Eur J Appl Physiol (1994) 68:413–417

European Journal of Applied Physiology
and Occupational Physiology

Power and work produced in different leg muscle groups when rising from a chair

Per Wretenberg, Ulf P. Arborelius

Kinesiology Research Group, Department of Neuroscience, Karolinska Institutet, S-17177 Stockholm, Sweden

Accepted: 26 January 1994

Abstract. The aim of this study was to determine the power output and work done by different muscle groups at the hip and knee joints during a rising movement, to be able to tell the degree of activation of the muscle groups and the relationship between concentric and eccentric work. Nine healthy male subjects rose from a chair with the seat at knee level. The moments of force about the hip and knee joints were calculated semidynamically. The power output (P) and work in the different muscle groups surrounding the joints was calculated as moment of force times joint angular velocity. Work was calculated as: work $= \int P\mathrm{d}t$. The mean peak concentric power output was for the hip extensors 49.9 W, hip flexors 7.9 W and knee extensor 89.5 W. This power output corresponded to a net concentric work of 20.7 J, 1.0 J and 55.6 J, respectively. There was no concentric power output from the knee flexor muscles. Energy absorption through eccentric muscle action was produced by the hip extensors and hip flexors with a mean peak power output of 4.8 W and 7.4 W, respectively. It was concluded that during rising, the hip and knee muscles mainly worked concentrically and that the greatest power output and work were produced during concentric contraction of the knee and hip extensor muscles. There was however also a demand for eccentric work by the hip extensors as well as both concentric and eccentric work by the hip flexors. The knee flexor muscles were unloaded.

Key words: Power – Work – Hip – Knee – Muscles – Biomechanics

Introduction

Extension of the leg is an important movement involved in many activities in daily life. One such activity is rising from a chair, a movement that is natural and easy for most people. However, old and disabled people with affected joints or muscle weakness often have difficulties with this movement. Analysis of how the different muscle groups work when rising from a chair can be useful in training/rehabilitation situations, and is also a way to reach a basic understanding of the leg extension mechanism.

Calculating loading moment of force on the leg joints during rising makes it possible to estimate the load on joints and muscle groups. A high flexing moment of force at a joint will require high activity in the extensor muscles, and vice versa. Joint load and muscle activity during the act of rising have been studied earlier (Ellis et al. 1979; Arborelius et al. 1992; Wretenberg et al. 1993a, b), and it has been shown that by using different aids, the maximal hip and knee moment of force can be reduced. Analysis of muscle activity (by electromyogram, EMG) during the movement is another possible method of studying "muscle work", but it does not show whether the contraction is concentric, eccentric or even isometric. In our opinion, examination of the mechanical power produced at different joints is important when assessing importance and function of the different muscle groups. Power output from individual muscle groups has been studied during activities such as level walking, running and ergometer cycling. Early calculations of power output from different muscle groups have been based on changes in the location of the centre of body mass (Elftman 1940; Cavagna et al. 1971, 1976). Later, more mechanically accurate methods have been used for calculating mechanical power output (Winter 1979, 1983; Gordon et al. 1980; Zarrugh 1981; Williams and Cavanagh 1983; Ericson et al. 1986; Ericson 1988). Power production during olympic weightlifting (Garhammer 1980) and during isokinetic knee extension (Rizzardo et al. 1988) has also been calculated. Gordon et al. (1980) have defined joint power as the power delivered to, or, if negative, taken from segments where they join, due to the work done by the joint reaction forces. Muscle power has, accordingly, been defined as the mechanical power delivered to or taken from segments where they

Correspondence to: P. Wretenberg

join, due to the work done by the muscle moment acting about the joint. The net muscle power output by the different muscles surrounding these joints is calculated by multiplying the net moment of force by the angular joint velocity. If the muscle power output from a muscle group is known, the net work done by this muscle group can also be calculated. Positive work originates mainly from concentric muscle contraction and elastic energy, negative work from eccentric muscle contraction and nonmuscle sources.

The aim of this study was to calculate the net power output and work generated in the sagittal plane at the hip and knee joints, and to discuss implications of muscle work during the act of rising.

Methods

Subjects. Ten healthy men, mean age of 26 years (range 20–32 years), volunteered for this study. Their mean weight was 71 kg (range 62–87 kg) and their mean height 181 cm (range 173–194 cm). All the subjects were without dysfunction in the lower limbs.

Experimental procedure. A chair with adjustable seat height was set to knee height (lateral epicondyle) for each subject. The seat was a small saddle-shaped wooden plate, so that the forces between the subject and the seat passed mainly through the ischiadic tubercles. Contact between thighs and seat was avoided, in order to exclude any uncontrolled contact force that could affect the calculated moment of force about the hip. The subjects had their arms crossed (in contact with the chest), and their feet placed symmetrically on a force plate. They were asked to rise from the seat at normal speed.

The model for calculations of hip and knee moments of force has been described in detail (Wretenberg et al. 1993a). To summarize; this model is based on a semidynamic method which incorporates ground reaction forces measured from a Kistler force plate and gravitational contributions from body segments. Dempster's anthropometrical data (Dempster and Gaughran 1967) were used to determine the lower-limb segmental masses and their mass centre locations. For motion analysis, a video system was synchronized with the force recordings from the force plate. The calculations were computerized.

The angular velocity for knee and hip joints was calculated from angular displacement between the pictures, 25 Hz.

The linear and angular accelerations of the lower leg and thigh segments, during rising from the seated position, were considered to be so small that inertial forces would have caused only minor errors in calculation of loading knee and hip moments. Similar methods for calculation of the lower-limb joint moments have been used earlier (Seedhom and Terayama 1976; Ellis et al. 1979; Dahlkvist et al. 1982; Németh et al. 1984; Burdett et al. 1985). The loading moment is counteracted by a net muscle moment that is equal in level but opposite in direction.

The mechanical power produced or absorbed (P) in the different muscle groups on flexor and extensor side of each joint was estimated by:

$$P = M \cdot w \qquad (1)$$

where M is the loading moment of force at the joint (in Newton meters) and w is the joint angular velocity (in radians per second).

Flexing loading moment of force and extending joint motion are expressed as positive. This means that, for example, a flexing loading moment of force during extension of the joint will result in positive power values; a flexing loading moment of force during joint flexion will give negative power values.

With the net muscle power output known, the net work (in joules) produced (corresponding to the area under the curve) about the joints was calculated as the area under the power curve:

$$\text{work} = \int P \,\mathrm{d}t \qquad (2)$$

Power production and absorption and work were calculated for the left hip and knee joint. Symmetry between the left and right legs was assumed.

Results

Moment of force was calculated from the beginning of the movement, as could be seen from the video, until the subjects reached an upright standing position. Due to problems with the recording system, one subject had to be excluded from the calculations. The mean time needed to performed the rising movement was 1.7 (SD 0.20) s. Figure 1 shows the mean (nine subjects) loading moment curves with 95% confidence intervals for the hip and knee joints. The computer program expressed a flexing loading moment as positive and accordingly the peak loading moments for both joints were flexing moments. The mean peak flexing moments of force for the hip joint was 35.8 (SD 6.0) N·m and for the knee joint 73.3 (SD 18.6) N·m.

The mean curves for hip and knee muscle power during the act of rising are shown in Figs. 2 and 3. Positive power values indicate that power is produced during concentric contraction and negative values occur from eccentric contraction. Positive power could arise through concentric contraction of the extensor muscles or from the flexor muscles, negative power through eccentric contraction of extensor or flexor muscles. Hence, from the total power curves, one cannot tell which muscle group is active. To show how the different muscle groups worked, the total power curves for each joint and each subject were divided into two curves, one showing the power produced/absorbed in the extensor muscles and one showing the power produced/absorbed in the flexor muscles. The direction of the loading moment of force was used to assign the power to the proper muscle group. For example, when

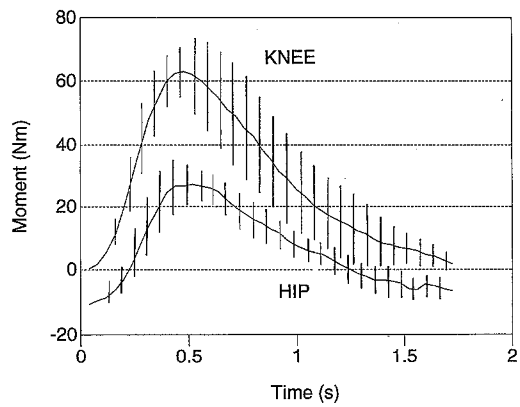

Fig. 1. Mean moment curves ($n = 9$) for hip and knee joints with 95% confidence intervals

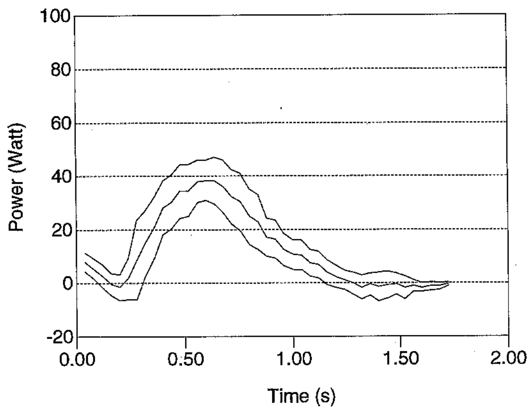

Fig. 2. Mean muscle power output ($n=9$) at the hip joint with 95% confidence intervals

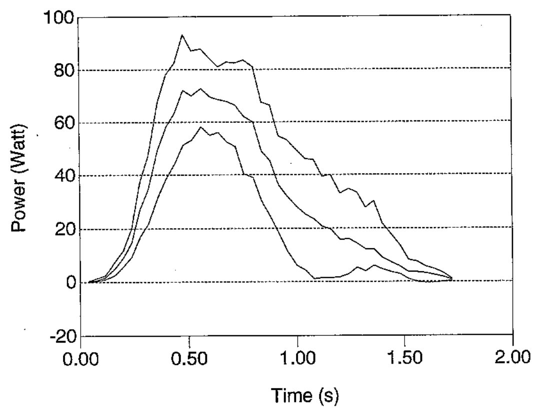

Fig. 3. Mean muscle power output ($n=9$) at the knee joint with 95% confidence intervals

the loading moment of force is flexing, muscle power is produced by the extensor muscles of the joint. The extensor muscles could work concentrically, causing an extension of the joint, or eccentrically during joint flexion. This principle is described in Table 1, where the direction of the moment of force is related to the direction of the movement. For example, if the hip loading moment of force is flexing (+), and the hip joint motion is also flexing (−), the hip extensor muscles will absorb work (−), during an eccentric contraction. As an example, curves from subject 3 are shown. The other subjects showed similar curves, although not identical. The hip and knee muscle power curves for the extensor and flexor muscles for this subject are shown in Figs. 4 and 5.

Figure 6 shows changes in the hip and knee joint angles with time, during the act of rising. The knee extends continuously, while the hip motion starts with flexion before the joint extends.

At the knee joint there is an extending movement and a flexing moment of force throughout the rising movement. This means that the knee extensor works concentrically all the time, and it also implies that there is no need for knee flexor muscles to be active. At the hip joint there is a more complicated situation,

Table 1. Sign analysis for the power curves concerning working muscle group and type of contraction

		Hip flexion −	Hip extension +
Extending moment of force	−	+ Concentric work hip flexors	− Eccentric work hip flexors
Flexing moment of force	+	− Eccentric work hip extensors	+ Concentric work hip extensors

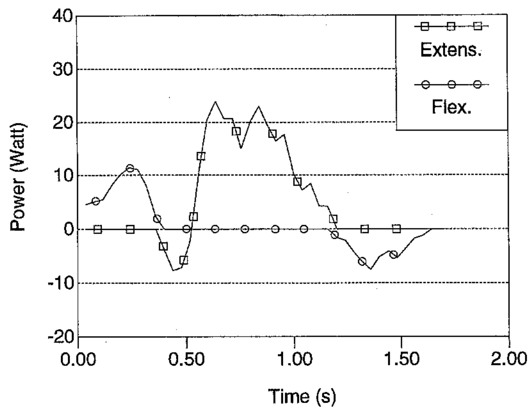

Fig. 4. Hip muscle power curves for extensor and flexor muscles for one subject, positive values indicate concentric work

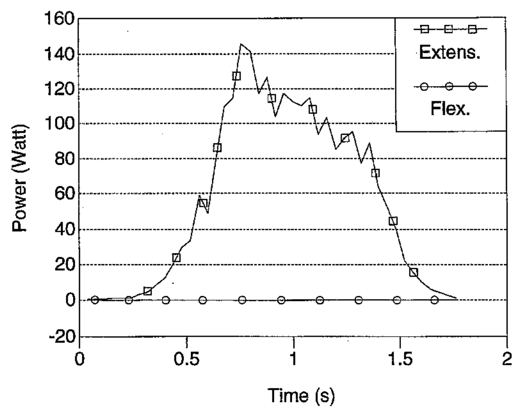

Fig. 5. Knee muscle power curves for extensor and flexor muscles for one subject, positive values indicate concentric work

since the movement initially is flexion and later extension, and since the moment of force changes from extending to flexing and back to extending. As can be seen in Fig. 4, both hip flexors and extensors are needed, and both groups work both concentrically and eccentrically. The flexor muscles work concentrically at the beginning and eccentrically at the end of the act of rising. The hip extensors work mainly concentrically and are mostly required during the mid-part of the act of rising.

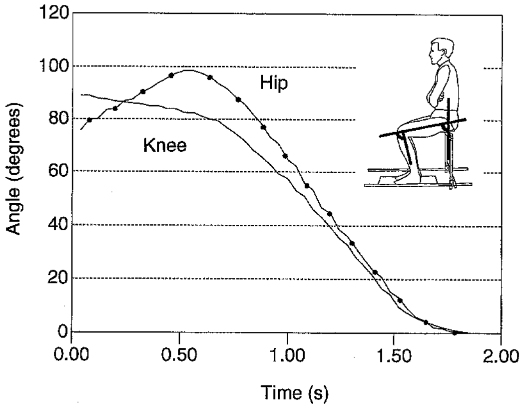

Fig. 6. Hip and knee angles for one subject in relation to time

The mean peak power output and work done by the hip and knee muscles during concentric and eccentric work during the rising movement are presented in Table 2. At the knee joint almost all the work was attributable to concentric contraction of the knee extensor muscles. The mean peak power output for this muscle group was 89.5 W and the accumulated work, during the rising movement, was 55.6 J (positive) for each limb. The hip extensors were the most important muscle group at the hip joint, but also the hip flexors worked both concentrically and eccentrically.

Discussion

This study was performed to investigate power and work produced in different muscle groups at the hip and knee joints during a rising movement. By calculating joint power and work produced in the different muscle groups, one can determine both which type of work (concentric or eccentric) is done by the different muscle groups and the relationship between the energy produced and the energy absorbed. The highest mean peak power and work were calculated for concentric work by the knee extensor muscles. The mean peak power output was 89.5 W and the corresponding work 55.6 J, which was 72% of the total concentric work at the hip and knee joints. Almost all remaining concentric work, 27%, was produced by the hip extensor muscles, with a peak power output of 49.9 W and corresponding work of 20.7 J. The results show that during a rising movement, the hip and knee extensor muscles are the most active and that these muscles work mainly concentrically. Ericson et al. (1986) have investigated standardized ergometer cycling with moderate load. For this activity also, concentric work by knee and hip extensor muscles dominated, with a mean peak power output of 110.1 W for the knee extensors and 74.4 W for the hip extensors. A direct comparison between the power output for the two movements could not be made, but the mainly concentric work done during the rising movement or ergometer cycling is a contrast to the great amount of eccentric work occurring during walking and jogging (Winter et al. 1983).

The hip flexor muscles work both concentrically and eccentrically (Fig. 4). The first flexor muscle contraction is concentric, and related to a hip flexion during the start of the movement. At the end of the movement the hip extension is braked by eccentric work by the hip flexor muscles (negative curve). The hip extensor muscles are not needed during the initiation of the rising movement, and then there is a small amount of eccentric work when the initial hip flexion is braked. Then comes the dominating concentric work by the hip extensor muscles. At the knee joint (Fig. 5) all mechanical work is done as concentric contraction of the knee extensor muscles. This can also be seen from the mean power curve (Fig. 3), since there are no negative values corresponding to eccentric work. The small amount of eccentric knee flexor work presented in Table 2 is due to minor knee flexor contractions at the end of the rising movement, which occurred in three of the subjects.

The mean power curve for the hip muscles (Fig. 2) shows a continuous change between concentric and eccentric work. This type of curve does not reveal whether the work is produced by extensor or flexor muscles. We think that a more adequate way to describe the muscle action during a movement like this, is by using the separated curves shown in Figs. 4 and 5. At the knee joint, there is a continuous flexing moment of force which is counteracted by an extending muscle moment produced by the knee extensor muscles. At the hip joint there is a more complicated situation since both the moment of force during rising and the angular movement change direction. The result is that all four possible combinations of contraction type and involved muscle group occur.

Table 2. Mean peak net power output (W) and muscle net energy (J) produced during concentric work and absorbed during eccentric work for nine subjects when rising from a chair

	Concentric work					Eccentric work				
	Peak power (W)		Energy (J)		% of total concentric work	Peak power (W)		Energy (J)		% of total eccentric work
	mean	(SD)	mean	(SD)		mean	(SD)	mean	(SD)	
Hip extensors	49.9	(12.4)	20.7	(5.8)	27%	4.8	(4.9)	0.6	(0.78)	27%
Hip flexors	7.9	(5.2)	1.0	(1.1)	1%	7.4	(6.5)	1.5	(1.9)	64%
Knee extensors	89.5	(34.0)	55.6	(20.7)	72%	0	(0)	0	(0)	0%
Knee flexors	0	(0)	0	(0)	0%	0.9	(1.4)	0.2	(0.27)	9%

Williams and Cavanagh (1983) and others have discussed transfer of energy through the action of two joint muscles, an aspect that is interesting concerning the rising movement. The EMG analysis has shown that both the ischiocrural muscles and rectus femoris are active during the rising movement (Arborelius et al. 1992). The calculations in the present study show that there was no work done by knee flexor muscles. This means that, during the rising movement, the ischiocrural muscles are used as hip extensor muscles. Since the knee joint is extending during the whole movement, it is possible that work produced during knee extension is transferred through the ischiocrural muscles creating extension at the hip. The study earlier mentioned (Arborelius et al. 1992) has also shown that except for the initiation of the rising movement, there was very low activity in the rectus femoris muscle. Since the knee is extending during the whole movement and the main work at the hip is concentric work done by the hip extensors, it is possible that the main task of the rectus femoris muscle is a passive transfer of work done by the hip extensors, creating extension at the knee.

We concluded that during a rising movement, concentric work by the hip and knee extensor muscles is the most important muscle activity, and that the power output and energy produced are highest for the knee muscles. There is, however, also a demand for eccentric work by both hip flexor and extensor muscles, and for concentric work by the hip flexor muscles. Analysing muscle function during getting up from a chair has in this way given us a basic understanding of the leg extension mechanism. This data can also be important during rehabilitation of people with leg disabilities after for example an injury.

Acknowledgements. This study was supported by the Karolinska Institute.

References

Arborelius UP, Wretenberg P, Lindberg F (1992) The effects of armrests and high seat heights on lower limb joint load and muscular activity during sitting and rising. Ergonomics 11:1377–1391

Burdett RG, Habasevich R, Pisciotta J, Simon SR (1985) Biomechanical comparison of rising from two types of chairs. Phys Ther 8:1177–1183

Cavagna GA, Komarek L, Mazzoleni S (1971) The mechanics of sprint running. J Physiol 217:709–721

Cavagna GA, Thys H, Zamboni A (1976) The sources of external work in level walking and running. J Physiol 262:639–657

Dahlkvist NJ, Mayo P, Seedhom BB (1982) Forces during squatting and rising from a deep squat. Eng Med 2:69–76

Dempster WT, Gaughran GRL (1967) Properties of body segments based on size and weight. Am J Anat 20:33–54

Elftman H (1940) The work done by muscles in running. Am J Physiol 129:672–684

Ellis MI, Seedhom BB, Amis AA, Dowson D, Wright V (1979) Forces in the knee joints whilst rising from normal and motorized chairs. Eng Med 1:33–40

Ericson MO (1988) Mechanical muscular power output and work during ergometer cycling at different work loads and speeds. Eur J Appl Physiol 57:382–387

Ericson MO, Bratt Å, Nisell R, Arborelius UP, Ekblom J (1986) Power output and work in different muscle groups during ergometer cycling. Eur J Appl Physiol 55:229–235

Garhammer J (1980) Power production by olympic weightlifters. Med Sci Sport Exerc 1:54–60

Gordon D, Robertson E, Winter DA (1980) Mechanical energy generation, absorption and transfer amongst segments during walking. J Biomech 13:845–854

Németh G, Ekholm J, Arborelius UP (1984) Hip joint load and muscular activation during rising exercises. Scand J Rehabil Med 16:93–102

Rizzardo M, Bay G, Wessel J (1988) Eccentric and concentric torque and power at the knee extensors of females. Can J Sports Sci 13:166–169

Seedhom BB, Terayama K (1976) Knee forces during the activity of getting out of a chair with and without the aid of arms. Biomech Eng 8:278–282

Williams KR, Cavanagh PR (1983) A model for calculation of mechanical power during distance running. J Biomech 16:115–128

Winter DA (1979) A new definition of mechanical work done in human movement. J Appl Physiol 46:79–83

Winter DA (1983) Moments of force and mechanical power output in jogging. J Biomech 16:91–97

Wretenberg P, Arborelius UP, Lindberg F (1993a) The effects of a pneumatic stool and a one-legged stool on lower limb joint load and muscular activity during sitting and rising. Ergonomics 5:519–535

Wretenberg P, Lindberg F, Arborelius UP (1993b) Effects of armrests and different ways of using them on hip and knee load during rising. Clin Biomech 8:95–101

Zarrugh MY (1981) Power requirements and mechanical efficiency of treadmill walking. J Biomech 14:157–165