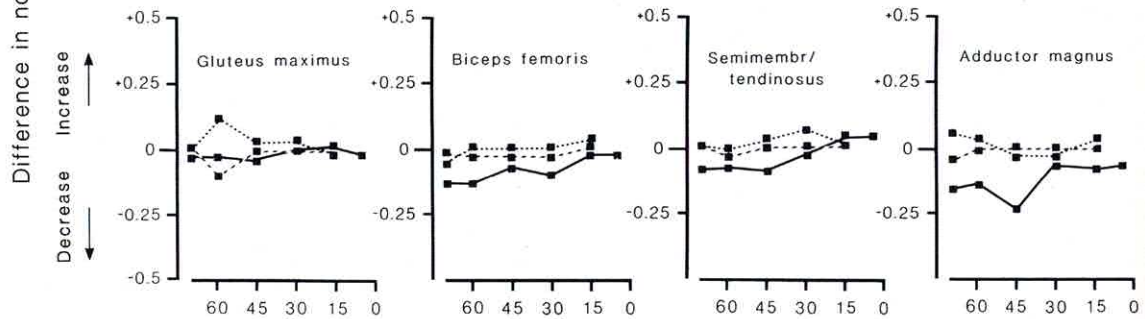
Altered extra weights attached to the device. The effect of reducing resistance from the exercise device is shown in Fig. 6a (ex. 5). The movable sled of the device was counterbalanced by attaching a 10 kg weight to the cord passing through the pulley (*d*, indicated in Fig. 1). This situation, which roughly corresponds to rising with only the body segments as load, did not appreciably alter the hip extensor activity. In Fig. 6b the device was further loaded with 10 kg attached to the handles of the movable sled (ex. 7). This increased the resistance from the exercise device. Activity in the gluteus maximus and adductor magnus was increased during the first part of the rising movement. One subject also showed an increase in the activity of the hamstrings.

EFFECT OF ALTERED FOOT POSITION

A. BACKWARD



B. FORWARD



Hip angle (deg)

Fig. 5. Effect of altered foot position. Other conditions unchanged. (A) Foot position further backward and (B) foot position further forward than the regular intermediate (exercise 1). The diagrams show the difference in

EMG activity in TAMP-R units compared with exercise 1 (zero level) for each individual. Exercise 1 is defined in Fig. 4. $n=3$.

Altered motion velocity. The fast performance (ex. 4), shown in Fig. 7a increased the initial EMG activity in the gluteus maximus and adductor magnus muscles in two subjects and reduced the activity in one subject. Fast performance with reduced load (-10 kg, ex. 6) (Fig. 7b) increased the hip extensor activity in one subject. Fast performance of the rising movement with 45° backward inclination of the trunk (ex. 9) (Fig. 7c) tended to slightly increase the activity in the hip extensors in two subjects.

DISCUSSION

The general level of the hip joint load reported in the present study is low, and the investigated hip extensor muscles were activated up to 35% of the activity level recorded on isometric maximum con-

traction. The adaptive adjustments to the exercise showed how it was possible to influence joint load and muscular activity.

The biomechanical calculations included the use of a force measuring platform. The acceleration force components were included in the recorded floor-to-foot reaction forces. The calculations, which were based on static biomechanics may thus be considered as semi-dynamic. The moment of inertia for the lower limb body segments has been excluded since it was considered to influence the results very little during the rising exercise. The co-contraction from the rectus femoris, occurring during ex. 1 (10° backward inclination, intermediate foot pos., no extra weight and slow perf.) will slightly increase the load moments calculated in this exercise. The EMG method used, involving the

EFFECT OF ALTERED DEVICE RESISTANCE

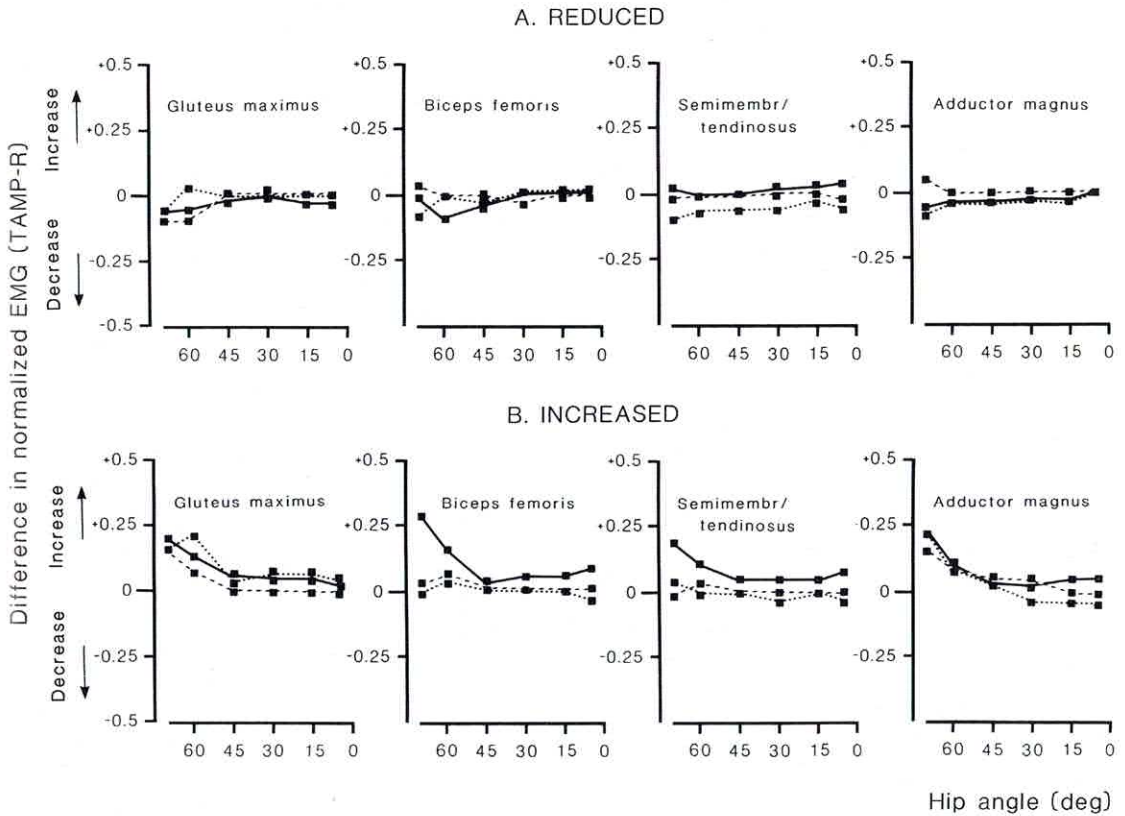


Fig. 6. Effect of altered extra weight attached to the device. Other conditions unchanged. (A) Reduced resistance from the device by balancing out with 10 kg.

(B) Increased resistance from the device by adding 10 kg. Arrangement of the diagrams as in Fig. 5. $n=3$.

normalizing procedure, allows comparisons between the level of muscular activity in different muscles and different individuals, and has been discussed elsewhere (7, 8, 21).

The hip joint load reported in the present study is lower than the load reported for level walking, climbing stairs and lifting 13 kg from the floor (1, 21, 22, 26). Also, in the light of maximum strength values for hip extensor muscles, 135 to 210 Nm in comparable subjects (20), the load moments reported in the present study are small.

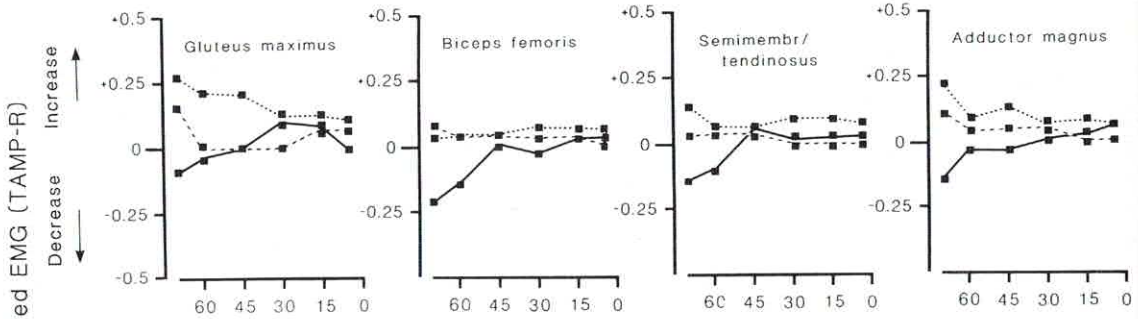
During the investigated rising exercise, the vertical floor-to-foot reaction forces (F_{z_a} and F_{z_p}) pass anterior to the bilateral hip joint axis (Fig. 2), thus causing a flexing (loading) moment about the motion axis. The horizontal reaction force, however, running in the posterior direction (F_y in Fig. 2), caused an extending moment. When the backward

inclination of the trunk was increased from 10° to 45°, the vertical reaction forces were reduced only slightly but the length of the moment arms to the hip motion axis was increased by 30–50%; the horizontal reaction force was slightly increased but the moment arm was reduced by 30–60%. The net effect of this was an increase in hip joint load moment, with a flexing direction. These factors explain why the hip joint load was increased when the backward trunk inclination was altered from 10° to 45°.

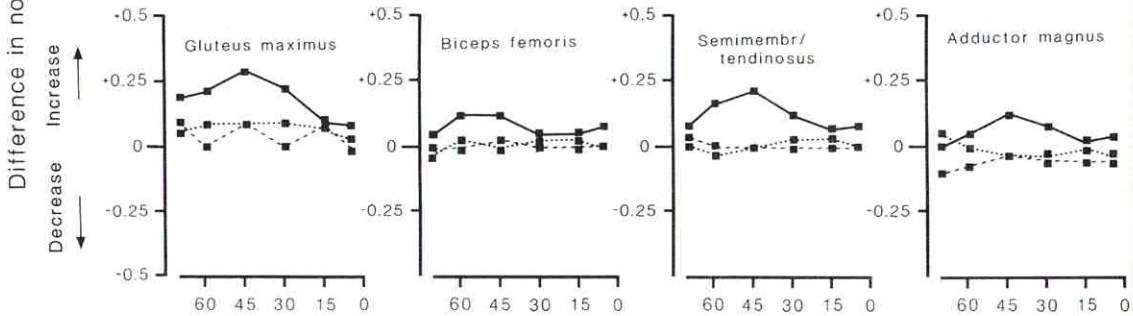
The levels of activation of the hip extensors in the present study were of the same magnitude as during hip extension resisted by 6 kg attached to the cord in a pulley apparatus (9). The activity pattern of the rectus femoris muscle during exercises with 10° trunk inclination indicated that there is a considerable co-contraction in this muscle in

EFFECT OF ALTERED MOTION VELOCITY

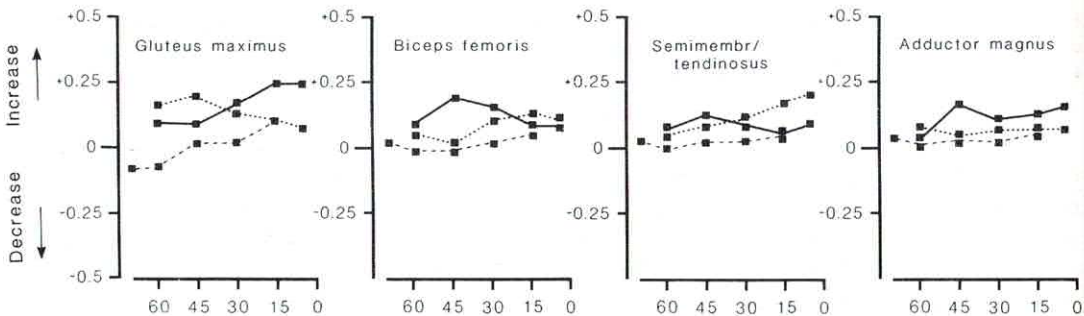
A. FAST



B. FAST AND REDUCED RESISTANCE



C. FAST AND 45° TRUNK INCLINATION



Hip angle (deg)

Fig. 7. Effect of altered motion velocity. (A) Fast performance of the rising exercise movement and the trunk inclined backward 10°. (B) Fast performance with reduction of the resistance from the device by balancing out with 10 kg. Backward trunk inclination 10°. (C) Fast per-

formance with the backward trunk inclination increased to 45°. Arrangement of the diagrams as in Fig. 5. Intermediate foot position and no extra weight attached to the device. $n=3$.

relation to the hip extensors in the beginning of the movement. This is related mainly to the tendency of this muscle to be activated with respect to the load moment of the knee joint during rising exercises (27).

The range of the sagittal plane motion of the hip during walking is 37°, during stair climbing 42–68° (1, 14) and when lifting a box from the floor 85° (21). Thus, the range of motion trained with the device investigated in the present study is adequate for

walking and stair climbing and probably also for lifting. However, sitting down on a chair and rising from sitting requires 103° sagittal motion and tying shoes 121° (15). The range of motion in the rising exercises was too small to be adequate as training for these latter activities of daily life.

The following summary may provide some guide for clinical practice.

1. With 10° backward inclination of the back support, intermediate foot position and no extra weight attached to the device, the mean hip loading moment was about 45 Nm during the initial part of the rising exercise. The load moment decreased during the movement.

2. Change of the backward inclination to 45° caused an initial loading moment of about 50 Nm, approximately maintained during the exercise.

3. The level of muscular activity in the hip extensors did not, in any subject, exceed 35% of the activity level recorded on isometric maximum contraction.

4. The rectus femoris showed considerable co-contraction activity during the first part of the rising exercise with the trunk inclined 10° backward.

5. Posterior foot position or reduced resistance (-10 kg) from the device lowered the hip joint load.

6. 45° backward inclination of the trunk or anterior foot position increased the hip joint load.

7. The level of muscular activity in the hip extensors was slightly increased by posterior foot position and by adding extra weight (+10 kg) to the device, thereby increasing the resistance from the device. 45° backward inclination of the trunk increased the hip extensor muscular activity in the final part of the rising exercise.

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Gunnar Németh, M.D.
Kinesiology Group
Department of Anatomy
Karolinska Institute
P.O. Box 60400
S-104 01 Stockholm
Sweden