ELITE SPRINTERS, ICE HOCKEY PLAYERS, ORIENTEERS AND MARATHON RUNNERS

Isokinetic leg muscle performance in relation to muscle structure and training

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CHRISTER JOHANSSON

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ABSTRACT

In male athletes from different sports, isokinetic knee extensor, and in orienteers also plantar flexor peak torque (PT), contractional work (CW) and integrated surface electromyograms (iEMG) were analysed.

Single contraction PT, CW and iEMG in sprinters and marathon runners were significantly correlated to the cross-sectional area (CSA) of m. quadriceps, and to the Type II fibre area of m. vastus lateralis. When correcting PT, CW and iEMG for CSA of m. quadriceps, such correlations were found only for Type IIA fibre area at 180° s⁻¹. Electromyographically, m. vastus lateralis (biopsied muscle) was representative for m. quadriceps. Calculated optimal mean power (CW s⁻¹) and electrical efficacy (CW/iEMG) approximated for sprinters 450° s⁻¹ and for marathon runners 270° s⁻¹, i.e. velocities at or above the upper limit of the dynamometers. In orienteers, plantar flexor PT increased during winter training, but decreased during competitive season. Knee extensor PT increased over the whole year. At 30 and 60° s⁻¹ only knee extensor PT was negatively associated with the running velocity at onset of blood lactate accumulation (V_OBLA). Changes in V_OBLA during winter period were negatively associated with changes in knee extensor PT at 180° s⁻¹. During competitive season, changes in V_OBLA were negatively associated with the ratio quality : quantity running. In ice hockey players PT varied non-systematically with training and games.

The biopsy specimens of marathon runners showed irregular fibre shapes, an increased amount of connective tissue and central fibre nuclei, indicating an early strain disease or functional adaptation to extreme demands.

During repetitive contractions in sprinters and marathon runners, fatigue, i.e. slope of decline in CW, was significantly associated with the Type II fibre area of m. vastus lateralis. For knee extensors of sprinters, ice hockey players and orienteers, a steep decrease in CW/iEMG was observed. In contrast, knee extensors of marathon runners and plantar flexors of orienteers showed an almost unaltered CW/iEMG throughout the test. The knee extensor endurance level (CW/iEMG) was significantly correlated to the maximal oxygen uptake. In orienteers, an increase in endurance level of both tested muscle groups during winter training paralleled an increase in V_OBLA and V_{O2,OBLA}. In ice hockey players, fatigue and endurance pattern (CW and CW/iEMG) changed non-systematically with training and games.

In conclusion, isokinetic measurements and iEMG reflect the structural properties of the knee extensor muscles in sprinters and marathon runners. The demonstrated characteristics and changes in leg muscle function in different groups of athletes apparently reflect varying demands from different sports activities.

Key words: Electromyography, endurance, enzyme histocytochemistry, fatigue, ice hockey, isokinetic, muscle contraction, OBLA, orienteering, running.
To my grandfather, Gustaf Rolf, 1906–1968, who initiated my interest for medicine and science, and taught me the greatest quality of life, inspiration.
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Key words: Electromyography, endurance, enzyme histocytochemistry, fatigue, ice hockey, isokinetic, muscle contraction, OBLA, orienteering, running.
This thesis is based on the following papers, which are referred to in the text by their Roman numerals:


INTRODUCTION


The demands of leg muscular output in sports practice vary due to the intensity and duration of the activity, i.e. from extreme sprints to marathon. In sports like competitive orienteering and ice hockey, the demands of leg muscle mechanical output probably are, with regard to intensity and duration of the activity, somewhere in between sprints and marathon. In muscular activity, the motor units are recruited in a fixed order, according to the level of force required from the whole muscle (Milner-Brown & Stein 1975). Great muscular force, required in high intensity, short duration activities, is preferentially associated with great functional capacity of Type II fibres (Coyle et al. 1979, Ivy et al. 1981, Komi et al. 1977, Thorstensson et al. 1977), and mainly anaerobic metabolism (Tesch et al. 1978b). In contrast, long distance activities such as marathon running, is preferentially associated with high functional capacity of Type I fibres and mainly aerobic metabolism (Saltin et al. 1977). Henriksson & Reitmann (1977) and Sjödin et al. (1976) demonstrated adaptations, concerning enzyme activity in the skeletal muscle, in response to endurance training. It has not previously been shown whether such training alters the isokinetic performance of the muscles.

It is presently not quite clear whether muscle fibre composition is related to
maximum isokinetic muscle output. During single contractions, peak torque (Nm) has, by some authors, been shown to correlate positively to the proportion of Type II fibres in tested muscle (Coyle et al. 1979, Gregor et al. 1979, Thorstensson et al. 1976). In contrast, some authors have reported no such correlation (Schantz et al. 1983, Nygaard et al. 1983). Failure to recognize the influence of muscle size (Close 1972), might to some extent explain the discrepancies in results. The issue is further complicated by the fact that the cross-sectional area is influenced by the fibre composition (Schantz et al. 1983). Moreover, the biopsied muscle may not be representative for the total torque producing muscle mass, and the biopsy might not represent the entire structure of the biopsied muscle (Lexell et al. 1983).

Training varies during the year in most sports, due to competition and off-season periods. Muscular performance of the loaded extremity muscles may thus be hypothesised to vary in response to the level of activity. The need of objective measurements of changes in training status is obvious. Running velocity at the onset of blood lactate accumulation ($V_{OBLA}$) has been suggested to be the best single predictive variable for marathon performance (Sjödin & Jacobs 1981). This “OBLA test” is frequently used in Sweden among all kinds of runners for evaluation of training effects. $V_{OBLA}$ has not been shown to have any predictive value for competitive orienteering running, which is synonymous with high intensity forest running for one to two hours. The terrain shows great variations in altitude and surface. Thus, loading of the leg muscles and the balance between aerobic/anaerobic metabolism are more complex than in marathon running.

Local muscle adaptation may occur due to differences in loading during running or due to other specific sport demands. Costill et al. (1974) demonstrated different patterns of local muscle glycogen depletion during different types of running. Level running depleted the glycogen in the calf muscles, while uphill and downhill running depleted the knee extensors predominantly. In ice hockey, which is a predominantly anaerobic sport (Seliger et al. 1972), the requirement of leg muscle output is not known. However, a rapid depletion of glycogen from m. quadriceps has been shown during supramaximal skating (Green 1978).

Extreme endurance running such as marathon has been shown to damage muscles on cellular level (Hikida et al. 1983, Siegel et al. 1983, Warhol et al. 1985). However, the long term effects of such muscle “injury” is not known, and the observations might express reversible changes due to the extreme demands in marathon. Indeed, there is no clear border between functional adaptation of the muscles in response to training or competition and overuse strain.

When discussing muscular performance in various sports, the relationship
between peak performance versus fatigue and endurance is of great interest. Simultaneous training for endurance and strength reduces the force output ability of the muscle, but does not lower the magnitude of increase in $V_{O_2max}$ (Hickson 1980, Dudley & Djamil 1985). Edwards (1983) defined muscular fatigue as failure to maintain the initial or expected force or power output. Endurance is, in terms of output, defined as the capacity to extend the power output over specific intervals of time (Hislop & Perrine 1967). Repetitive maximum isokinetic contractions have been used to relate fatigue, in terms of fall in peak torque, to muscle structure (Tesch et al. 1978a, Thorstensson et al. 1976). Individuals with a high proportion of Type II fibres in their muscles, were shown to be more susceptible to fatigue during dynamic loading, than individuals with muscles rich in Type I fibres. In contrast, no such correlation has also been reported (Clarson et al. 1982). When analysing muscular fatigue, both peak torque and contractional work (Fugl-Meyer et al. 1982) have been used to measure decreases in mechanical output. Contractional work is defined as the time integral of the torques over that part of a circle covered by the isokinetic manoeuvre (Mild et al. 1981, Winter et al. 1981). In the present investigations of fatigue and endurance we have used contractional work, which in contrast to the peak torque describes the total torque production.

Komi (1984), suggested that both the mechanical output and the electromyographic input should be analysed when studying muscle function. Electromyographic registrations with surface electrodes have been found to be representative for the electromyographic activity of the muscle as such, and also for the developed muscle torque (Bigland-Ritchie 1979, Milner-Brown & Stein 1975, Moritani & deVries 1981, Hof & van den Bergh 1977). Low pass filtered, integrated electromyographic registration (Fugl-Meyer et al. 1982), which we have used in the present investigations, represents the input to the muscle during the entire isokinetic contraction. By combining output and input measurements, i.e. contractional work/integrated electromyographic activity, we also analysed the electrical efficacy of the muscle (Gerdle et al. 1986).
AIMS OF THE INVESTIGATION

The overall aim of this study was to describe characteristics for isokinetic leg muscle maximum strength, fatigue and endurance in athletes from various sports. Furthermore, we intended to relate the muscular performance to muscle size, structure, electromyographic activity and to performed training.
MATERIAL AND METHODS

I-III: Five male sprinters (age 23 ± 3 years), with a mean best performance on 100 meters of 10.9 s (range 10.7—11.3), and five male marathon runners (age 29 ± 4 years), with a mean best performance in marathon of 2.36 hours (range 2.33—2.42), volunteered to participate.

IV-V: Fifteen male orienteers (age 22 ± 3 years) participated in study IV, while fourteen of these subjects participated in study V. They were all, at the time of the investigation, orienteers on district elite level, except for three runners who competed on national elite level.

VI: Ten male elite ice hockey players (age 21 ± 4 years) from the Swedish elite division team Björklöven, Umeå, participated.

The subjects in all six studies were carefully informed about the design of each investigation. Approval were obtained from the athletes as well as from the Local Ethics Committee.

All athletes participating in the studies were healthy and had no musculoskeletal injury during the time of investigation.

In studies I, II and III the investigations were performed about two weeks after the last competition of the season in September. In studies IV and V, three tests were performed covering different parts of the year. Test I was in November, at the start of the winter training period, Test II in April after the winter training period and Test III after the competitive season in September. In study VI, four tests were performed. Test I was in April after the competitive season, Test II in September after the first off-season training period, Test III at the mid-competitive season in December, and finally Test IV in September the following year, after the second off-ice training period.

In all studies (I—VI), training was performed in the ordinary way, typical for the various sports, without any intervention from us. However, the two off-ice training periods in study VI differed markedly. The first off-ice period was dominated by aerobic training with low intensity, long duration activities and almost no short duration, high intensity training. The second off-ice
period was designed as mainly anaerobic training with short duration, high intensity activities and almost no low intensity training.

In all studies (I—VI), except for III, isokinetic peak torque (PT) and contractional work (CW) of m. quadriceps were analysed. In studies IV and V similar analyses of m. triceps surae were also performed. For the isokinetic procedures, two standard Cybex II dynamometers (Lumex Inc, New York) were used. Throughout usage, both dynamometers were calibrated by applying known weights to the lever arms at different velocities of angular motion. Using this method of calibration, changes between calibration never exceeded 2 Nm. The measurements of m. quadriceps were performed in the supine position, with the hips flexed 20 degrees, the pelvis firmly strapped and the knees hanging over the edge of a plinth. The lever arm was attached at identical distance from the knee joint in all subjects. The measurements of m. triceps surae were performed wearing specially designed shoes, with fully extended knees. During single maximum contractions, subjects lay supine, while in the repetitive test the prone position was used. Great care was taken to align the talocrural joint with the axis of the apparatus. To ascertain that the subjects co-operated adequately, one of us (CJ) conducted all the experiments and took care to standardize the instructions and verbal encouragements. The manoeuvres were also monitored by simultaneous display on a storage oscilloscope in order to accomplish bio-feedback. Prior to the measurements, which was performed on separate days for each muscle group, subjects aquainted themselves with the procedure, by performing manoeuvres for five minutes. During the repetitive test subjects chose a comfortable rate of contractions with no intervention from the test leader, in order to accomplish maximum strength throughout each contraction.

Electromyographic activity was registered for each contraction, with pairs of surface electrodes (Medico tests, Ölstycke, Denmark). The centres of the two electrodes were 38 mm apart. The electrodes were placed at the maximum bulges of m. rectus femoris, m. vastus lateralis, m. vastus medialis, m. soleus and the two bulges of m. gastrocnemius. The electromyographic signals were full wave rectified, low pass filtered (100 ms) and integrated (iEMG) (Figure 1). Maximum isokinetic performance during single contractions(I, IV, VI) was measured at 30, 60, 120 and 180° s⁻¹, while repetitive manoeuvres (II, V, VI) were performed at 90° s⁻¹ (knee extensions) and at 60° s⁻¹ (plantar flexions). Peak torque (Nm), contractional work (J) and the time for the manoeuvre (s) was registered for each contraction (Figure 2). Instantaneous power (Nm × s⁻¹), mean power (CW × s⁻¹) and the ratio of contractional work/integrated electromyographic activity (CW/iEMG) were also calculated.

During single contractions, the manoeuvre with the highest peak torque out of three attempts at each angular velocity was used. During the repetitive
Fig. 1. Schematic illustration of the quantification (iEMG) of the electromyographic signal.

Muscular fatigue, was, according to the definition of Edwards (1983), considered as the slope of decline in contractile work during the repetitive contractions.

Muscular endurance, was, according to the definition by Hislop & Perrine (1967), considered as the plateau level of the ratio of CW/iEMG, i.e. the electrical efficacy (Gerdle et al. 1986).

In sprinters and marathon runners (I, II, III), open biopsies were taken from the superficial layer of m. vastus lateralis. The muscle fibres were classified into Type I and Type II (A and B) according to their mATPase stainability. Fibre cross sectional area was measured by a digitizing tablet connected to a microcomputer. The absolute area of the different fibre types was calculated by combining the data of the relative distribution, the mean fibre area and the cross sectional area of the whole muscle. The mean number of fibres was calculated by dividing the muscle cross sectional area by the mean fibre area.

To assess the muscle cross sectional area and its parts, computerized tomography was performed using a Siemens Somatotom 2 Scanner measuring the
Fig. 2. Schematic illustration of an isokinetic mechanical output curve at a preset velocity of angular motion. Contractional work is defined as the time integral of the torques over that part of a circle covered by the isokinetic manoeuvre.

Fig. 3. Mechanical output during isokinetic repetitive contractions. The initial level of performance (A) is considered as mean of contraction 1—5. Fatigue (B) is considered as the slope of decline (linear regression) of contraction 6—25. Endurance (C) is considered as mean of contraction 75—150 (CW/iEMG). The end of test is considered as mean of the last five contractions.
Fig. 4. For determination of the quadriceps cross-sectional area, computerized tomography was used (Paper I and II).

Fig. 5. For determination of muscle structure, open biopsies from the superficial part of m. vastus lateralis were obtained (Paper I, II and III).
cross sectional area at the level of the biopsy. Area calculations were performed with the statistical evaluation of the computer. M. vastus lateralis could not be separated from m. vastus intermedius.

Running performance (IV, V), was considered as the running velocity at the onset of blood lactate accumulation ($V_{OBLA}$) (Sjödin & Jacobs 1981). This was estimated during running with stepwise increases of the speed on a treadmill without inclination. After five minutes of slow pace warming up, the speed was increased by 2 km h$^{-1}$ every four minutes, starting at 14 km h$^{-1}$. At the end of each 4 minute period a blood sample was taken from a non heparinized teflon antecubital venous catheter without interrupting the running. The test was stopped when the lactate concentration exceeded 4 mmol l$^{-1}$. The running speed was plotted versus the venous blood lactate concentration. Expired air was collected in Douglas bags during the last minute of each 4 minute period, and was immediately assessed for minute ventilation ($\dot{V}_E$) by a calibrated wet gas spirometer. Oxygen uptake and carbon dioxide output were calculated based on $\dot{V}_E$ (STPD), $O_2$ and $CO_2$ concentrations.

Maximal oxygen uptake was measured with gas samples from Douglas bags, on a separate day from the OBLA test. A constant running speed of 70 per cent of $V_{OBLA}$ was used. After a five minutes low pace warming up on the treadmill, the inclination of the treadmill was increased by one per cent every 30 second, starting at the horisontal level. The test was performed until exhaustion (subjective grading 19—20 on the Borg scale). Expired air was collected in a Douglas bag during the last minute of each test. Oxygen uptake was calculated as described above. Heart rate was registered continuously from the ECG, recorded on an ink writer.

**Statistical methods**

Results in the tables and text in presented papers are generally given as mean ± standard deviation. To evaluate associations between pairs of variables, linear regression analysis was used. For comparison of data, the Wilcoxon non parametric or parametric test was used (Snedecor & Cochran 1967). All statistics presented as different or associated, fulfil the criteria of $p < 0.05$ significance, if not otherwise noted.
RESULTS

Paper I
In male sprinters and marathon runners, isokinetic knee extensor peak torque (PT), contractional work (CW), instantaneous power (IP), mean power (CW s\(^{-1}\)), and integrated electromyographic activity (iEMG), were significantly correlated to the cross-sectional area of m. quadriceps and to the calculated absolute Type II fibre area of m. vastus lateralis. When correcting PT, CW and iEMG for the cross-sectional area of the quadriceps muscle, such correlations were found only for Type IIA fibre area at 180° s\(^{-1}\). M. vastus lateralis (biopsied muscle) was, electromyographically, found to be representative for m. quadriceps. The calculated optimal mean power output (CW \(\times\) s\(^{-1}\)) and electrical efficacy (CW/iEMG) approximated for sprinters 450° s\(^{-1}\) and for marathon runners 270° s\(^{-1}\).

Paper II
In male sprinters and marathon runners, the slope of decline in contractional work during repetitive contractions at 90° s\(^{-1}\) was significantly correlated to the calculated absolute Type II fibre area of m. vastus lateralis, also after correction for the cross-sectional area of m. quadriceps. Due to a pronounced decline in CW, sprinters showed a steep decline in the ratio of contractional work/integrated electromyographic activity (CW/iEMG). Only two out of five sprinters could perform more than 50 contractions due to local muscle pain. In contrast, marathon runners showed a minor similar decline in both CW and iEMG resulting in a virtually constant CW/iEMG ratio throughout the test.

Paper III
Structural deviations were found in the biopsy specimens in four out of five marathon runners, but not in any of the sprinters. The pathological changes included poorly organized fascicles, diffusely spread connective tissue, central fibre nuclei, irregular fibre shapes and signs of fibre type grouping.
Paper IV
In male orienteers, no intra-individual significant correlation in peak torque (PT) was found between m. quadriceps and m. triceps surae. A negative correlation was observed between PT of m. quadriceps at 30 and 60° s⁻¹ and the running velocity at onset of blood lactate accumulation (V<sub>OBLA</sub>). PT of m. triceps surae increased during winter training period and decreased during competition season, while for m. quadriceps an increase in PT was found for the whole year. Changes in V<sub>OBLA</sub> during the winter period were negatively correlated to the changes in PT of m. quadriceps at 180° s⁻¹. The changes in V<sub>OBLA</sub> during the competition period were, for the majority of the subjects, negatively correlated to the ratio of quality : quantity running, i.e. high content of forest/high intensity running.

Paper V
In male orienteers, m. quadriceps showed a steep decline in CW and in the ratio of contractional work/integrated electromyographic activity (CW/iEMG) during the first 30 manoeuvres of the repetitive test, which was followed by an unchanged plateau level. In contrast, m. triceps surae showed a minor similar decline in both CW and iEMG, resulting in a virtually unaltered CW/iEMG level from the start to the end of the experiment. The plateau level of CW/iEMG for m. quadriceps was significantly correlated to the maximal oxygen uptake of the athletes. After winter training, an increase in the plateau level of CW/iEMG in both studied muscle groups was found. No such changes occurred during the competitive period. The running velocity at the onset of blood lactate accumulation (V<sub>OBLA</sub>) increased during both training and competition periods, despite no changes in maximal oxygen uptake. The increase in V<sub>OBLA</sub> was, during the winter period, paralleled by an increase in oxygen uptake at OBLA.

Paper VI
M. quadriceps in male ice hockey players showed great inter-individual differences in isokinetic peak torque, fatigue and endurance pattern (contractional work and integrated electromyographic activity), despite similar body size and identical training programs. Intra-individually, but not for the whole group, changes in peak torque, slope of decline in contractional work and in the plateau level of CW/iEMG were found within different training and competitive periods.
GENERAL DISCUSSION

It must be stressed that the isokinetic laboratory procedure does not necessarily reflect the functional muscular performance in sports. However, the method, in combination with registration of electromyographic activity, provide objective and reproducible measurements of the concentric function of single muscle groups.

Several factors must be considered when discussing isokinetic laboratory results and muscle function in sports practice. As Komi (1984) pointed out, the stretch-shortening cycle, i.e. the combination of concentric and eccentric contraction, that is necessary in functional muscle performance, is not considered in the isokinetic procedure. Pre-stretch activity increases the tension of the muscle (Cavagna et al. 1976). A greater contribution to mechanical output of the elastic components of the muscles can thus increase the contractile work, despite no increase in neuromuscular input. In the present investigations we did not measure the muscle pre-stretch activity. Neither did we measure coactivation of the hamstrings muscles, which during knee extension might lower the knee extensor output (Osternig et al. 1986).

The isokinetic procedure used, allows measurements from 0 to 300° s⁻¹. These velocities of angular motion constitute 25 to 50 per cent of the optimal contraction velocity of the knee extensors (Mc Cartney et al. 1983, Thorstensson 1976). Our observations demonstrated that the used velocities of angular motion were suboptimal with regard to the mean power output (I). We measured the muscle peak torque at a free angle, in contrast to the suggestion of Perrine & Edgerton (1978), who measured the torque at a preset angle. Yates & Kamon (1984) could not demonstrate any differences between these two methods concerning torque-velocity relationships.

We found that, even after correction for cross-sectional area of m. quadriceps, the isokinetic peak torque at 180° s⁻¹ correlated positively to the absolute Type II fibre area of m. vastus lateralis (I). Our test group consisted of "extreme" athletes, with regard to functional sports demands i.e. duration and intensity of the activity, and also with regard to the muscle structure (I). The homogeneity within the two groups might affect our statistical analysis. However, our observations confirmed and extended the findings of Coyle et
al. (1979), Gregor et al. (1979), Ivy et al. (1981) and Thorstensson et al. (1977), but contrasted the findings of Schantz et al. (1983) and Nygaard et al. (1983). The authors referred to above, with the exception of Nygaard et al. (1983), obtained the biopsy from m. vastus lateralis when correlating knee extensor isokinetic strength and muscle structure. Our observations indicated that this muscle is representative for the total knee extensor muscle group (I). The open biopsy technique allowed us to standardize the depth of the biopsy, i.e. the superficial layer. This is of importance since the fibre structure vary within different parts of the muscle (Lexell et al. 1983).

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The computerized tomography that was used for measurement of the cross sectional area, allowed indirect calculation of the total fibre area and mean number of fibres (I, II), but also included the inter-fibrial areas, i.e. small vessels and connective tissue. This might affect the conclusion that the intrinsic strength of the Type II fibre is greater than that of the Type I fibre (I). Thus, if the inter-fibrial area was relatively greater in marathon runners, due to an increased amount of connective tissue (III), which we can neither confirm nor exclude, the calculated number of fibres was too great and hence the calculated peak torque per fibre was too low.

During repetitive manoeuvres, the slope of CW decline, i.e. fatigue pattern, showed a positive correlation to the absolute Type II fibre area in m. vastus lateralis (II). The great slope of decline of m. quadriceps in sprinters, ice hockey players and orienteers probably indicate a great recruitment of Type II muscle fibres during the initial contractions. However, considering the great changes in the slope in response to training, as shown for the ice hockey players (VI), muscle structure solely can probably not explain the fatigue pattern.

When comparing the fatigue pattern of m. quadriceps with that of m. triceps surae in the orienteers (V), it might be hypothesised that biomechanical differences, i.e. muscular demands during plantar flexion and knee extension \textit{per se}, could explain the differences between the muscles. Thus, when walking or running slowly on level ground, the plantar flexors may provide the required total mechanical output. Low intensity running probably requires mainly recruitment of the Type I muscle fibres and mainly aerobic energy. In contrast, when increasing the speed, or running uphill or downhill, the runner must accomplish a greater muscular output from larger muscle groups, such as the thigh and hip muscles e.g. m. quadriceps. Tentatively, in this situation, the recruitment of Type II fibres and of anaerobic energy might increase.

M. quadriceps in the marathon runners showed similar fatigue pattern (II) as m. triceps surae in the orienteers (V). This observation can be explained by adaptation to the economic running style of the marathon runner, hardly lifting the feet above the ground. The knee extensors in this situation probably work mainly as eccentric stabilizers at step down, when retarding the negative
forces of the moving body. The low content of Type II fibres in m. quadriceps in the marathon runners could thus indicate an adaptation to extreme repetitive, low intensity, hard surface demands. In total, varied running techniques recruit not only different fibre types within the muscles, but also involve changes in predominance between different muscle groups.

The plateau level of CW/iEMG of m. quadriceps correlated positively to the maximal oxygen uptake of the athletes (IV). Identical mean relative levels of CW/iEMG of m. quadriceps were found in ice hockey players (VI) and in orienteers (IV), although the absolute output and input levels were much greater in the ice hockey players. When discussing the “electrical efficacy” of a muscle (Gerdle et al. 1986), the absolute levels of output and input to the muscle must also be considered. Our observations, with regard to the fatigue and endurance pattern, indicated that m. quadriceps in the orienteers is adapted to greater output demands compared to marathon runners. The plateau level of CW/iEMG probably expresses central aerobic capacity, i.e. the supply to the muscle with oxygen, and also the local muscle capacity to produce and withstand the influence of lactate.

In total, we observed changes in isokinetic function during different periods of the year, or after different training (IV, V, VI). We do not know whether the changes are of structural or neuromuscular origin. A pronounced ability of adaptation of the lower extremity muscles seems evident. The loading during winter road running in the orienteers (IV) was sufficient to increase the peak torque of m. triceps surae. An excessive loading is one possible mechanism causing overuse injury in the lower extremities, which are most common during the winter training period in orienteers (Johansson 1986). Acute overuse (running downstairs) result in damage to the Z-band in m. quadriceps in untrained persons (Fridén et al. 1983). When examining m. quadriceps in the marathon runners (III) more than two weeks after the last competitions, structural changes of pathological significance were shown. However, no clinical signs of overuse injury or discomfort were found in the runners, who on the contrary performed extremely well. Although an adaptation to functional demands seems relevant to explain the structural changes, detrimental fibre injury must also be considered.

In essence, the present investigations have demonstrated that the lower extremity muscles respond to training with changes in both peak performance as well as in fatigue and in endurance characteristics. Isokinetic measurements and electromyographic registrations provide important information of the concentric function of single muscle groups. The demonstrated tests may be used in training follow up in athletes and patients undergoing muscular rehabilitation. The complexity of muscular performance in different sports does not, however, allow us to draw any general clinical conclusions from the
isokinetic results. From our studies, it seems highly reasonable to suggest that an individually planned training is necessary for optimal leg muscle performance both in individual sports like orienteering and in team sports like ice hockey.

Further analyses, relating isokinetic muscle function to eccentric performance, to the stretch shortening cycle, to biomechanical demands and to functional muscle activity in different sports are essential.
GENERAL SUMMARY AND CONCLUSIONS

Paper I, IV and VI. Single maximum manoeuvres
Knee extensor peak torque (PT), contractional work (CW) and integrated electromyographic activity (iEMG) were significantly correlated to the calculated absolute Type II fibre area of m. vastus lateralis in sprinters and marathon runners. Electromyographically, m. vastus lateralis (biopsied muscle) was representative for m. quadriceps. Calculated optimal mean power (CW s\(^{-1}\)) and electrical efficacy (CW/iEMG) approximated for sprinters 450° s\(^{-1}\) and for marathon runners 270° s\(^{-1}\). In orienteers, plantar flexor PT increased during winter training period and decreased during competitive season, while knee extensor PT increased during the whole year. At 30 and 60° s\(^{-1}\), knee extensor PT was negatively correlated to the running velocity at onset of blood lactate accumulation (\(V_{OBLA}\)). Changes in \(V_{OBLA}\) during winter correlated negatively to the changes in knee extensor PT at 180° s\(^{-1}\). During competition season, changes in \(V_{OBLA}\) correlated negatively to the ratio quality : quantity running. In ice hockey players, knee extensor PT varied non-systematically with training and games.

Paper III
The biopsy specimens in four out of five marathon runners showed pathomorphological deviations. It is not known whether these changes express an early strain disease or a functional adaptation to extreme demands.

Paper II, V and VI. Repetitive maximum manoeuvres
The initial CW, and subsequent slope of decline in CW, considered as fatigue, was significantly correlated to the Type II fibre area of m. vastus lateralis. The knee extensors of sprinters, orienteers and ice hockey players showed a steep decrease in CW/iEMG. In contrast, knee extensors of marathon runners and plantar flexors of orienteers showed an almost unaltered CW/iEMG ratio throughout the test. The endurance level (CW/iEMG) was significantly correlated to the maximal oxygen uptake. In orienteers, an increase in endurance
level during winter training period paralleled an increase in $V_{OBLA}$ and $V_{O_2OBLA}$. In ice hockey players, fatigue and endurance (CW and CW/iEMG) changed non-systematically.

In conclusion, isokinetic PT, CW and iEMG reflect structural properties of knee extensors in sprinters and marathon runners, at the relatively low angular velocities used. The observed inter-individual and inter-muscular differences, as well as the intra-individual changes in isokinetic muscle function apparently reflect varying demands in different sports.

Figs. 6 and 7. The demands of leg muscle performance in sports vary due to the intensity and duration of activity. Adaptations to training, with changes in concentric muscle function and in extreme cases with structural deviations have been demonstrated in this study. Measurements of peak torque, contractional work and integrated electromyographic activity may be validly used for categorization and training follow up of the concentric muscle function in athletes.
REFERENCES


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